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HIGHWAY RESEARCH REPORT

EVALUATION OF ELECTRIC LOGGING AND GAMMA RAY DEVICE FOR BRIDGE BORING INTERPRETATION

Louisiana Department of Highways – Research & Development Section

EVALUATION OF ELECTRIC LOGGING AND GAMMA RAY DEVICE FOR BRIDGE BORING INTERPRETATION

by

STEVE G. BOKUN
ASSISTANT RESEARCH & DEVELOPMENT GEOLOGIST

and

WILLIAM C. WALTERS
RESEARCH & DEVELOPMENT GEOLOGIST

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SYNOPSIS

For many years, well drilling firms and explorers of the subsurface have been using various mechanical, electronic, radiation and a host of other logging devices to record properties of the subterranean formations in an attempt to discover what is below the surface. Most notable among the devices are instruments that record the electric properties of materials as well as the gamma radiation that they emit. Oil companies started electric logging in the early 1930's while the larger water well companies began somewhat later. Now virtually all drillers of holes for informational purposes use some sort of logging technique other than human determinations; all, it would seem, except engineering personnel who deal with foundation problems.

This work was initiated to determine what use can be made of the two most common logging techniques (electric and gamma ray) in the field of Highway and Foundation Engineering. An attempt was made to correlate values obtained from a shallow electric and gamma ray logging device combination to parameters which interest engineers who work with foundation problems. Such parameters as unit weight, plasticity, voids ratio, permeability were measured in the laboratory and statistically compared with the field results using the logging device.

It was found that the machine worked very well in the manner that has been used for the past 40 years, but as a field instrument for determining engineering parameters, it has little value. That is to say, electric logging techniques readily distinguish major and moderate textural differences and pinpoint the elevation of the interface. With experience in interpretation, less moderate to somewhat minor textural differences may be distinguished. Thus, layer thickness can be determined, pile elevation selections enhanced, etc. Other uses that can be made of these data are discussed in the text. However, it was not possible to develop a correlation between electric logs and other engineering values from the findings obtained in this study. Nevertheless, electric logging is recommended for adoption in Louisiana based on its rather accurate textural differentiation capability, its low cost both initial and operational, and ease of operation.

Gamma ray log results did not prove even as useful as electric logs, and the down hole device alone is almost two times the cost of the electric set up in its entirety. Thus gamma ray logging is not recommended for adoption.

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INTRODUCTION

This research endeavor is presented in compliance with the agreement between the Louisiana Department of Highways and the U. S. Department of Transportation, Federal Highway Administration, designated as HPR 1(8) 69-1S. The field work, research of pertinent publications, evaluation of data and the assimilation of this information into the resulting report was accomplished by personnel of the Research and Development Section of the Louisiana Department of Highways. Laboratory testing was accomplished by the Materials Section of the Louisiana Department of Highways.

The electric log and gamma ray log have been tools used by the oil exploration industry and by water well companies for many years. Their primary purpose is strata identification between holes. The logs' usefulness along these lines is well documented, and the fact that such instruments can distinguish with varying degrees of success between sands, clays, shell layers, etc. and can approximate their elevations and layer thicknesses is beyond doubt. As far as could be determined through a quick literature search and through conversations with people scientifically interested in logging, nothing had been done with electric log or gamma ray values on foundation investigations for highway use.

PURPOSE AND SCOPE

Since shallow electric logging devices and gamma ray devices (for use in holes of less than 200 feet in depth) have recently been developed, it was the aim of this work to ascertain if correlation between electric logs and/or gamma ray logs and known conditions could be resolved to determine engineering parameters of the soils encountered, such as soil type, density, shear strength, bearing capacity, etc.

A statistical approach was to be attempted using regression analysis in the hope that the relative importance of each parameter could be defined. With this information it was thought that the instruments could be used to interpret foundation conditions which would be useful to bridge designers in establishing pile lengths, bearing capacities and number of pile.

A previous study performed here in Louisiana entitled "Pressuremeter Correlation Study" by C. M. Higgins correlated the Menard-Pressuremeter developed by L. Menard of France to Louisiana foundation soil strength characteristics. This device uses hydrologic pressure applied to the walls of the bore hole and measures the yielding characteristics of the soils at depth. These characteristics are then used to compute strength and consolidation curves for each layer. The correlation worked well for this device, and it was hoped the logging device studied here could be used in conjunction with the Pressuremeter to furnish a nearly complete testing program in the field without sampling and laboratory testing.

METHOD OF PROCEDURE

Equipment Description

The equipment used on this project was a Model KP Neltronic miniature portable logger w/dual chart speed and 300 feet steel armored cable (Figure 1) and the Model GM gamma ray logging downhole tool (Figure 2). The KP logger consists of a portable winch and recording system for both electric and gamma ray logging. The hand operated winch is complete with measuring system which

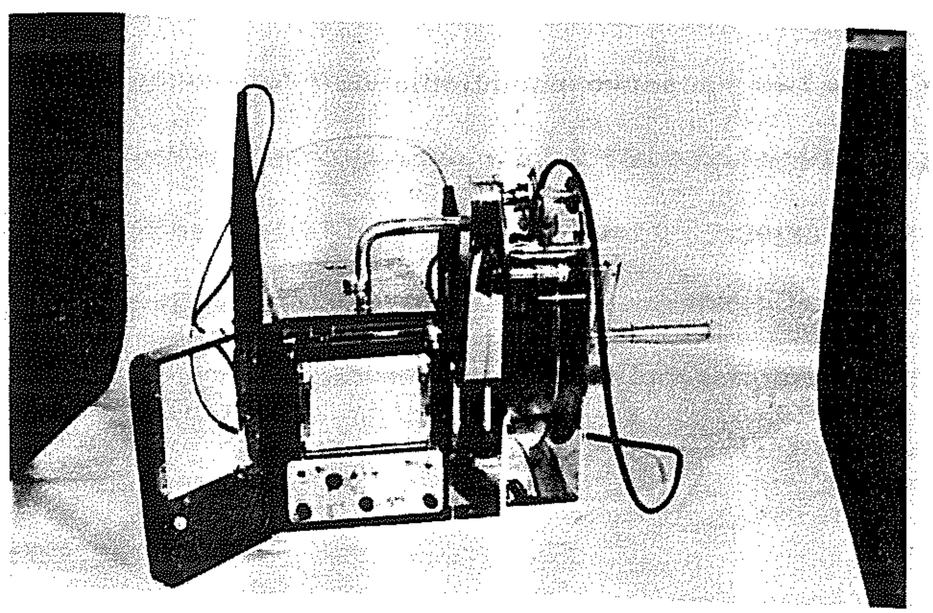

FIGURE 1: Miniature Portable Logger (Neltronic - Model KP)

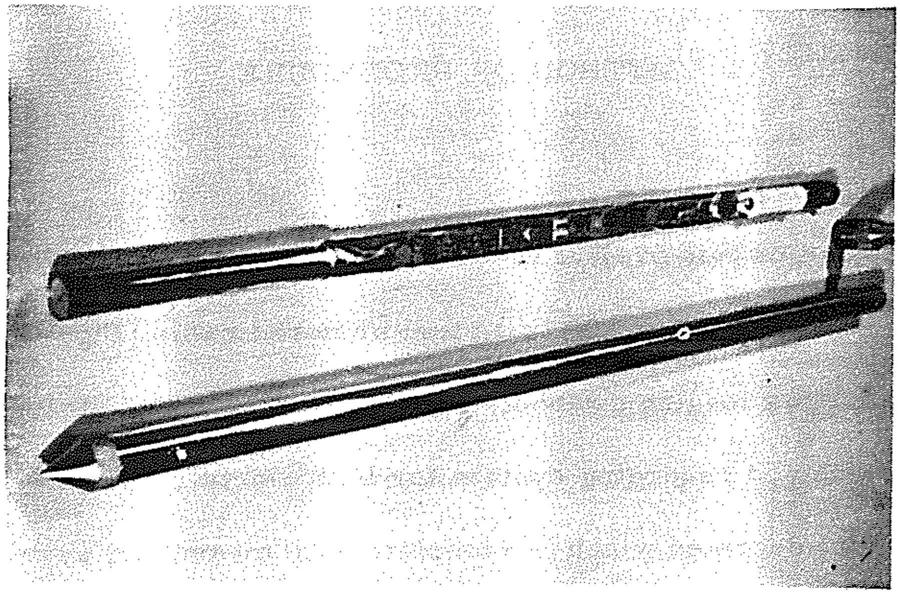

FIGURE 2: Gamma Ray Logging Tool (Neltronic - Model GM)

indicates cable depth on an odometer and drives the recorder charts directly. The recorder is a two pen servo-potentiometric type complete with signal conditioning circuitry and control for performing resistivity, self potential and gamma ray logging. Power for the system is derived from a rechargeable internal 10 volt Ni-Cd battery. The electronic circuitry is powered directly from a converter power supply that produces regulated plus 12 volts and minus 6 volts. Power is controlled by the function switch.

Data Acquisition

The system provides for the simultaneous recording of single point resistivity and self potential logs. When the function switch is in the EL position, power is turned on, and the electric log signal conditioning circuits are activated.

The AC excitation for the resistivity log is generated by a multivibrator and delivered to the cable by a constant current output stage, thus the voltage that appears on the cable is proportional to the resistance seen by the measuring elecrode. The AC voltage is rectified and fed to the recorder circuit input. Ranging is accomplished by simple signal attenuation.

The direct current self potential signal is extracted from the AC resistivity signal through a filter and fed to the other recorder circuit input. Ranging is also accomplished for the self potential signal by signal attenuation.

Logging Theory and Concepts

Perhaps a discussion of what the self potential, resistivity, and gamma ray logs actually are and how they are produced is in order now.

The science of logging is based on a natural law discovered by physicist George Ohm that all materials have different, but characteristic, resistance to an electric current passing through them. Some materials will conduct electrical current more readily than others, and the same is true with geologic. formations.

All formations differ in their electrical conductivity and conversely their resistivity. These differences are due mostly to the physical properties of the formations and/or to the fluids which the formations contain and not so much their mineralogy or the chemistry of the mineral grains themselves. Some dense formations (a physical property) will be highly resistant to the flow of electrical current because they have such small amounts of pore space and therefore contain very little fluid. By the same token, loose formations are less resistant because of their usually higher moisture content. Clays, because of their characteristically high porosity or void ratio, are less resistant than sands. The resistivity curve then is a result of measurements of the difference of potential impressed on two electrodes by an outside current which is sent into the ground.

The other half of the electric log is the SP curve. This curve depends on the fact that porous formations contain water of varying degrees of saltiness. These fluids generate various amounts of natural electricity current by themselves. This natural electricity is called self or spontaneous potential. It is a measure of the electromotive force occurring when the water in the drilling mud is squeezed into the porous permeable formations in the bore hole. These electromotive forces can be measured and used to help identify the nature of the generating fluid, the kind of formation containing it, and give an indication of the porous zones. Thus, the self potential curve is often referred to as the "porosity curve."

Figure 3, below, is an idealized example of an electric log showing the different situations encountered in the bore hole. The formations marked dense are dense formations with little pore space; therefore they contain little fluid and are highly resistive to the passage of current. Both the self potential and resistivity curves are shown.

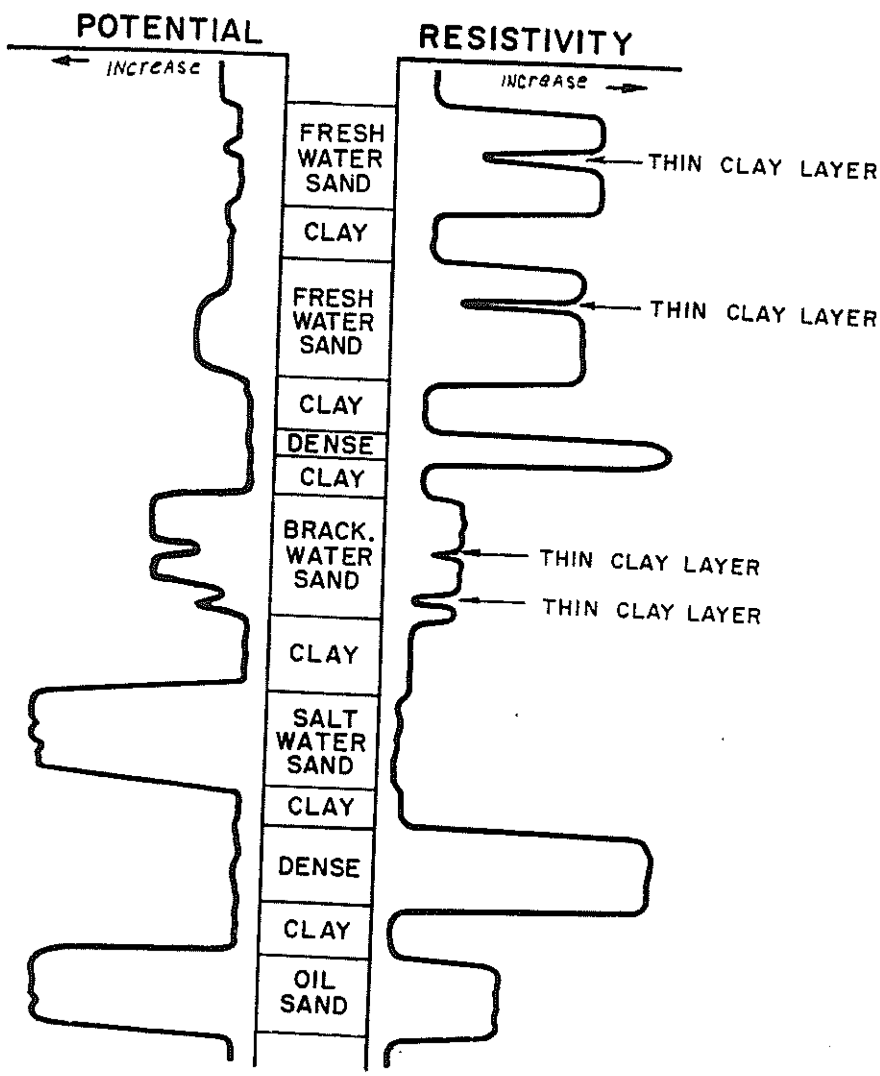

FIGURE 3: Idealized Electric Log

The resistivity and SP measurements are made with an instrument called a sonde. The sonde is a rod insulated with rubber on which electrical wires are fastened, ending in terminals called electrodes. It is lowered into the bore hole on the end of an electrical cable. From batteries at the surface, known amounts of electricity are sent down the cable to the sonde.

The current passes out of the sonde electrodes into the surrounding formations. Formations opposite the sonde will conduct a certain amount of current, depending on their characteristic resistivity. Return flow of the current is picked up by the sonde and sent back up the surveying cable to the surface. At the same time, the amount of self potential in the formation is measured and also sent back up the cable. At the surface, wires of the cable carry the currents of electricity to a galvanometer.

An ink pen is attached to the galvanometer, and a trace of the deflections is made on a moving strip of paper. Thus, with the chart moving at the rate of 1 inch per 20 feet, a permanent record of the resistivity and self potential curves are read together. One curve by itself is hard to interpret without the other.

The other type of log used in the investigations was the gamma ray log. Radioactivity can be defined as the spontaneous change of the atoms of one element into another. During this change, alpha, beta, and gamma rays are given off. The alpha and beta rays may be said to be low-energy rays.

The gamma rays are high-energy rays and can be measured and recorded to produce the gamma ray curve of the radio activity well log. With the gamma ray log, an outside electrical current is used in recording the log.

With the function switch in the gamma ray position, the right-hand recorder channel and range switch serve for the gamma ray log, and the left-hand recorder is disabled. The gamma ray signal on the cable is in the form of random negative pulses, approximately 10 volts high and 25 microseconds long. The average rate of these pulses is determined by the gamma ray signal conditioning circuitry which provides the recorder circuit input with a DC signal proportional to this rate. Ranging is accomplished at the recorder input by attenuation of the signal. Averaging time is adjustable by means of the time constant switch.

A gamma ray sonde is used to record the gamma log. This sonde has its own built-in batteries. It contains a scintillation detection crystal. When the crystal is subjected to small amounts of gamma radiation from the formations, a current is produced. The magnitude of this current is directly proportional to the intensity of the gamma radiation that penetrates the crystal from the surrounding layers. This minute current is amplified and transmitted up the logging cable to the recorder. Here, through additional amplifiers and sensitivity controls, the variable intensity of the current is graphed by a pen-type recorder on a moving strip of paper. This is the gamma ray curve of the radioactivity well log.

Field Procedure

The first month or so was spent in familiarization of the Geophysical personnel with the operation and use of the Neltronic logger and how to best fit the logging procedure into the sampling procedures of the Soils Exploration Unit of the Materials Section. Once the Geophysical personnel became familiar with the use of the equipment, logs were gathered from different parts of the state.

The actual logging procedure was one of observation and the physical taking of the logs. As the Soils Exploration Unit went through its sampling procedure, personnel from the Geophysical Unit would be on hand to observe the samples brought out of the hole. The driller's log book was also read to get a general picture of the foundation profile according to the driller. After the Soils Exploration drilling rigs were moved from over the hole, Geophysical personnel would then set up the Neltronic logging equipment.

The first step was to position a tripod over the hole to run the cable down the hole. After the electric logging sonde or probe was attached to the armored electric cable and the probe was lowered to the bottom of the drill hole, the depth was noted. Both the self potential log and resistivity log were recorded on the same trip up the hole accomplished manually by a hand crank. A "ground" was produced by running a second electrode to a shallow surface hole filled with water. The function switch was placed in the electric position and the millivolt (MV) and ohmmeter (Ohm/m) range switches were set for the proper sensitivity of the self potential log and resistivity log respectively. Sometimes, several electric logs had to be run at different sensitivity settings to keep the recording pens on scale. One sensitivity setting might be on scale in clay, but the pens would run off scale when sand was encountered; therefore, another setting was needed to keep the pens on scale for the entire trip up the hole. The log was produced on the upward trip only. After a satisfactory set of self potential and resistivity logs was produced for the hole, the function switch was turned off, and the electric log probe was removed.

The gamma ray logging sonde was attached to the cable and lowered to the bottom of the hole, and the depth noted. The function switch was placed in the gamma position, the CPS (cycles per second) sensitivity range was set, and the TC (time constant) was also set. The gamma ray probe was also manually cranked up the hole at a slightly slower rate than the electric log sonde because gamma ray radiation was not steady, but passed from a maximum to a minimum value in regular sequence. Gamma ray logging was conducted at a rate slow enough to record the "average" rate of emission of gamma rays from each bed or stratum in the bore hole. Any gamma rays which were recorded came from the formations within a few inches of the walls of the bore hole; therefore, this curve was considered a shallow inspection of the strata through which it was run. After a satisfactory gamma log was taken, the function switch was turned off, and the logging operation was completed.

Records of the state project numbers, log numbers, types of logs (electric or gamma), dates, station numbers and locations, and the depths reached by the logging probe were kept in a field book. A record was also kept as to the sensitivity settings on each log run. Any other pertinent information such as the distance of water level in the bore hole, amount of casing in the hole, etc., was also recorded in the field book.

DISCUSSION OF RESULTS

Electric Logging

The first portion of the analysis of the data is taken up with the electric logs; a discussion of the gamma ray logs follows:

It should be recalled that we had intended to use a statistical analysis to correlate our log values on the self potential and resistivity curves to determine engineering parameters of the soils encountered. These engineering parameters included such things as soil type, density, shear strength, plastic limit, liquid limit, etc. A regression analysis of the importance of each of these engineering parameters to the electrical values was to be attempted. In an attempt to fulfill this requirement, a total of 175 logs were run on 39 holes in 13 different locations. Only example logs are included in the text, and only the useable or most representative logs are presented in the appendix

An inherent problem in the logging system was that it was not possible to define a finite value for the resistivity and self potential curves. Due to different conditions in the bore hole, the sensitivity controls had to be set differently for each hole. One sensitivity setting, say 10 MV and 20 Ohms, might have been on scale for one hole, but the same setting was off scale in another hole in the same area. The second hole might have required sensitivity settings of

20 MV and 50 Ohms in order to keep the pens on scale. This situation was encountered on several different bore holes in the same general area. When a good "on scale" log was produced, it was not possible to tell where a finite base line value would be on the resistivity or self potential curves. The sensitivity setting might be set on 20 Ohms, but it was not possible to establish where the 20 Ohms base line crossed the resistivity curve. The same problem held true for the self potential curve. Because it was not possible to establish what the electrical values for the curves represented as numbers, a statistical analysis could not be run on the curves.

Through visual interpretations of the electric logs, it was possible to determine some of the conditions encountered in the bore holes. Where there was a definite break between a fine grained material and a granular material, the electric logs picked up this break well.

On the log shown as Figure 4, there is a definite break, near 30 feet, from a granular material in the bottom of the hole to fine grained material in the top 30 feet. The resistivity curves moves to the left and stays fairly straight from around 30 feet to the surface. Below 30 feet is a sandy material, and above is a clayey material.

Figure 5 shows a granular material from 85 feet up to 74 feet, then a fine grained clayey layer from 74 feet to 68 feet, back to granular material from 68 feet up to 50 feet, and finally back into a fine grained material in the top 50 feet. A organic layer shows around 24 feet, where the SP curve increases and the

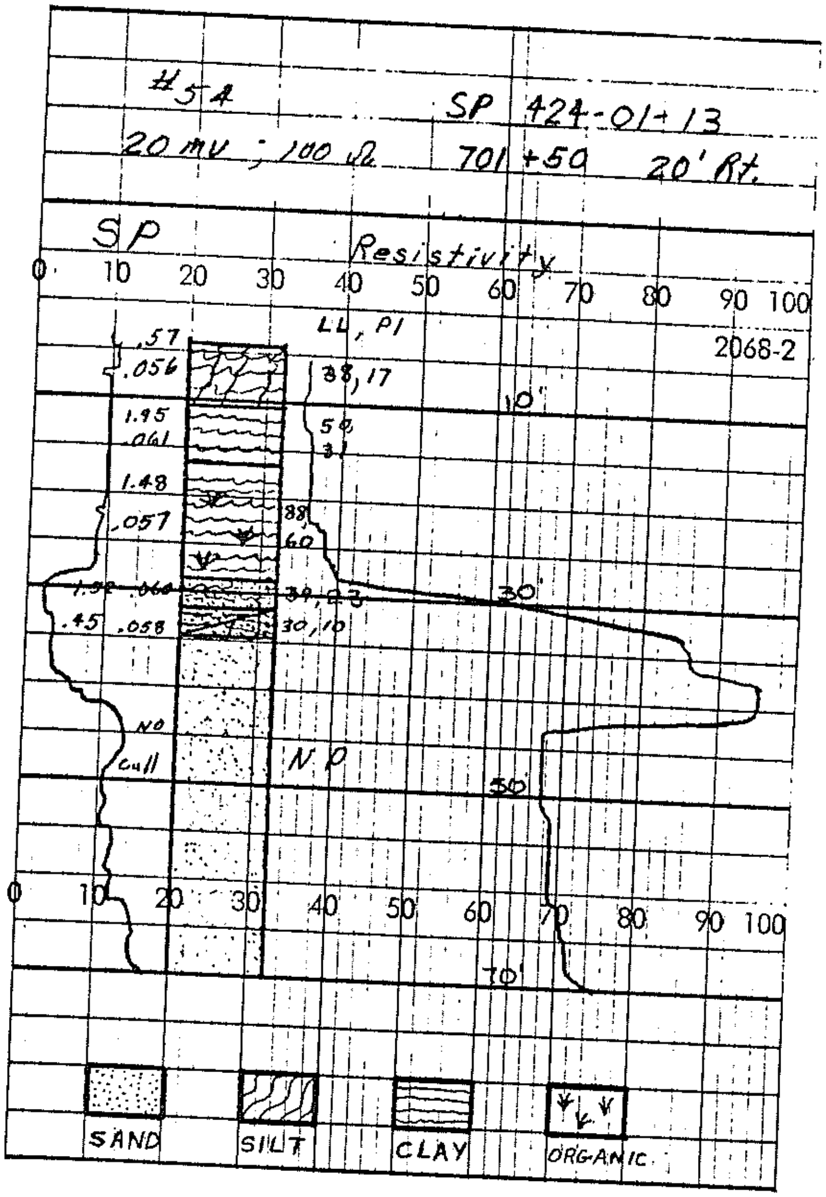

FIGURE 4: Electric Log - State Project Number 424-01-13

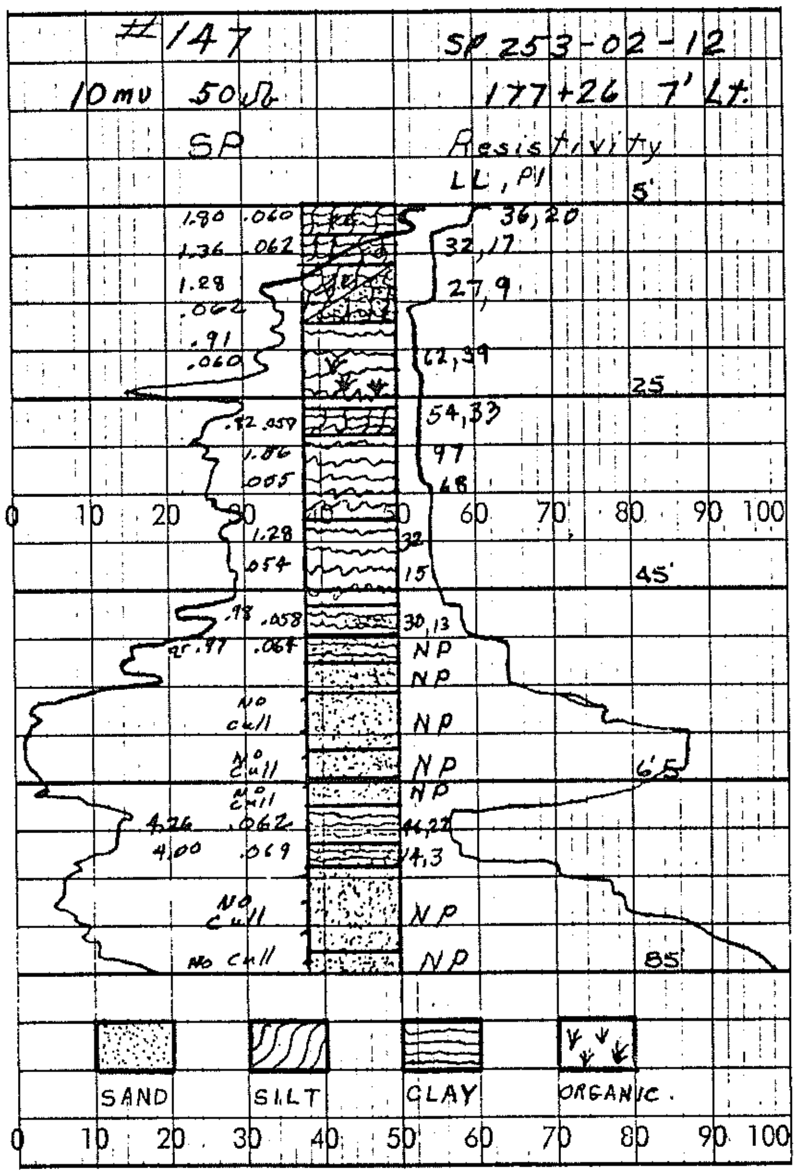

FIGURE 5: Electric Log - State Project Number 253-02-12

resistivity curve decreases. Granular materials generally show when the resistivity increases and the SP also increases. Fine grained materials show as both resistivity and SP curves decrease.

Figure 6 shows a clayey layer (the sampling crew apparently missed in their field description). This layer shows up well on the resistivity and self potential curves at the 50 foot level. Another clayey layer is around 41 feet.

Gamma Ray Logging

The gamma ray logs showed little when a correlation between the log and the driller's log was attempted. Figure 7 is an example of a gamma ray log alongside the driller's log data. In sandy material at the bottom of the hole, the gamma ray log generally stays to the left, then moves to the right at 75 - 67 feet in a clayey layer and back to the left above 67 feet in sand. Around 50 feet the soil turns into a plastic material and remains plastic to the top, but no correlation with these parameters was found. The gamma ray curve did not show a definite soil change break boundry, but gradually changed from one to the other and was very difficult to interpret because of this gradual change. Therefore, little could be made of the gamma curves.

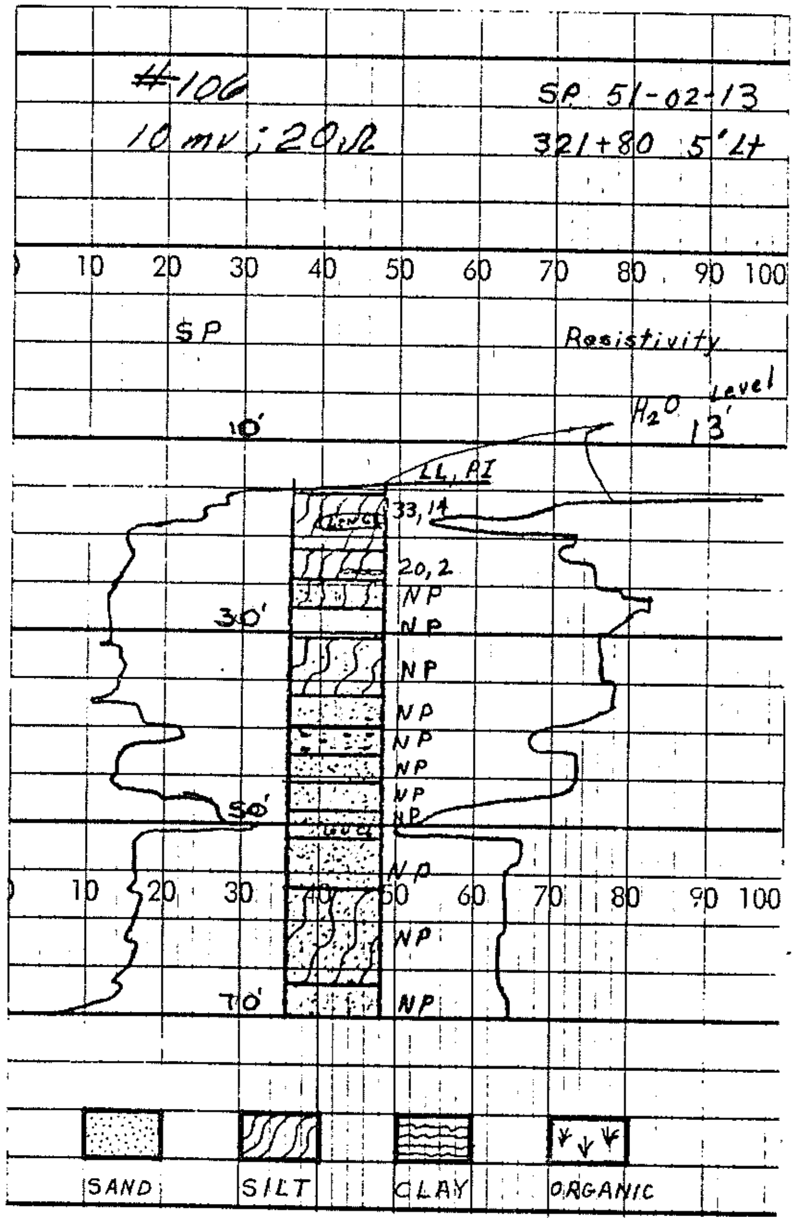

FIGURE 6: Electric Log - State Project Number 51-02-13

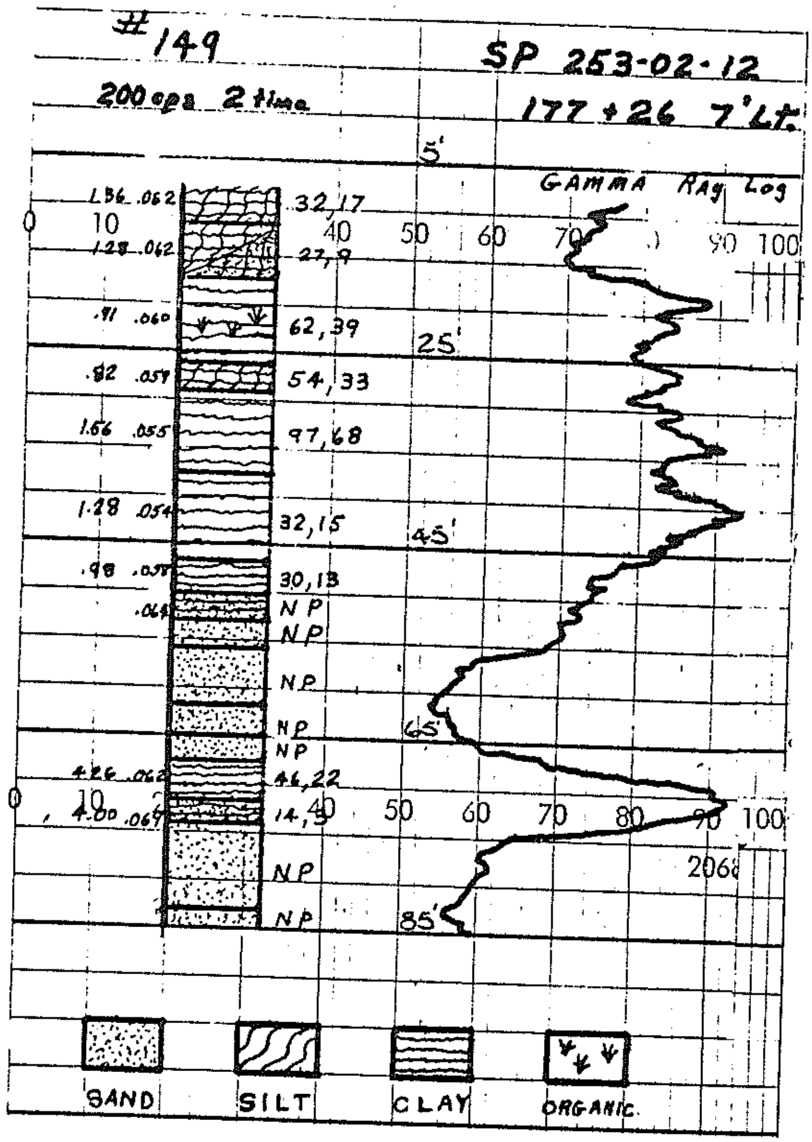

FIGURE 7: Gamma Ray Log - State Project Number 253-02-12

CONCLUSION

As a whole, the electric logs and gamma ray logs do not seem to be of satisfactory use in defining engineering parameters for highway work. Since it was not possible to establish what the electrical values of the self potential cuves and resistivity curves were, no correlation could be made with engineering parameters such as density, shear strength, plastic limit, liquid limit, etc. However, through a visual interpretation of the resistivity and self potential curves, an idea of general soil types encountered, depths, and thicknesses of soil formations could be formed.

Many times here in Louisiana it is necessary to search for non-plastic or low plasticity select materials on the bottoms of bodies of water. This logging system could be used instead of the continuous sampling procedure with rotary rigs now used. The system would only require a hole and would do away with the innumerable round trips up and down the bore hole to continuously sample the materials encountered. Electric logging could also be used as a comparative tool to assist in better physical sampling or logging of a sampled drill hole. Using the electric log would enable the Materials Section to pick a more representative sample of each strata to be tested for engineering parameters. Rather than just picking a sample which visually appears to be an average sample core, the self potential and resistivity curves should be interpreted to select a depth for the most truly representative sample of the strata under investigation.

RECOMMENDATIONS

In spite of the shortcomings of these devices with respect to identification of engineering parameters, it is recommended that electric logs be run on each boring location after completion of drilling. The device is relatively easy to operate and consumes only a short time, particularly after the operator becomes familiar with the unit. Its cost is less than $1,000 without the gamma ray detection tool. Gamma ray logging is not recommended.

Examples of the information to be gained are presented below:

1. Electric logs added to the standard boring sheets as a part of the boring log itself in a manner such as has been presented herein with the SP curve to the left of the boring diagram and the resistivity curve to the right will balance the value reporting system. 2. Continuity of beds across the construction project shows up well. Often thin layers of material are missed by the drilling crews, but these will normally show up on electric logs. 3. Additionally, SP and resistivity traces can point out thinly laminated formations that are normally identified by laboratory tests as intermediate mixtures of the textural types. "Varved clays" are principal examples found in Louisiana's subsurface. These are old lake bed deposits made up of thin layers (1/4" to 1/2" thick) of light colored silts interbedded with slightly thicker laminations of clay, the two combining to form a strata several feet thick. These beds are difficult to distinguish using laboratory tests for it is simply impractical, if not impossible,

to test the two materials separately. As a result, the driller's log is refuted by the test data, and the engineer has to guess which is right. With the use of electric logging, additional supporting data will be supplied.

This type of information becomes especially valuable when a foundation cross section is necessary. For instance, varved clays along with other more granular soils serve as drainage layers during consolidation. Correlation of layers between drill holes must certainly be enhanced with electric logging.

4. Finally, as more experience is gained with logging more information will become evident from the curves. Location of the water table may be determined in certain geographic locations, a unit weight range may become more perceivable with usage, and even an idea of porosity may be interpreted with intelligent study after a period of time.

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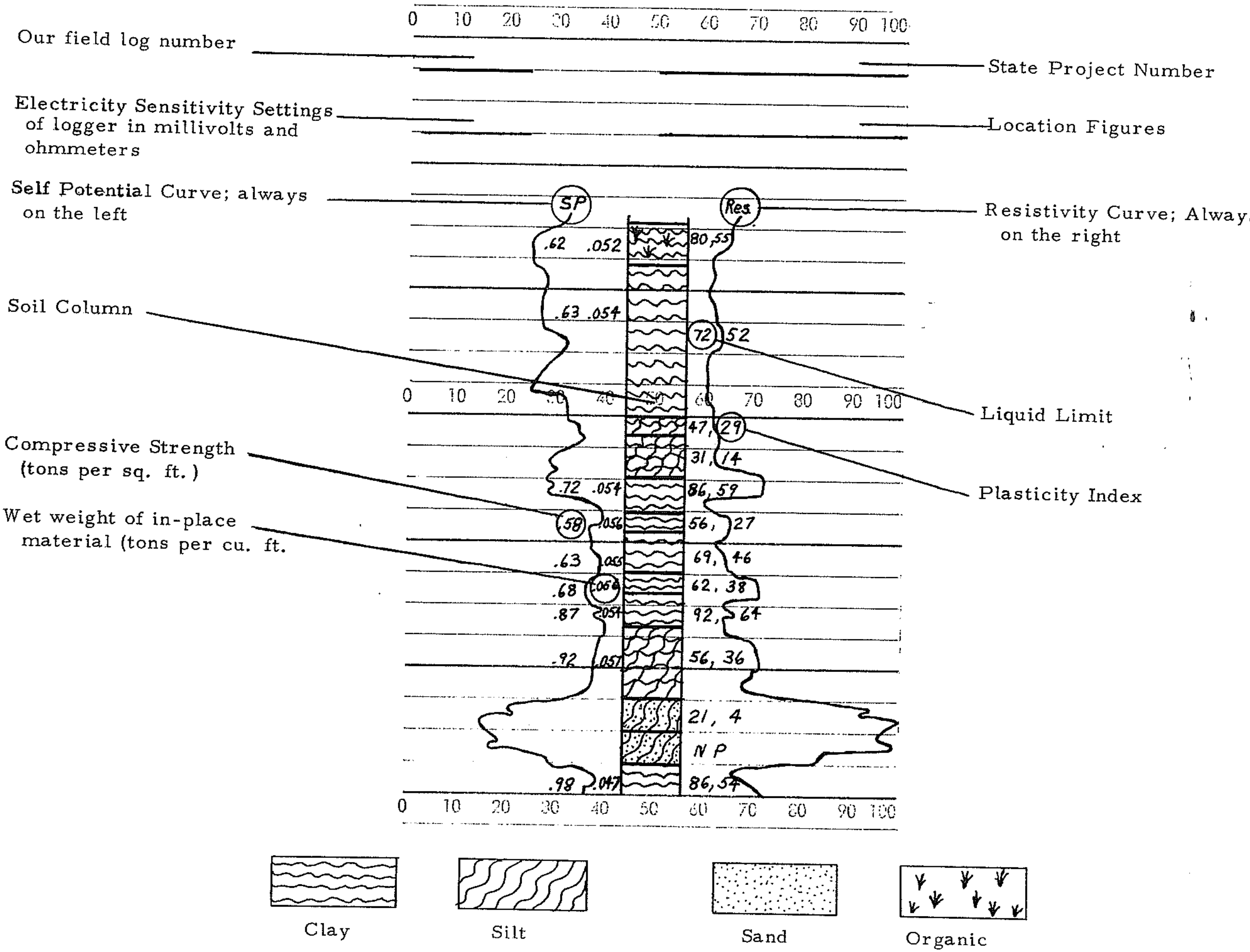
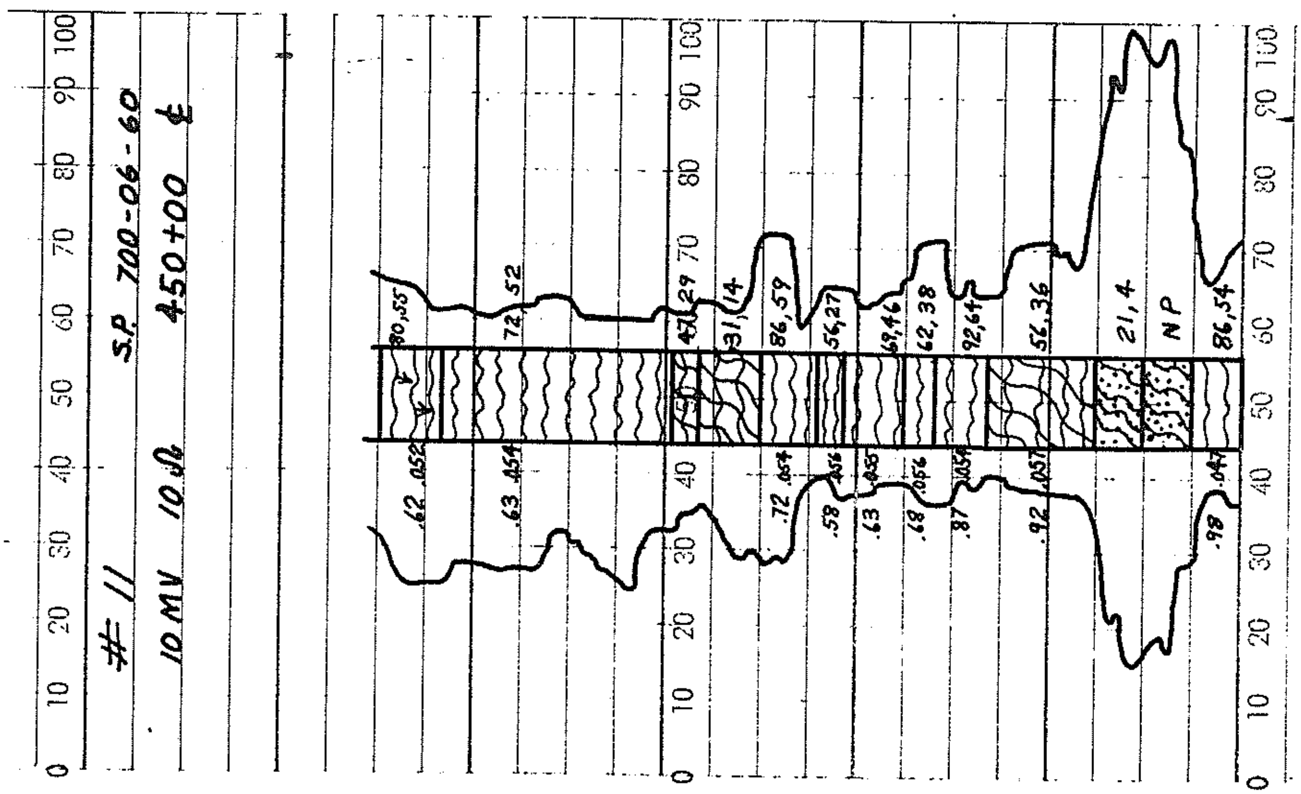
APPENDIX



TYPICAL LEGEND SHOWING INFORMATION CONTAINED ON LOGS



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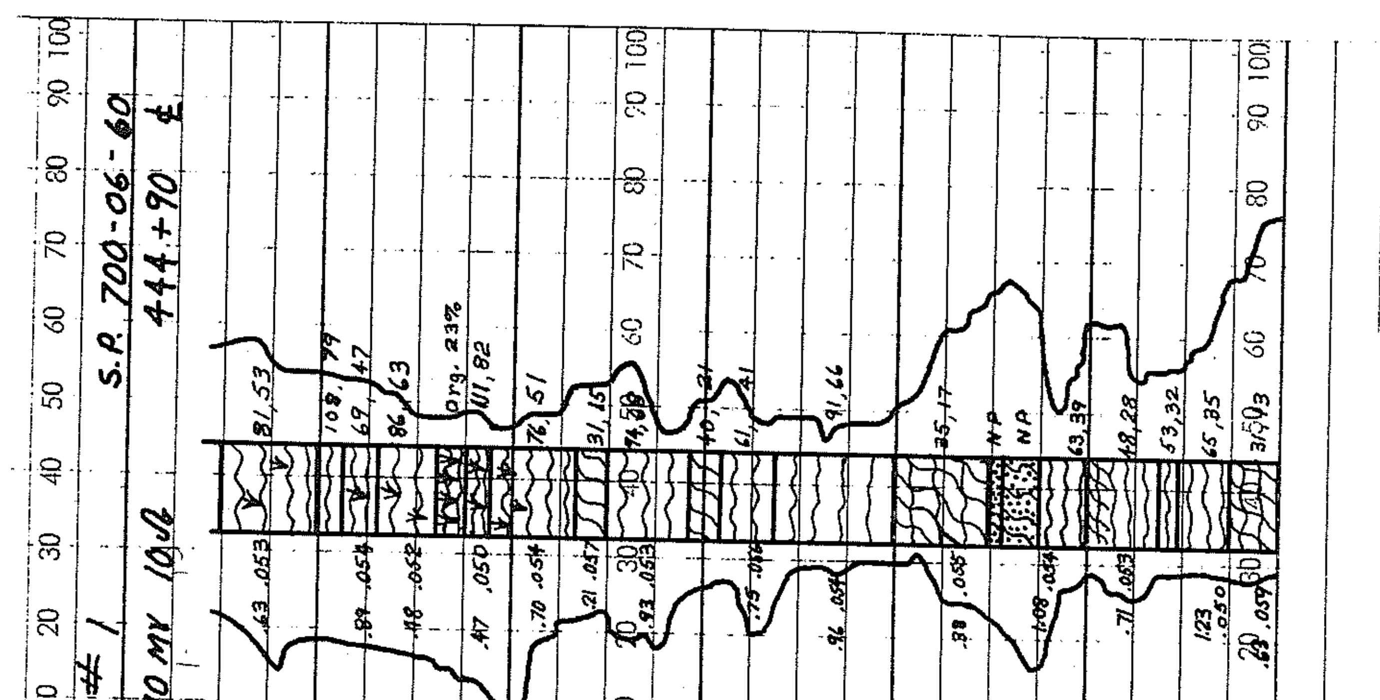

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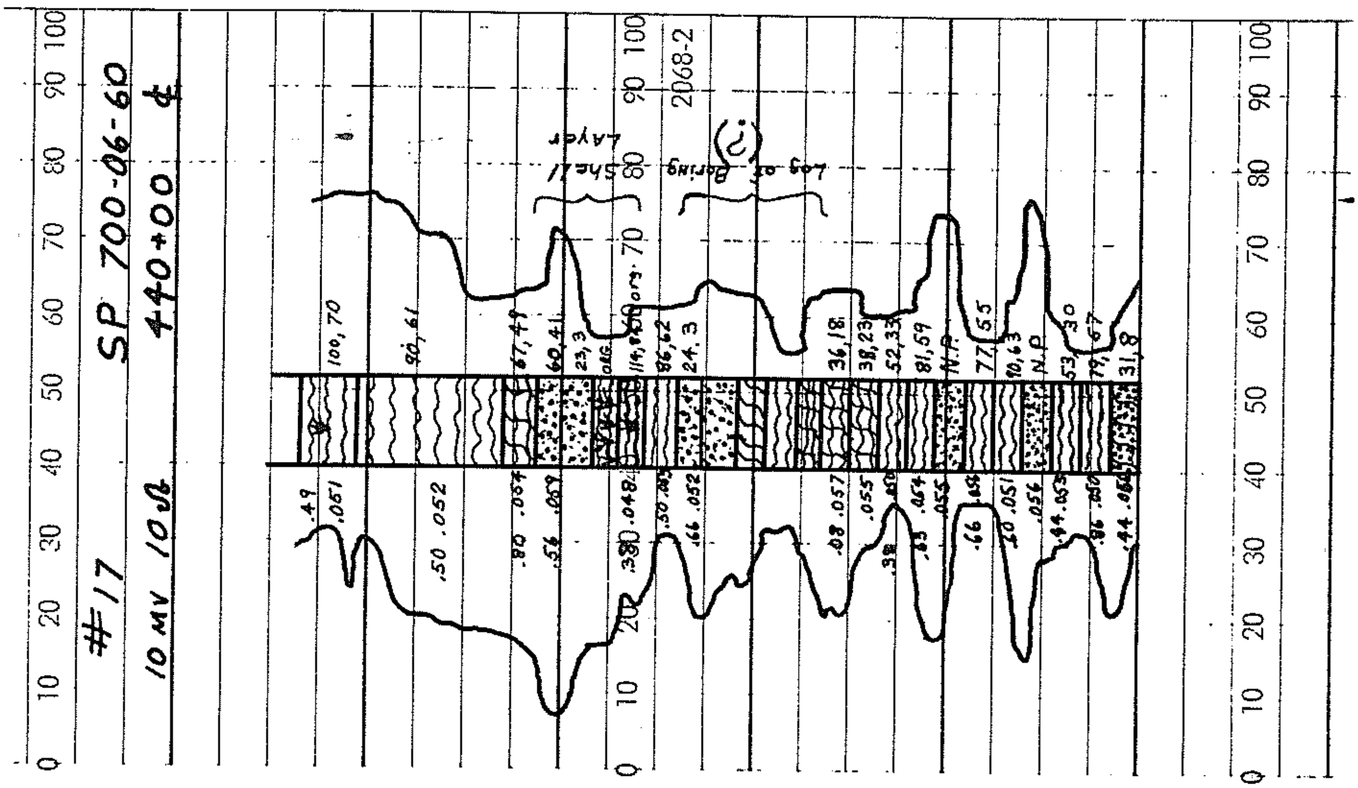
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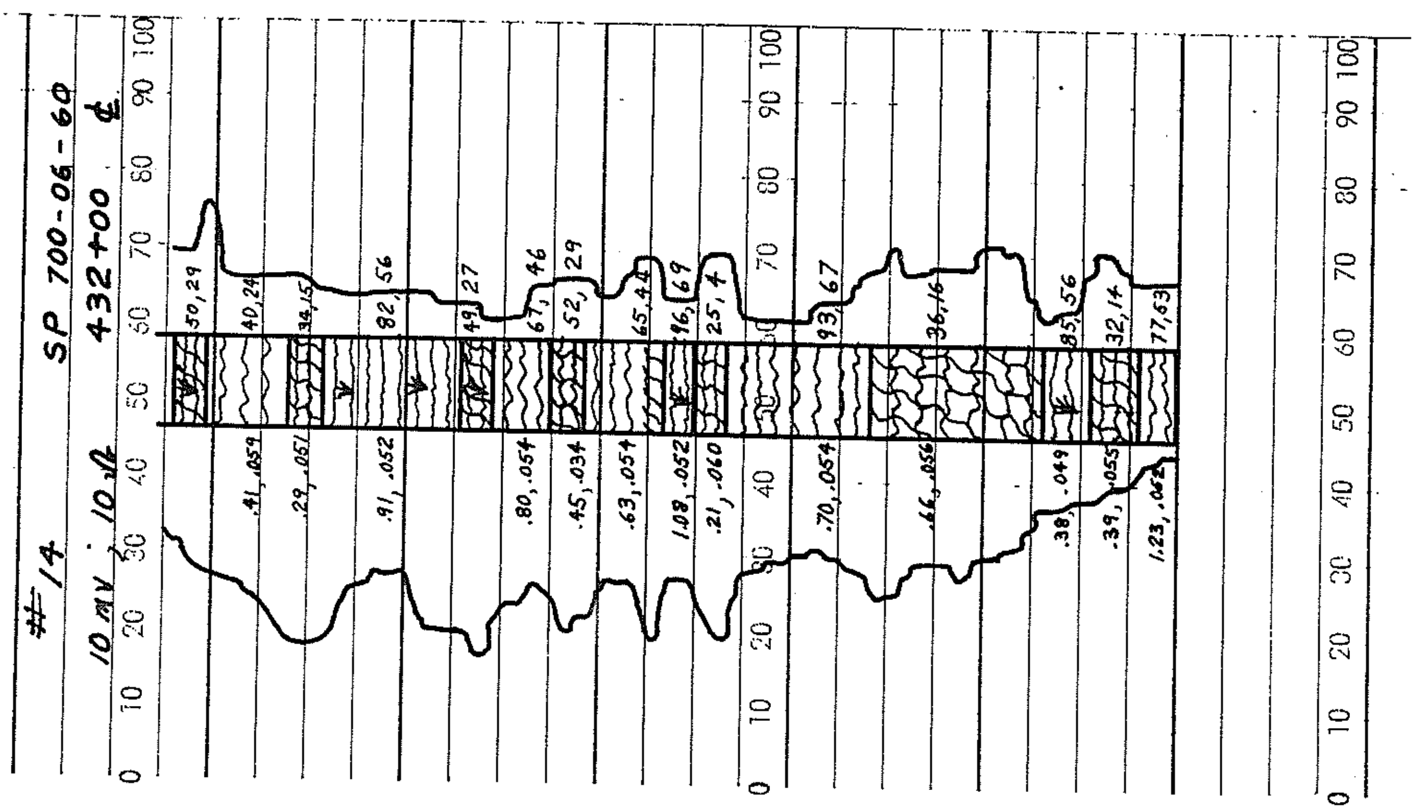
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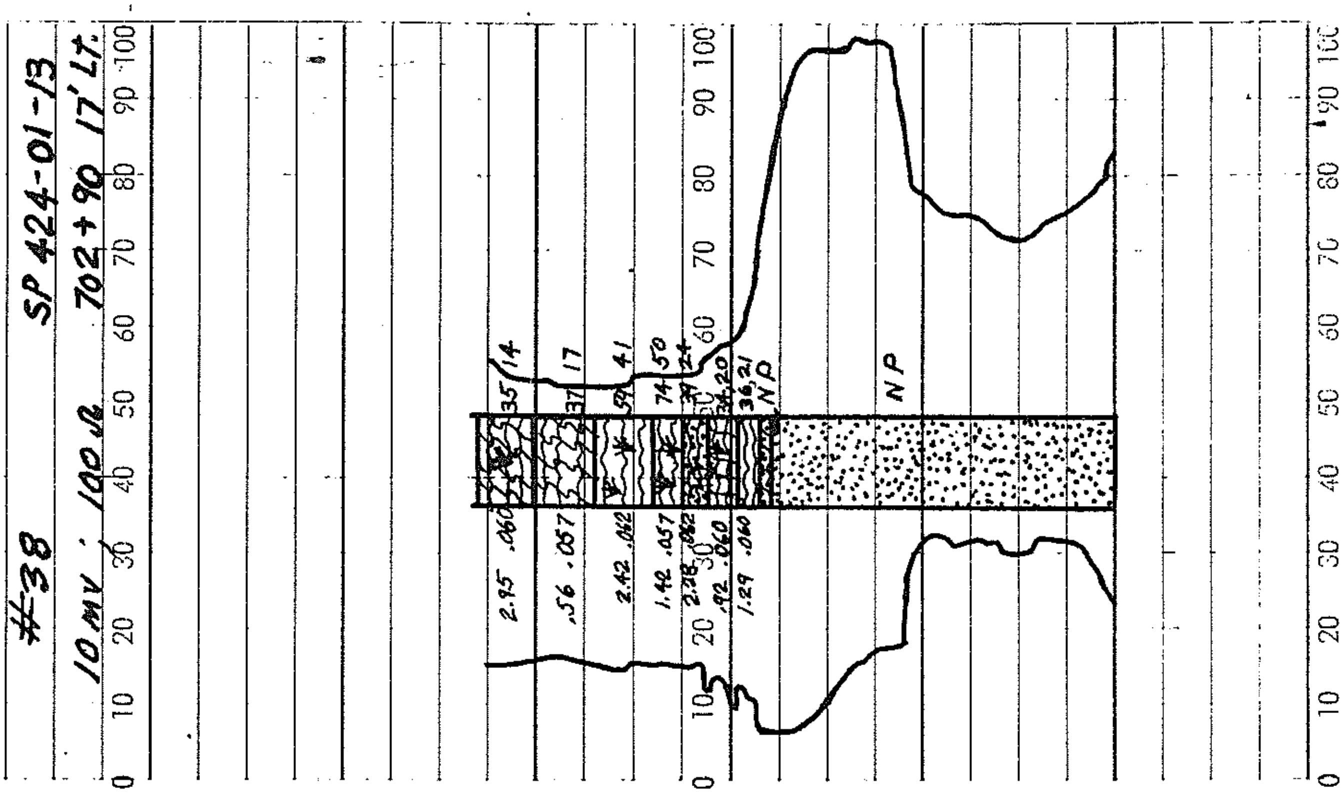
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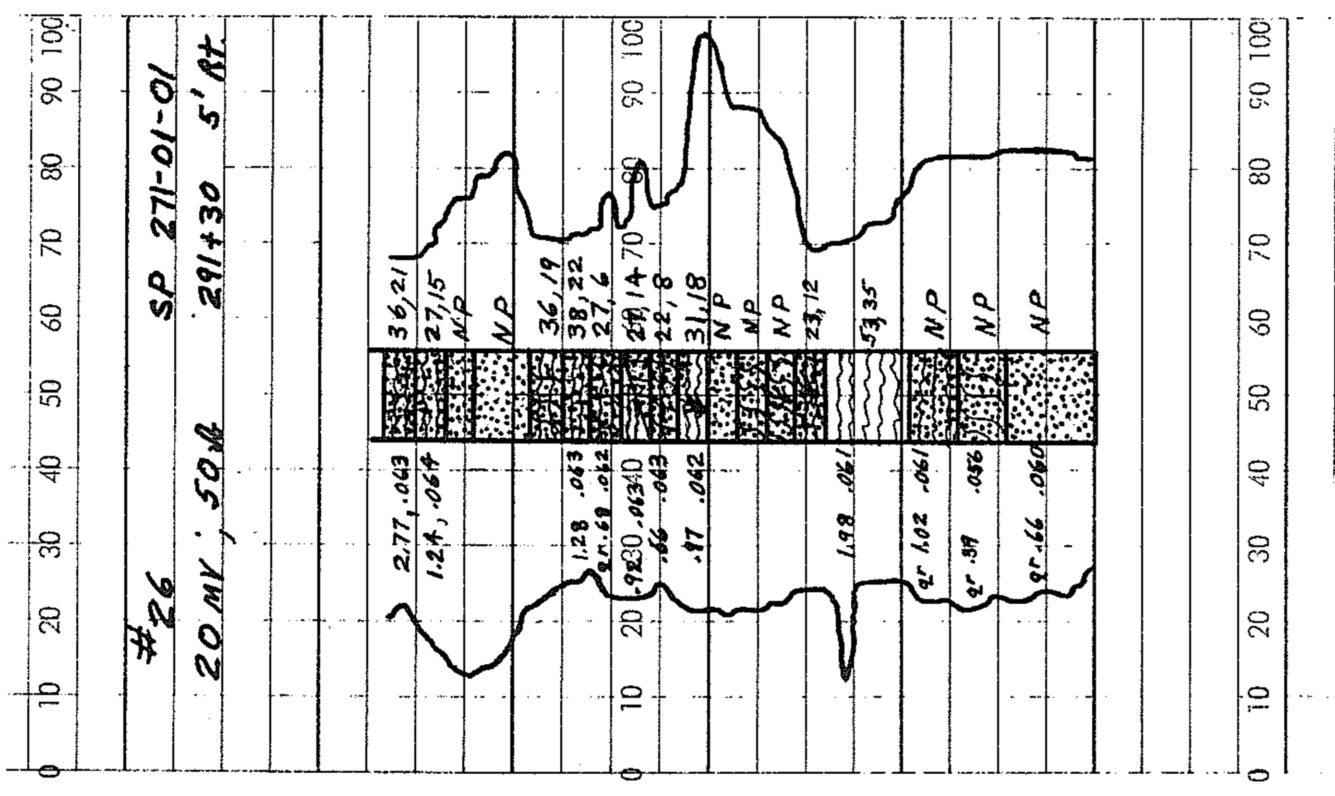
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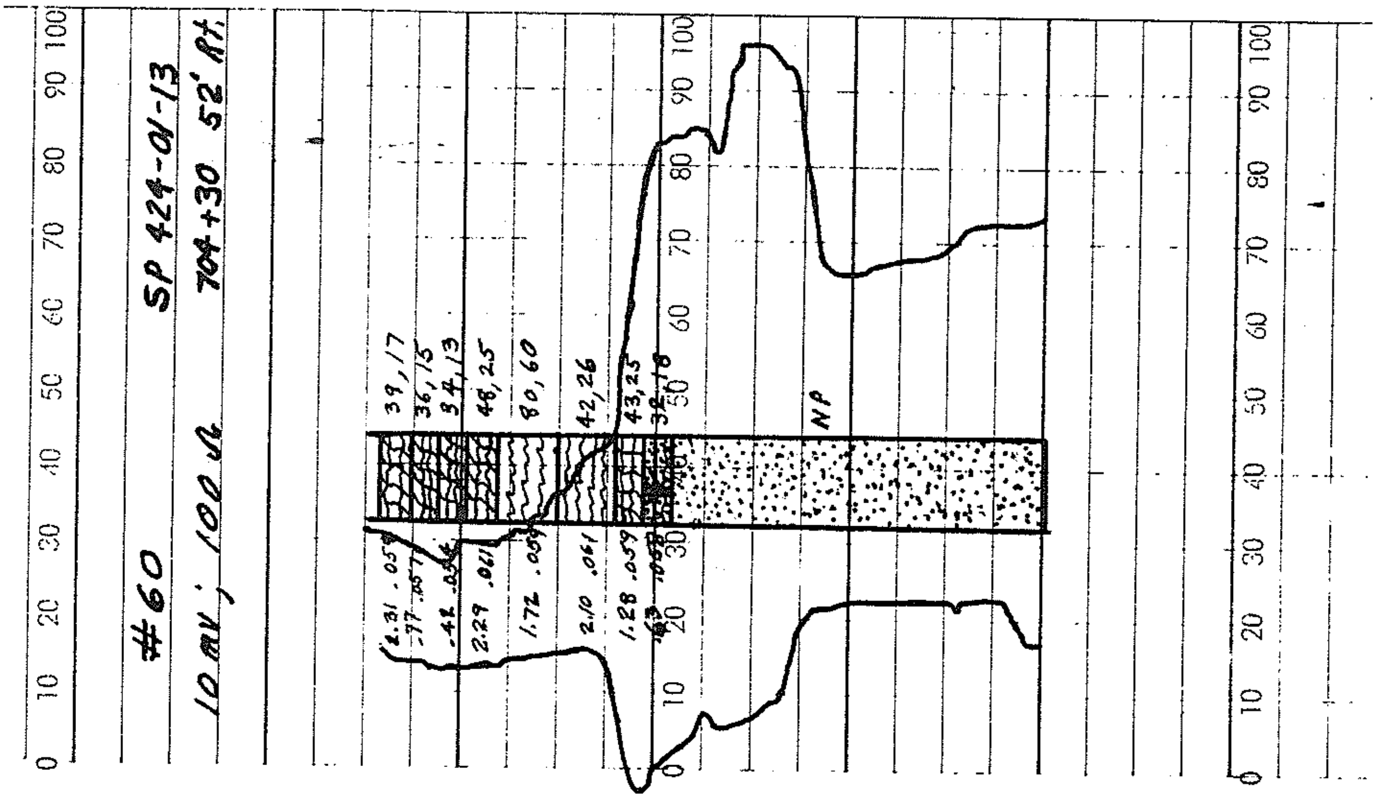
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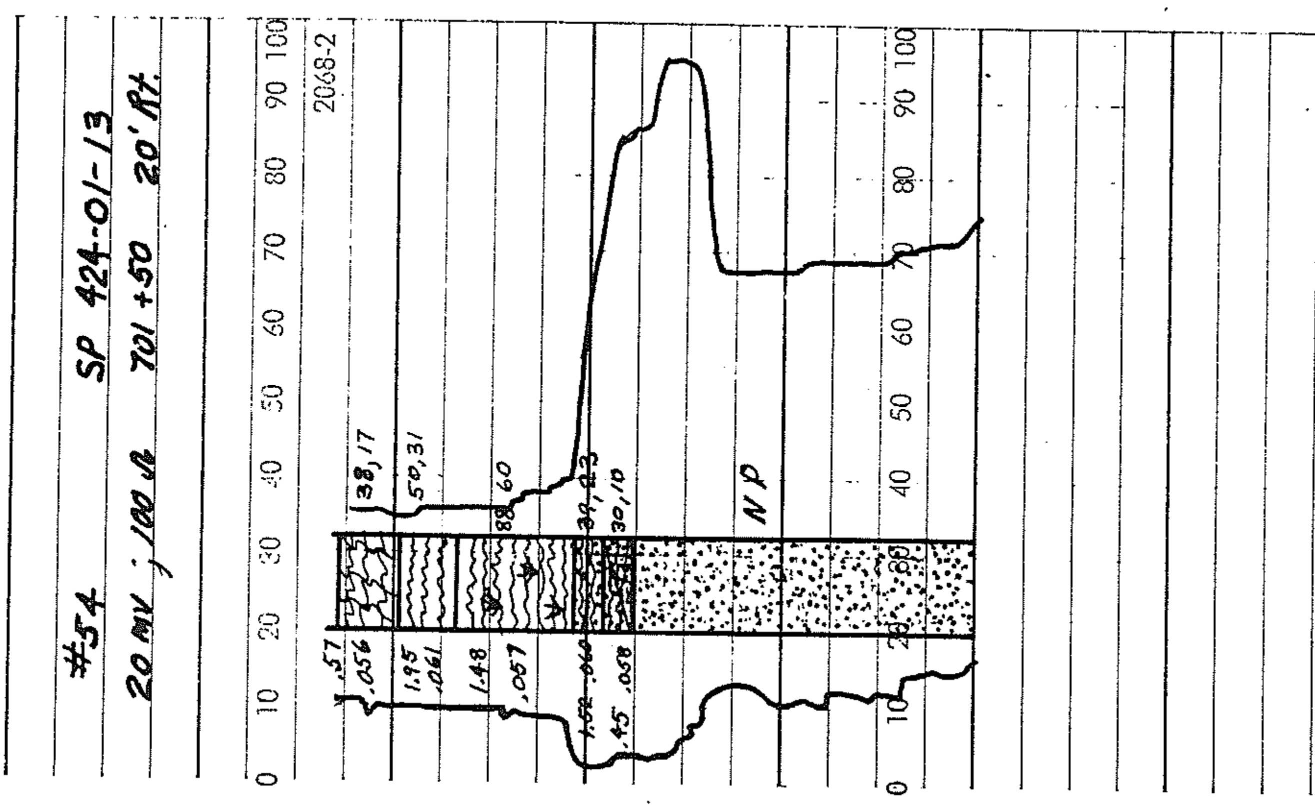
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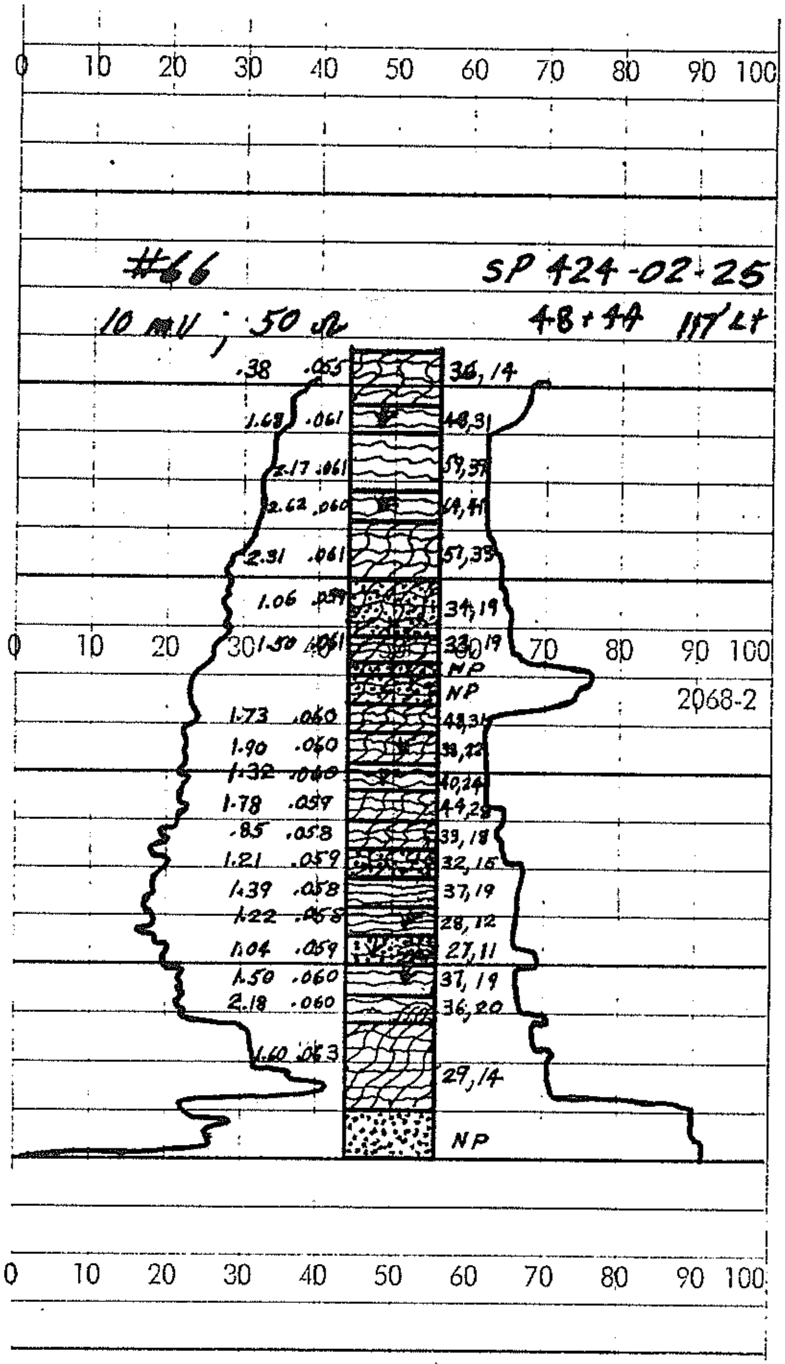
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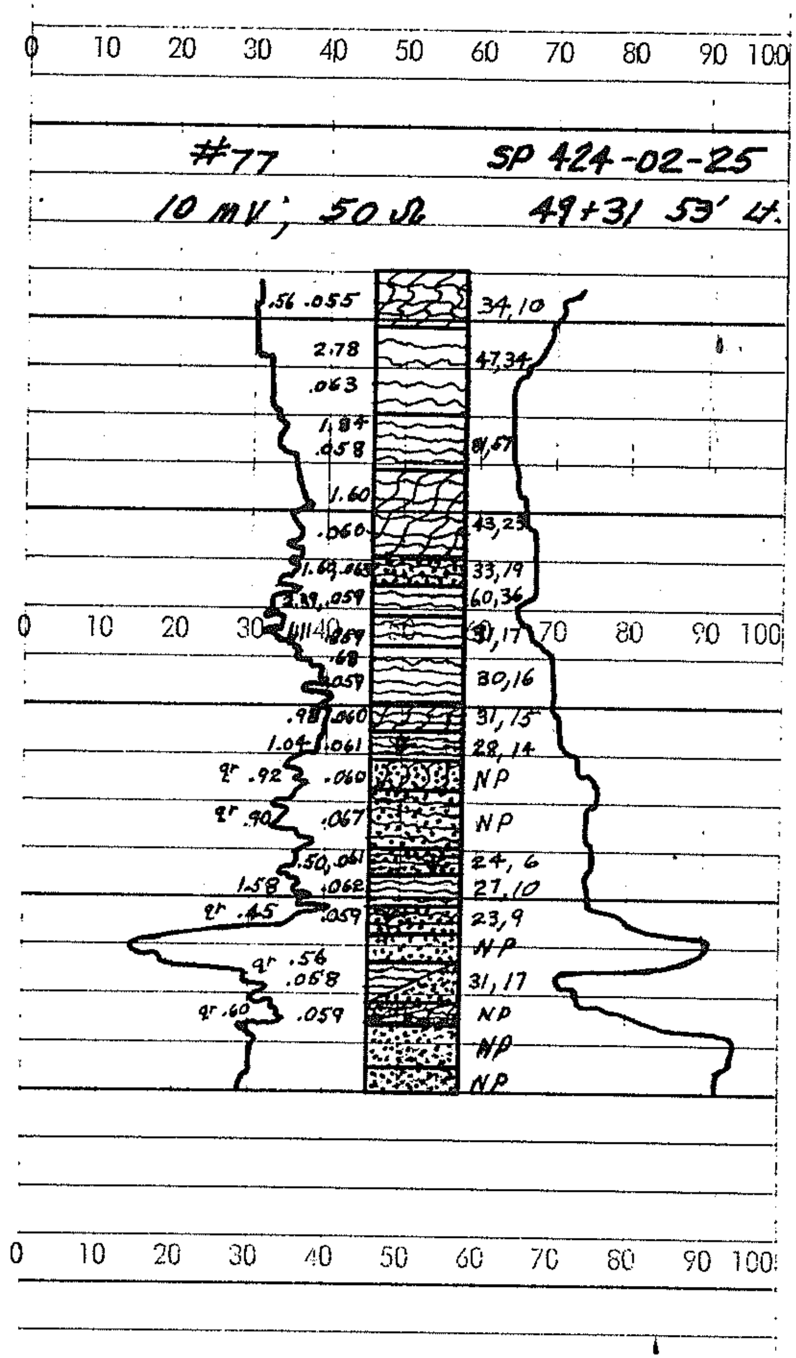
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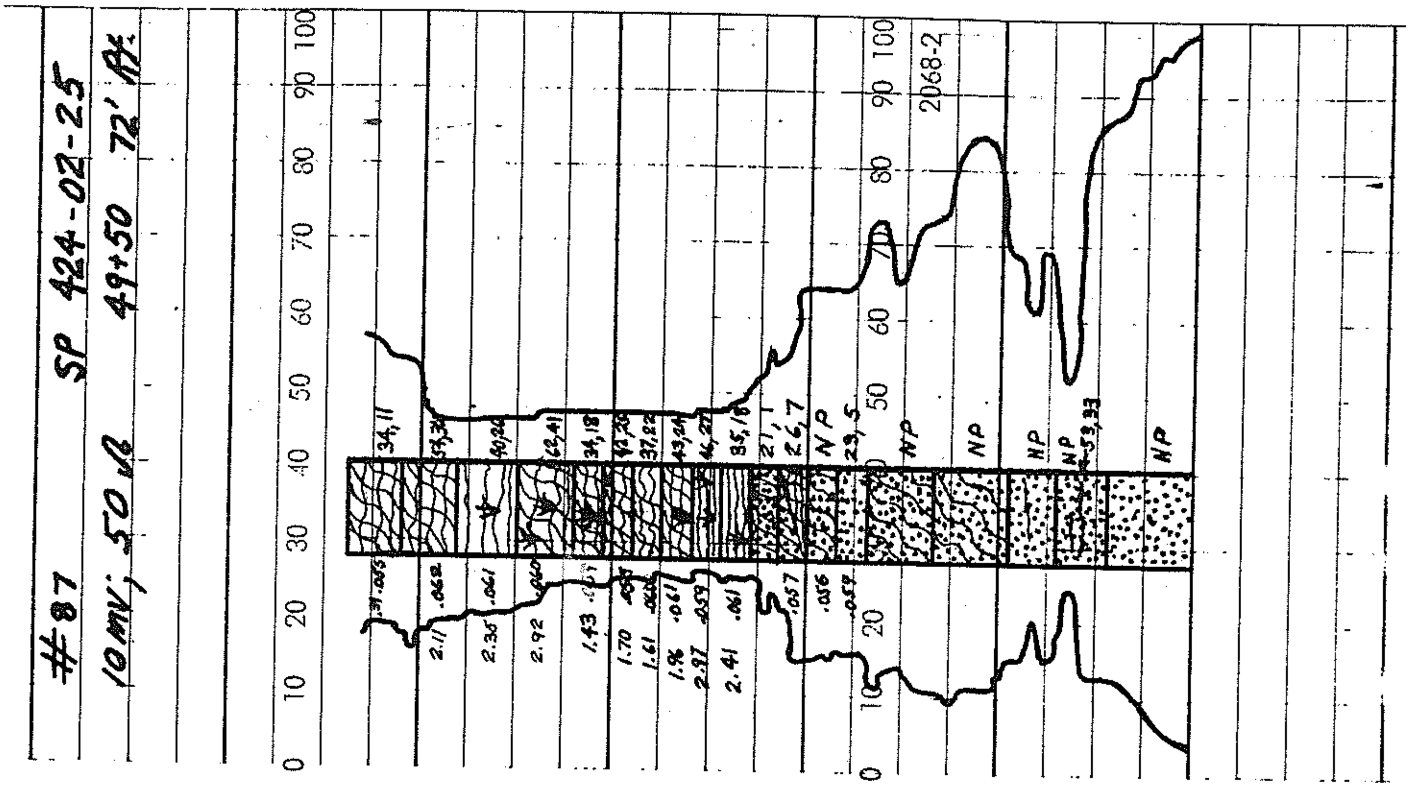
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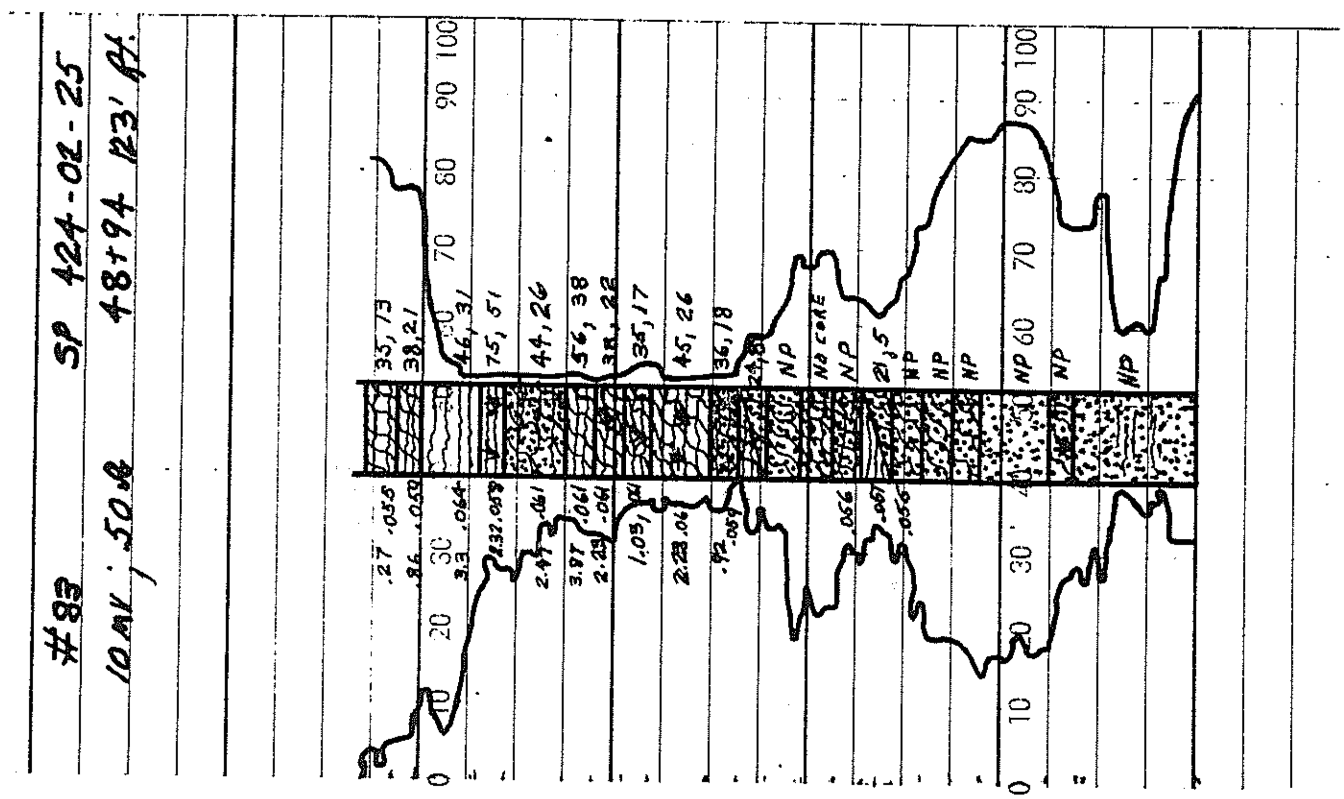
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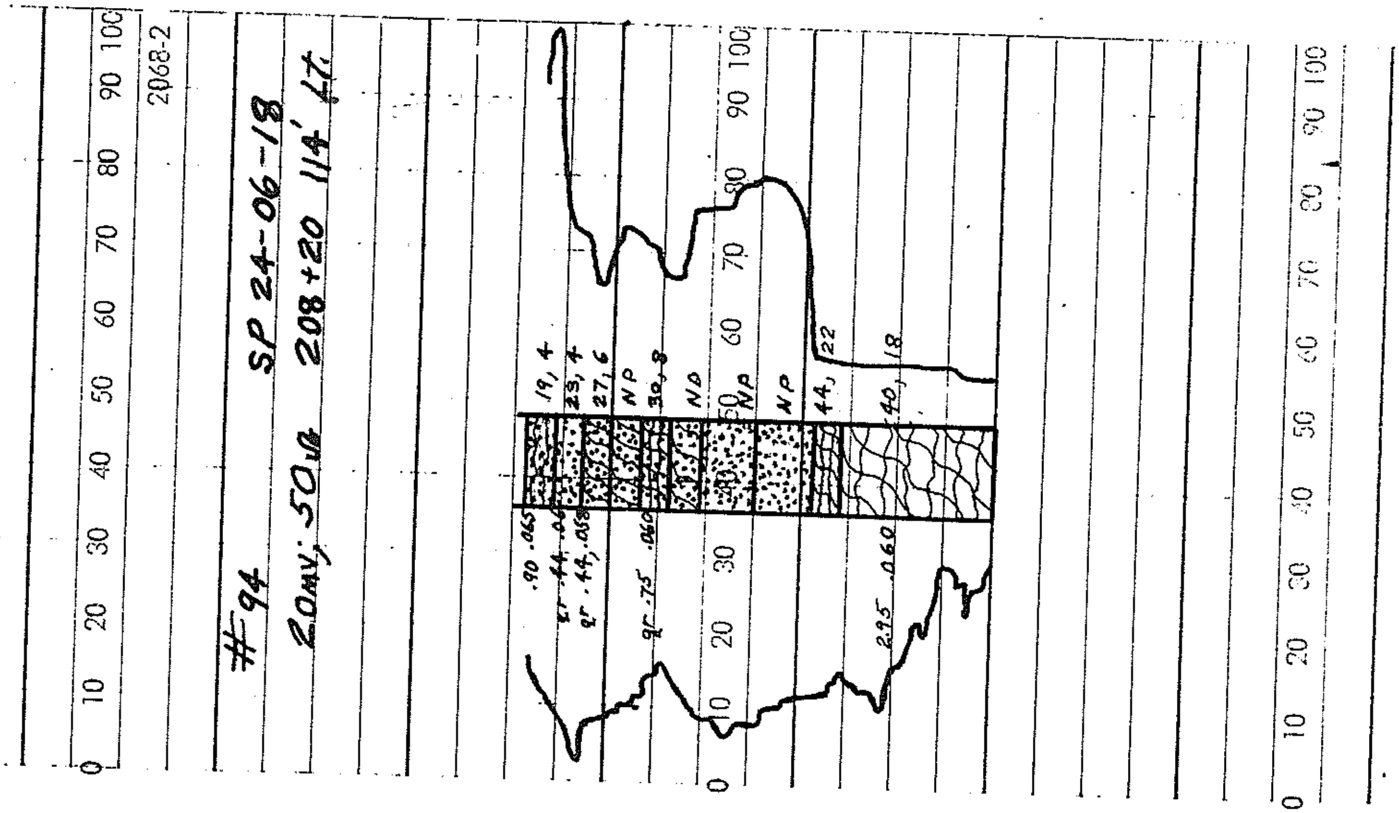
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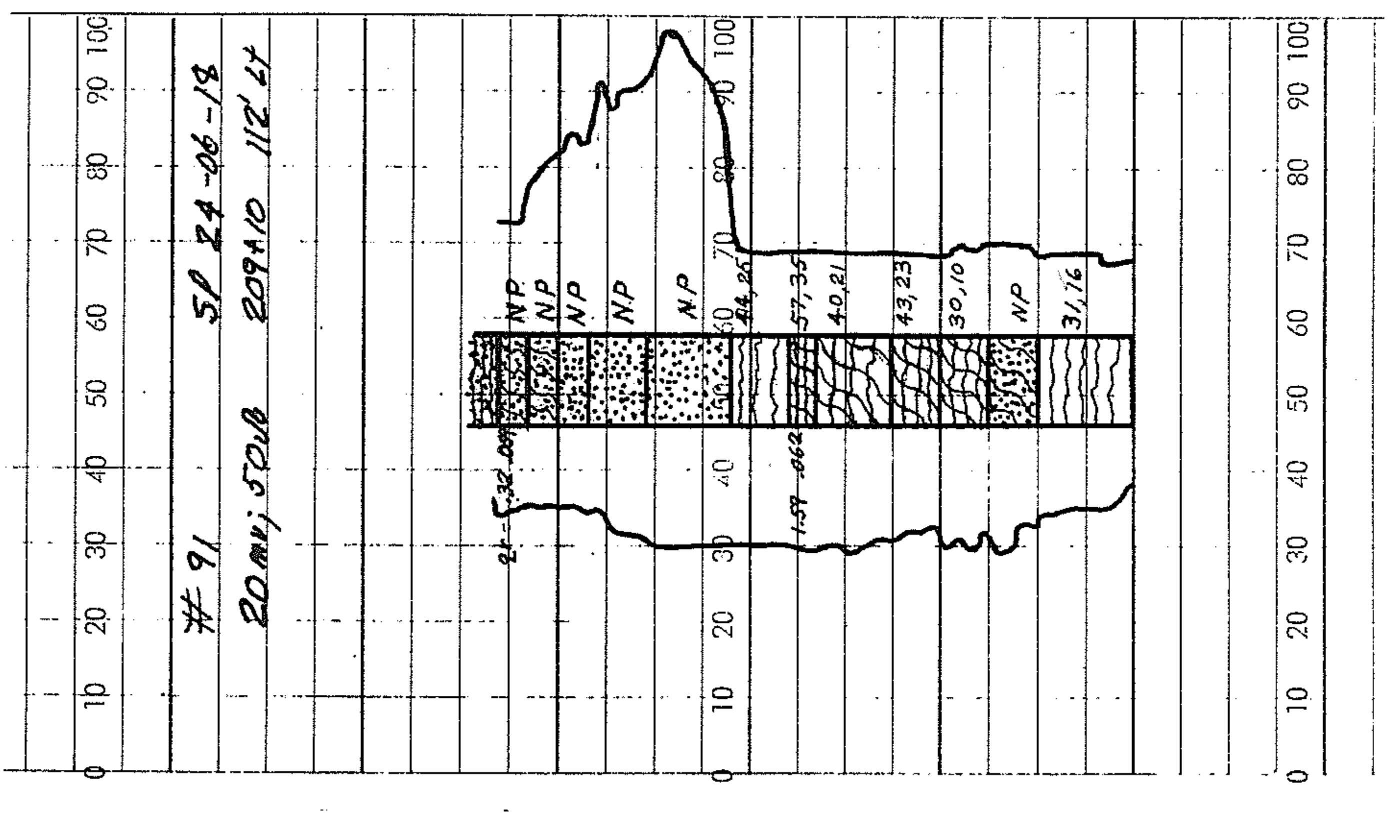
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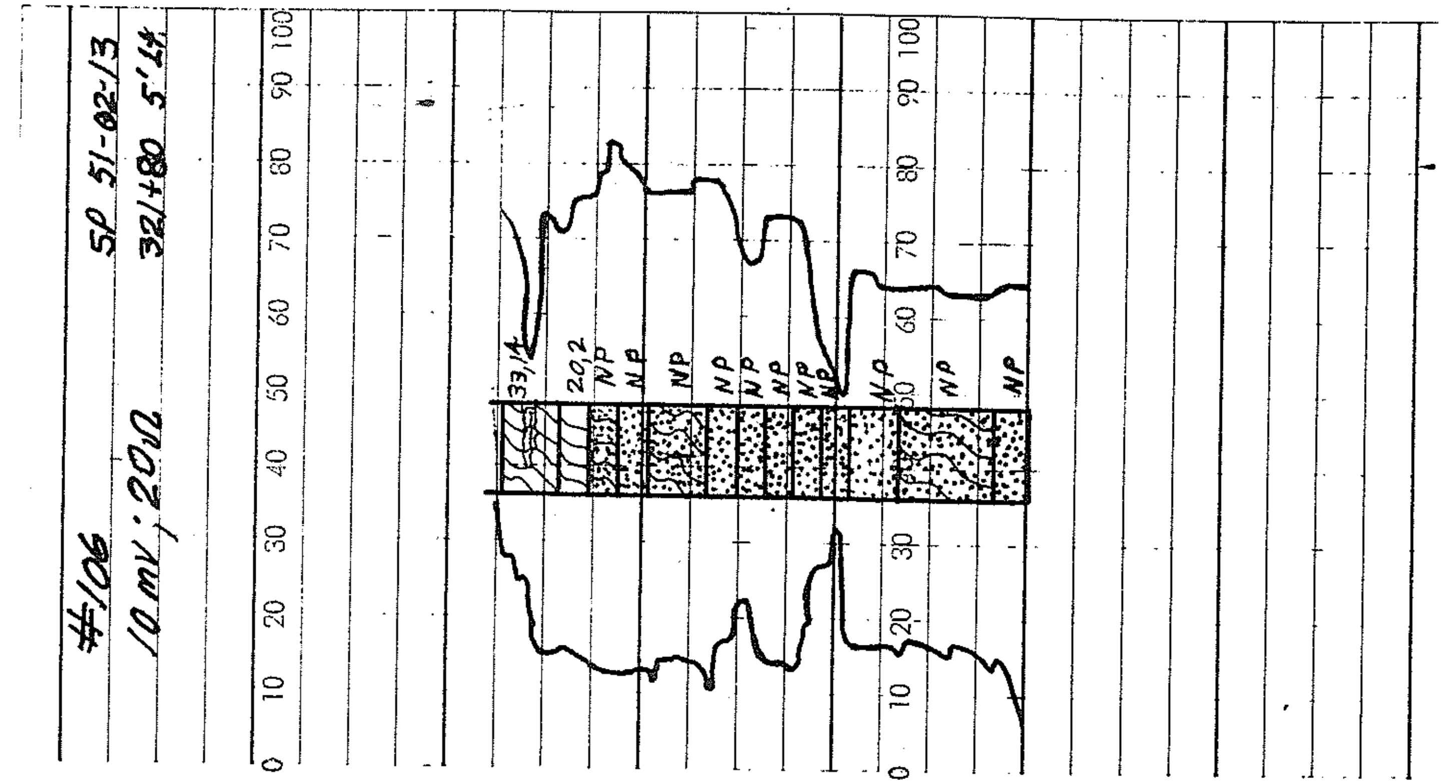
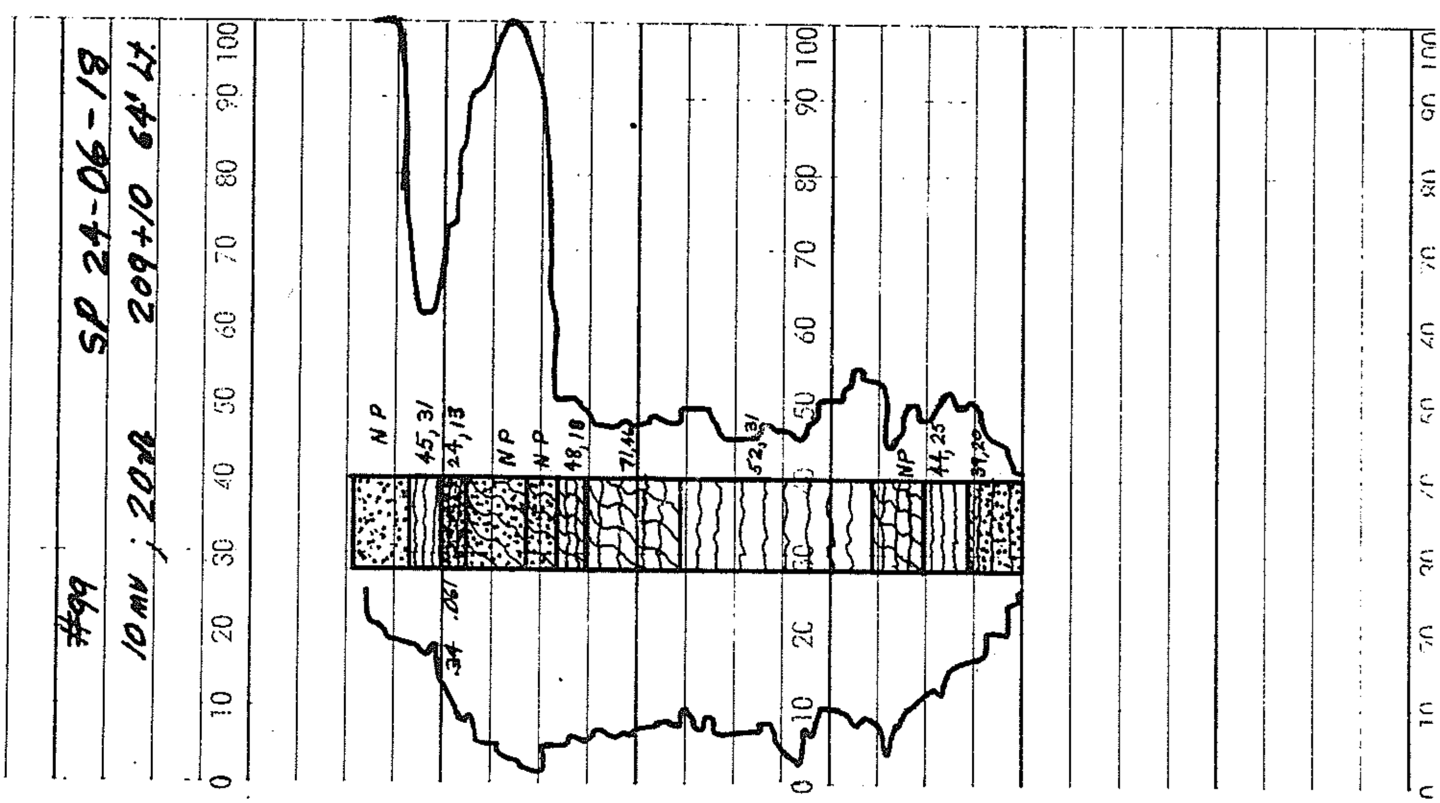
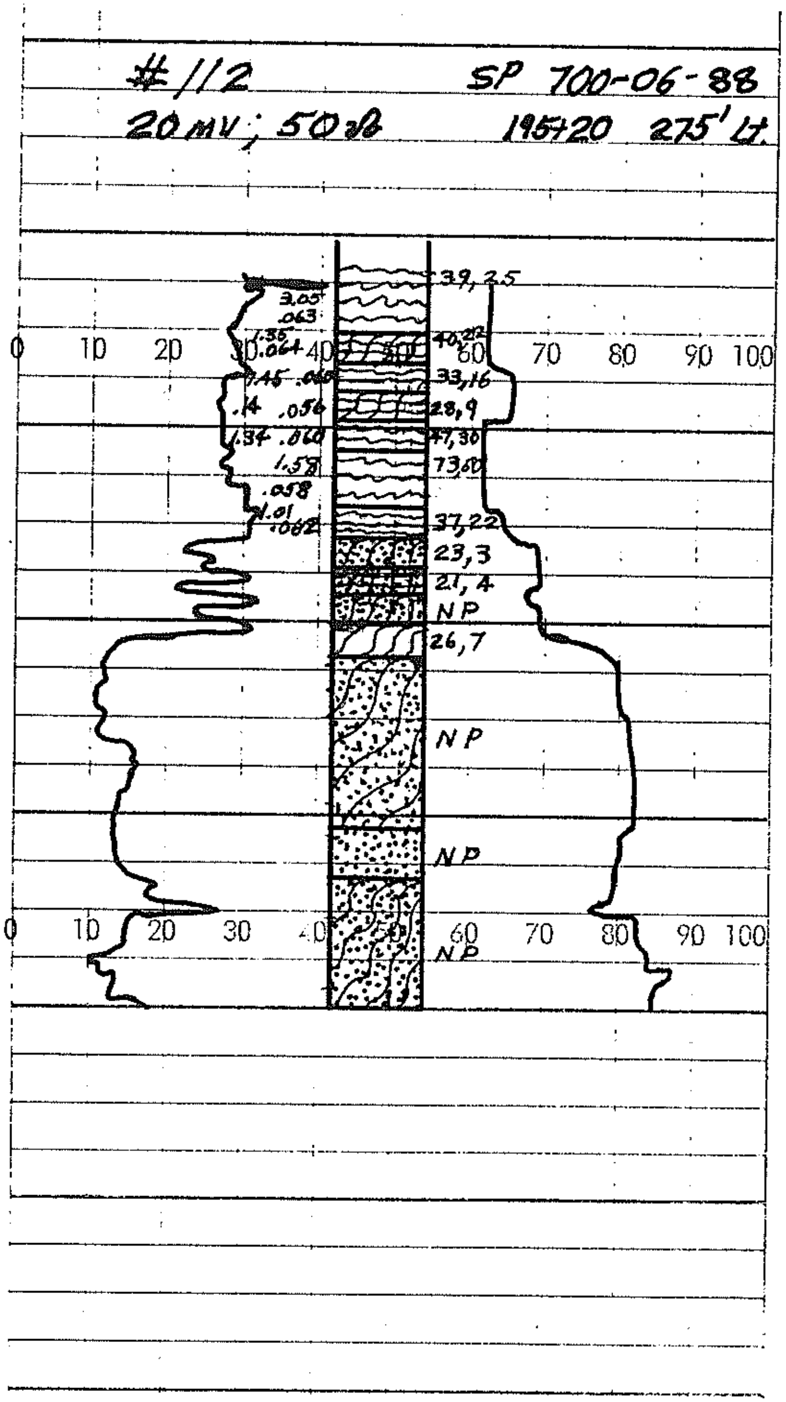
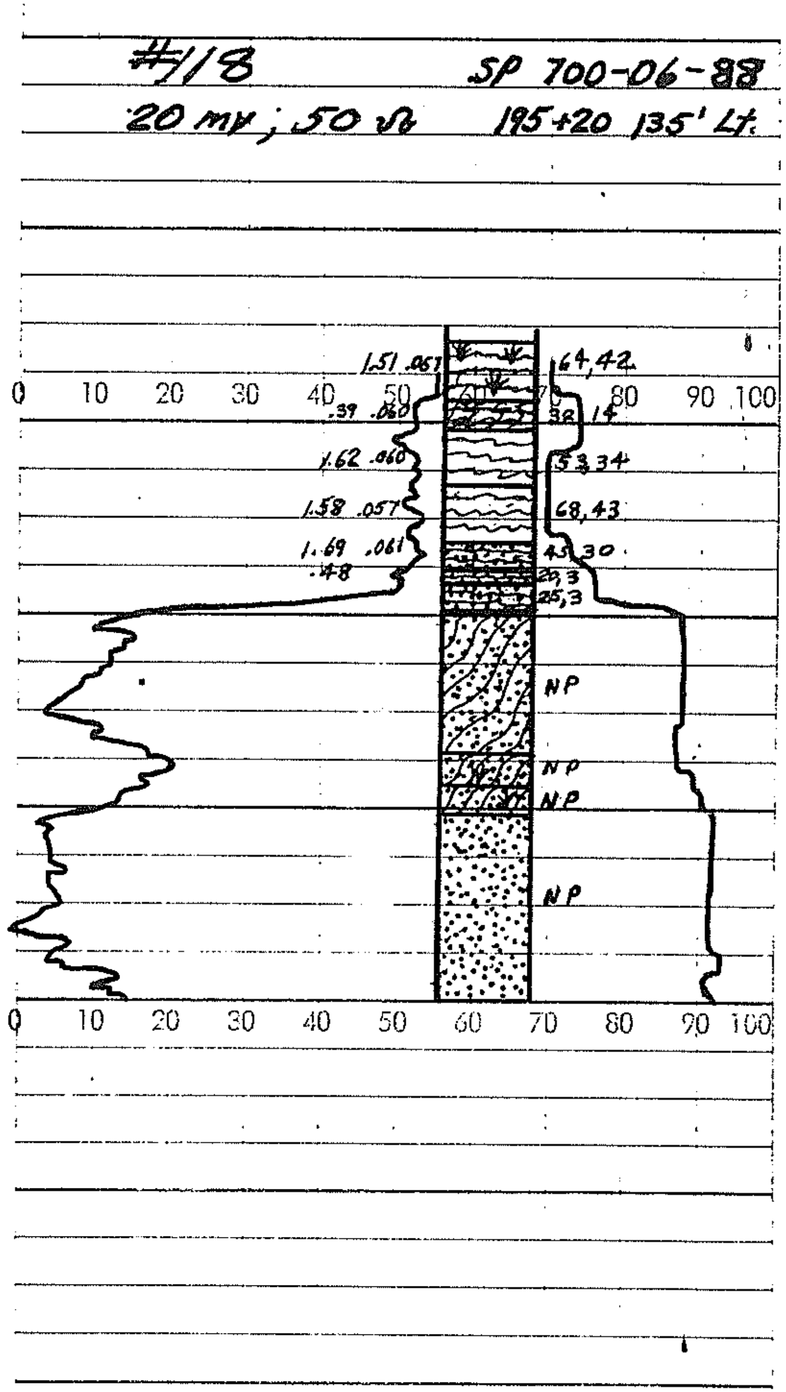
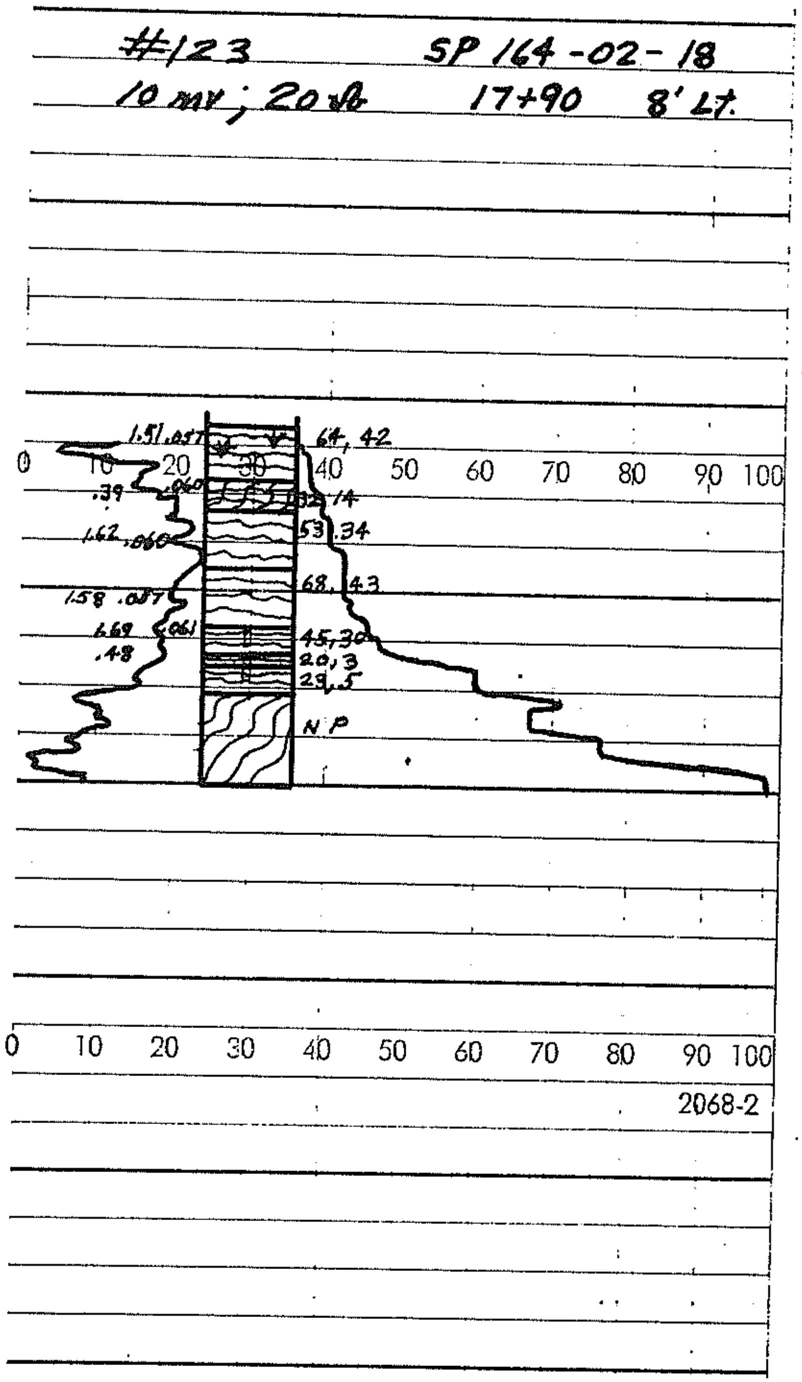
NP
31,16

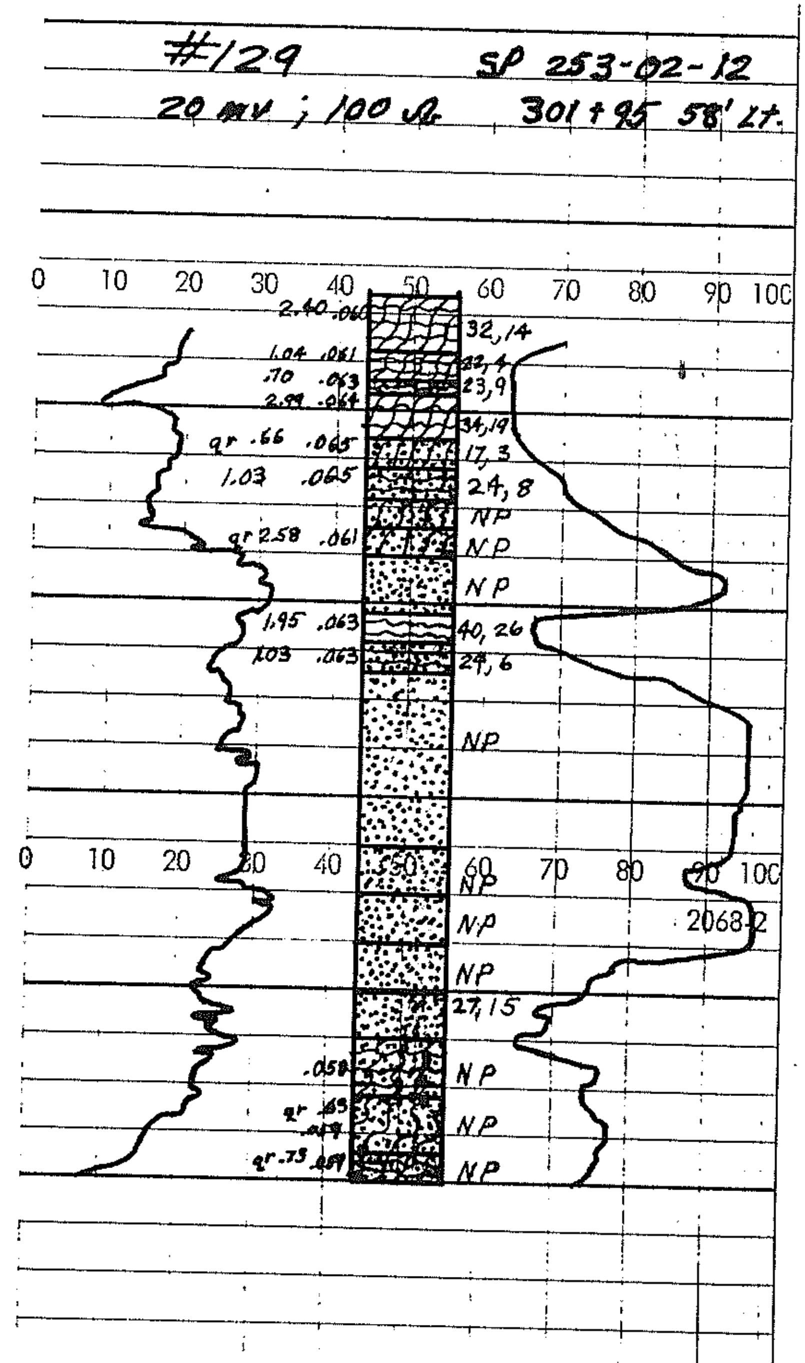

#106
10 mv ; 20Ω
SP 51-02-13
32+80 5' Lt.
33,14
20,2
NP
NP
NP
NP
NP
NP
NP
NP
NP
NP

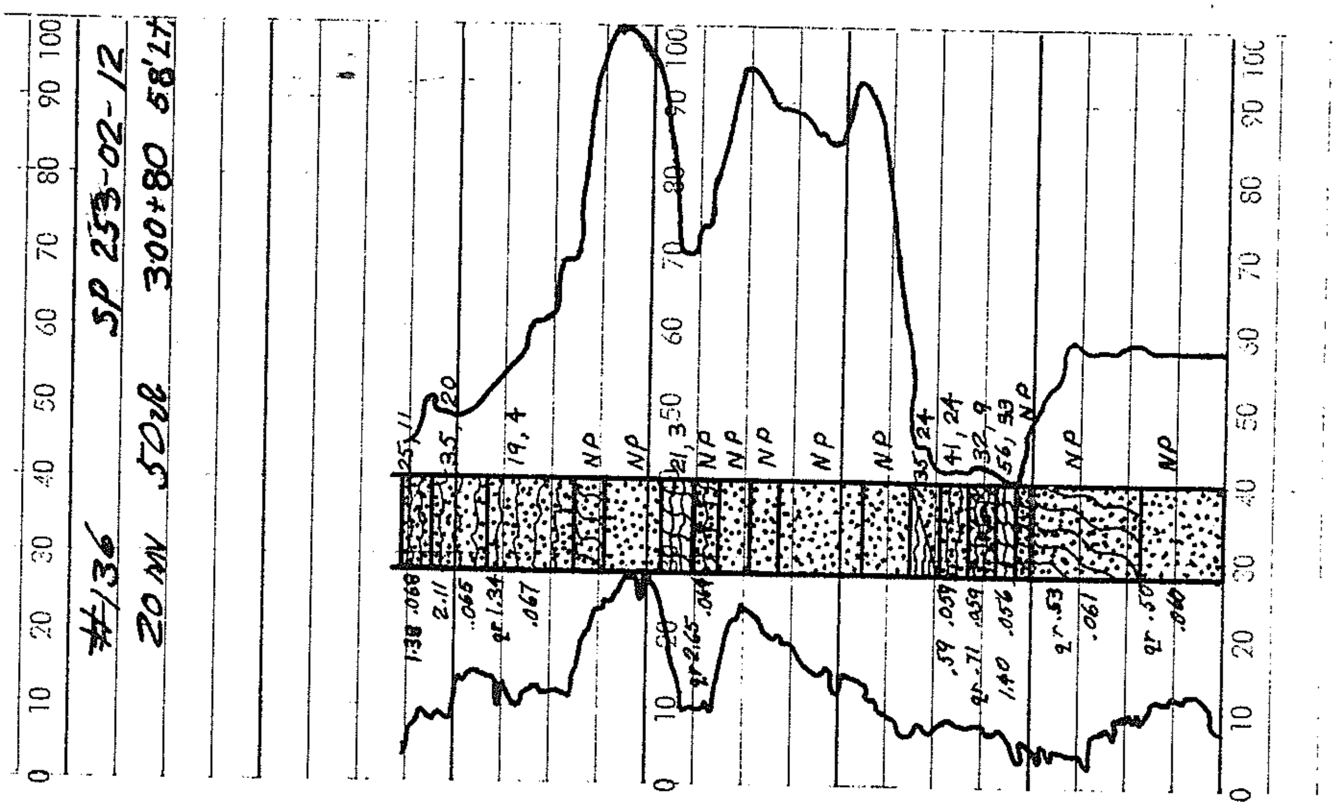

#99
10 mv ; 20Ω
SP 24-06-18
209+10 64' Lt.
NP
45,31
24,13
NP
NP
48,18
71,46
52,31
NP
44,25
.34
.061

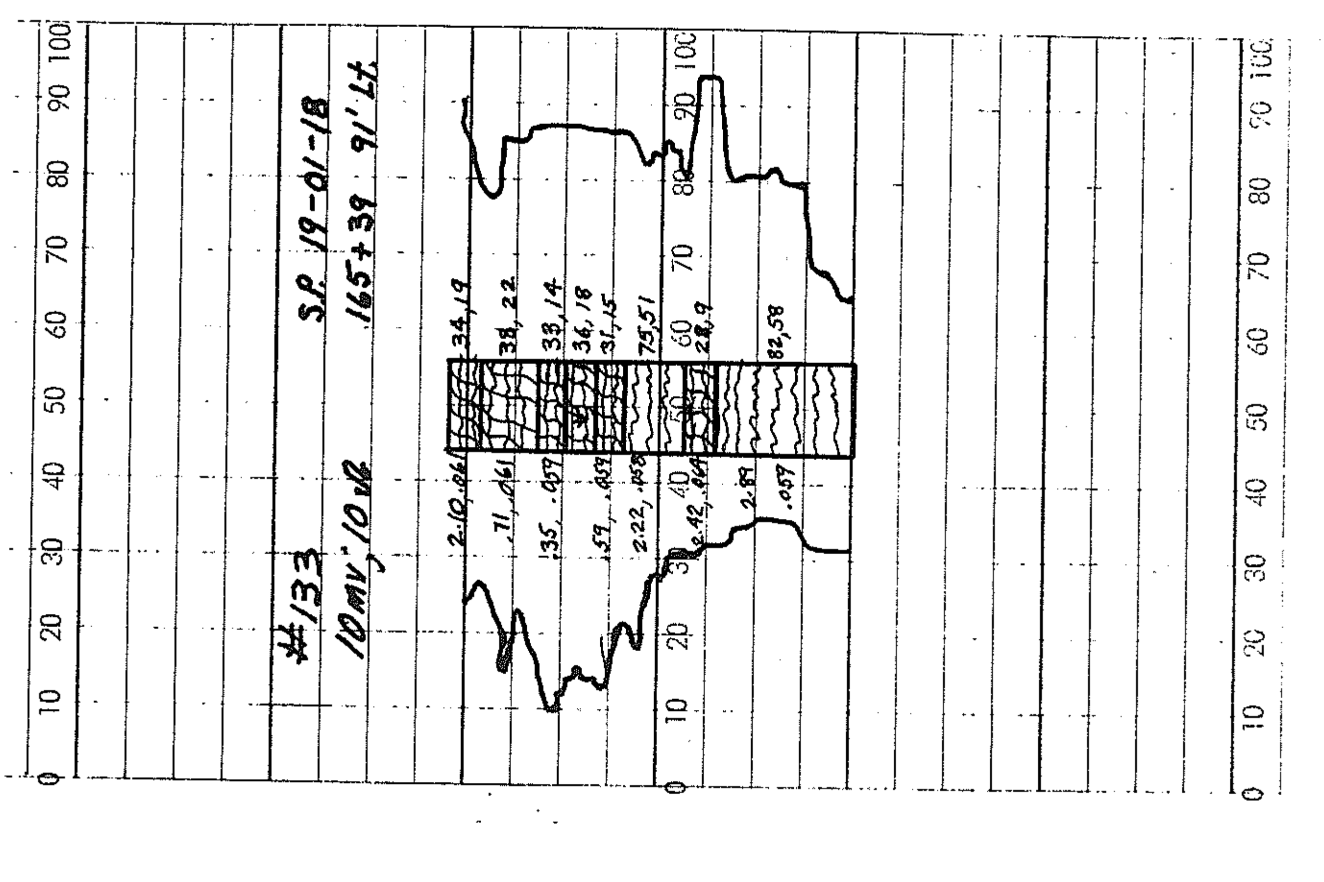

#112
SP 700-06-88
20 MV; 50 Ω
195+20 275' Lt.
0 10 20 30 40 50 60 70 80 90 100
3.05 .063
1.35 .064
1.45 .060
.14 .056
.34 .060
1.58
.058
1.01 .062
39,25
40,22
33,16
28,9
47,30
73,60
37,22
23,3
21,4
NP
26,7
NP
NP
NP

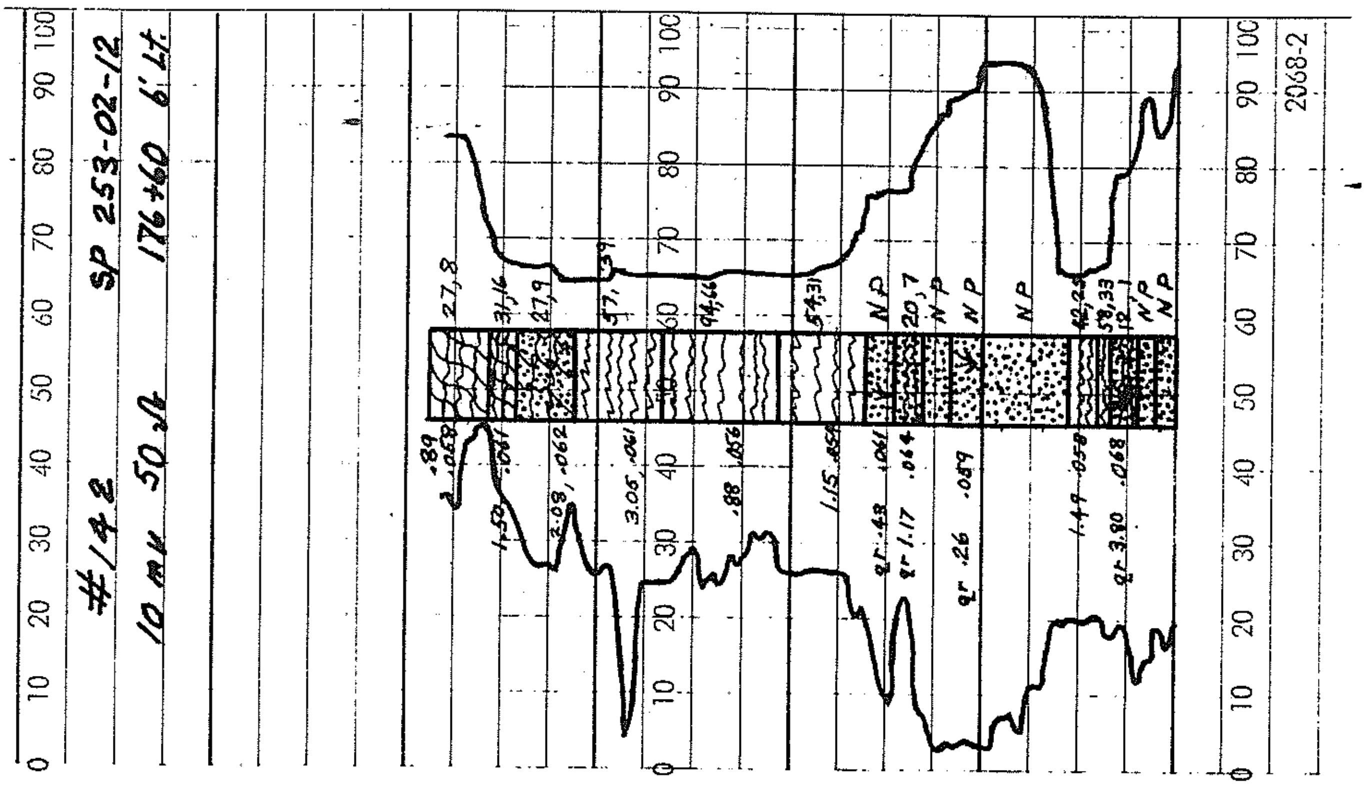

#118
SP 700-06-88
20 MV; 50 Ω
195+20 135' Lt.
0 10 20 30 40 50 60 70 80 90 100
1.51 .057
.39 .060
1.62 .060
1.58 .057
1.69 .061
.48
64,42
38,14
53,34
68,43
43,30
29,3
25,3
NP
NP
NP
NP

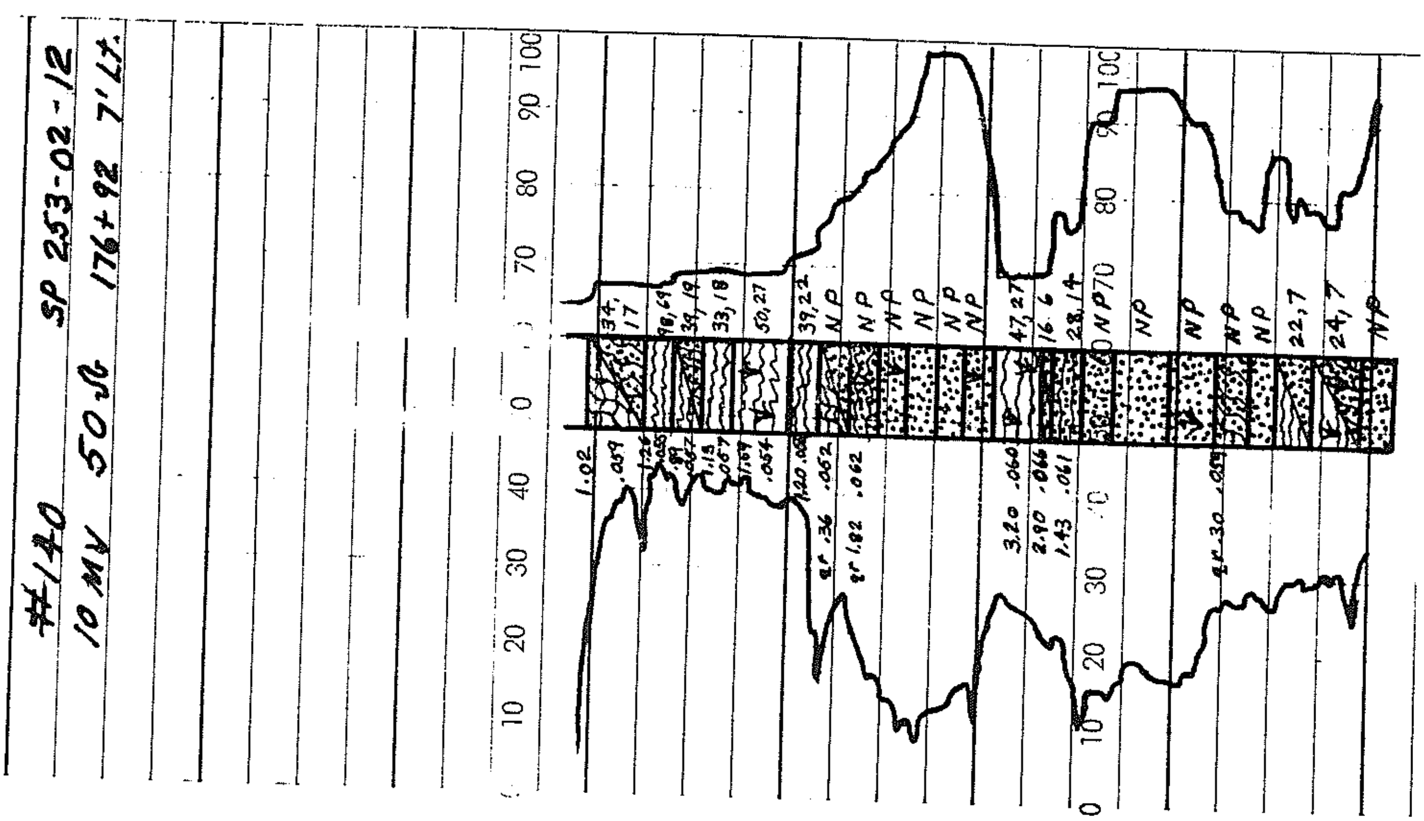

#123
SP 164-02-18
10 mv ; 20 Ω
17+90 8' Lt.
2068-2

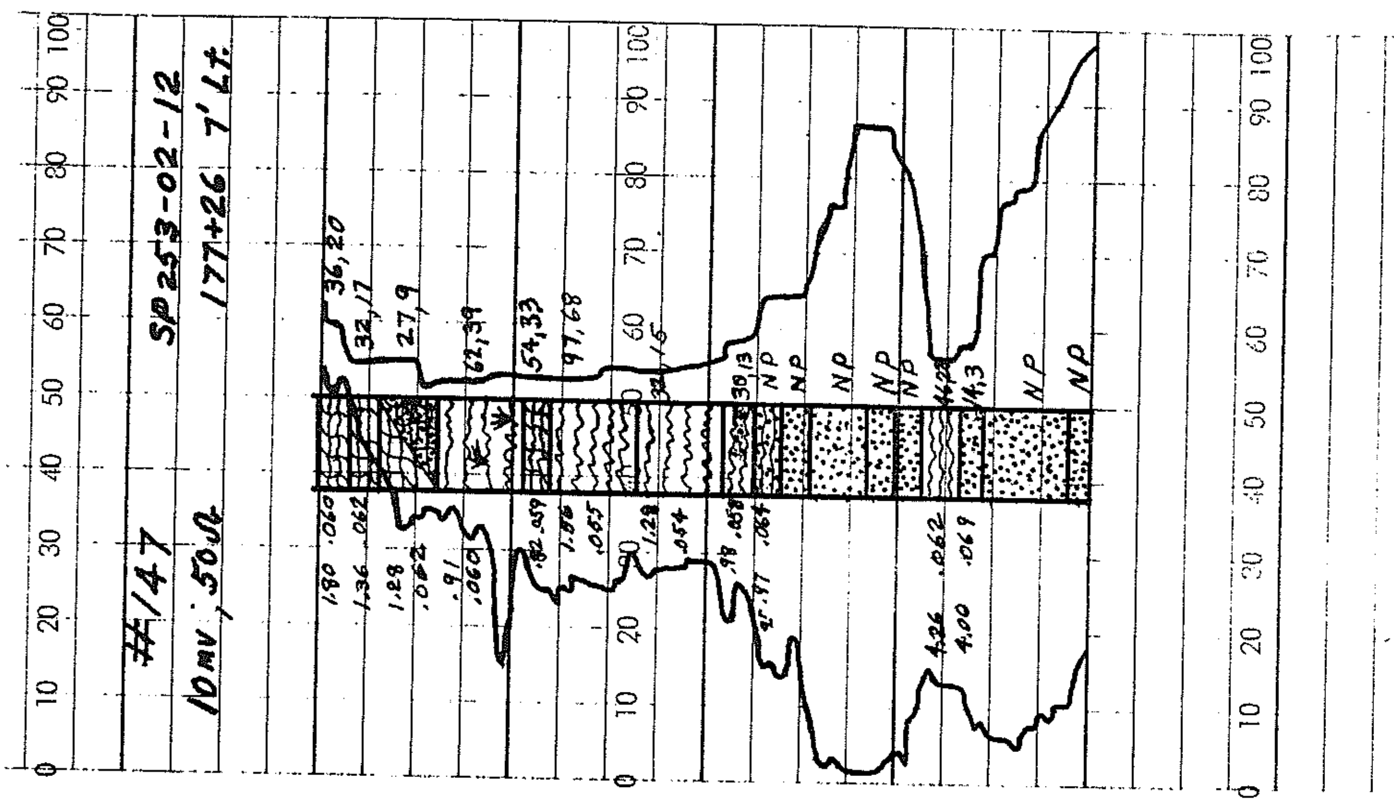

#129
SP 253-02-12
20 mv ; 100 Ω
301+95 58' Lt.
2068-2


#136
SP 253-02-12
20 MV
300+80 58' Lt.


#133
S.P. 19-01-18
165+39 91' Lt


#142
10 MK 50 J
SP 253-02-12
176+60 6' Lt.
2068-2


#140
10 MY 50 J
SP 253-02-12
176+92 7' Lt.


#147
SP 253-02-12
177+26 7' Lt.
10mv, 50Ω
NP