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Geophysical Well-Log Measurements
in Three Drill Holes at Salt Valley, Utah

by

Jeffrey J. Daniels, Robert J. Hite, and James H. Scott

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ABSTRACT

Three exploratory drill holes (DOE Salt Valley No. 1, No. 2, and No. 3) were drilled at Salt Valley, Utah, to study the geologic, physical, geochemical, and hydrologic properties of the evaporite sequence in the Permian Paradox Member of the Hermosa Formation. The results of these studies will be used to help to determine the suitability of salt deposits in the Paradox basin as a storage medium for radioactive waste material.

The following geophysical well-log measurements were made in each of the three drill holes: (1) density, (2) neutron, (3) acoustic velocity, (4) normal resistivity, and (5) gamma ray. Widely spaced resistivity and conductivity well-log measurements were made in the deep drill hole (DOE No. 3). Each of these well-log measurements shows the division of the evaporite sequence into halite and interbed sections. At the present time the most useful well-logging measurements for determining the individual lithologies in an evaporite sequence are gamma ray, neutron, density, and acoustic velocity.

The high resistivity contrast between the drilling fluid (0.5 ohm-m) and salt (10,000 ohm-m) makes it difficult to obtain quantitative measurements of electrical properties in an evaporite sequence. Tests of widely spaced electrode configurations show that the effects of the brine on the resistivity measurements can be reduced, and the depth of investigation increased, by

increasing the source-receiver electrode spacing. Tests of a single-coil induction probe show good resolution of the contrasting electrical properties of the various interbed lithologies.

INTRODUCTION

During the summer and fall of 1978 three holes were drilled by the U.S. Department of Energy at Salt Valley, Utah, to study the geologic and hydrologic characteristics of the evaporite sequence in the Permian Paradox Member of the Hermosa Formation. The approximate depths of these three drill holes are as follows: (1) DOE Salt Valley No. 1 (SV1) was drilled to a depth of approximately 390 m, (2) DOE Salt Valley No. 2 (SV2) was drilled to a depth of approximately 375 m, and (3) DOE Salt Valley No. 3 (SV3) was drilled to a depth of approximately 1240 m.

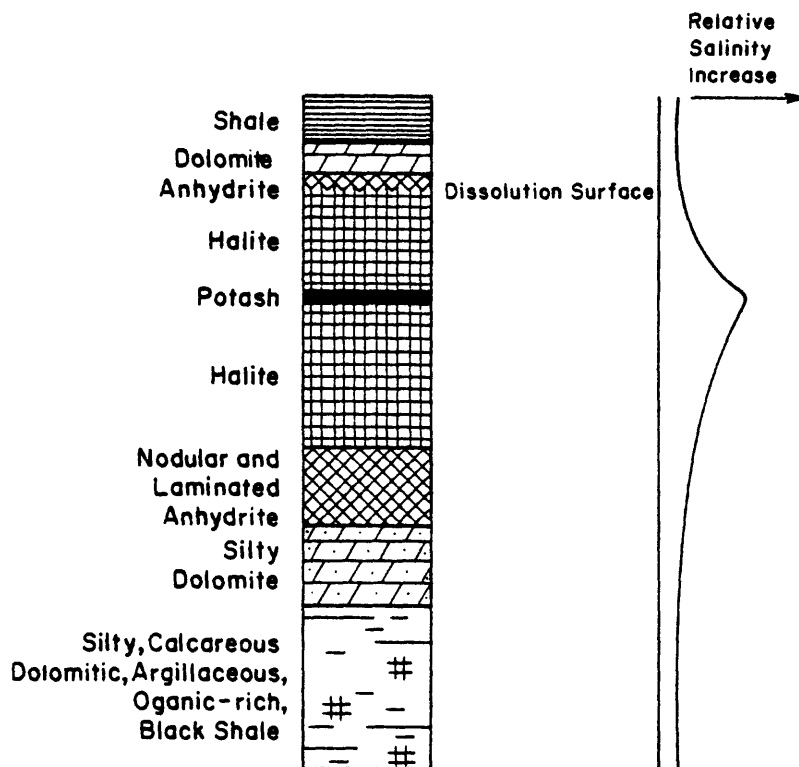
Borehole geophysical measurements were made (using U.S. Geological Survey borehole geophysical equipment and contract equipment) in each drill hole before casing was set (at the top of the salt), and in the remaining open hole after the drilling was completed. These measurements were made in order to better understand the physical properties of the various lithologies associated with the evaporite sequence. Geophysical well-logging information is necessary to interpret deep-penetration geophysical measurements (such as hole-to-surface and hole-to-hole electrical measurements) that can be used to evaluate the geologic viability of a site without extensive drilling.

GEOPHYSICAL WELL-LOG RESPONSE IN EVAPORITES

A general analysis of the well-log response measurements from drill hole SV3 was given in a previous paper (Daniels and others, 1979). Some of these data are repeated in this report.

The evaporite sequence at Salt Valley can be divided into three different stratigraphic regimes as follows: (1) a weathered caprock, (2) halite sections below the caprock, and (3) interbeds of anhydrite, shale, and dolomite separating the halite sections. Figure 1 illustrates an idealized geologic section showing typical evaporites in the Paradox basin. This evaporite sequence is repeated in a cyclic manner as a result of salinity changes in the basin during deposition. Previous investigators (Tixier and Alger, 1970; Nurmi, 1978) have described the basic physical properties of an evaporite sequence. These general properties, summarized in figure 1, appear to apply to the Salt Valley evaporite sequence.

A geophysical well-log measurement is a function of the physical properties of the rock framework, the fluid in the formation, conditions in the borehole (fluid and rugosity), the volume of the rock investigated by the probe, the vertical resolution of the probe (thin-bed resolution), and the design characteristics of each individual logging probe. Therefore, the response measured with a geophysical well-logging probe should always be considered an apparent, rather than a true, physical-property value. The response characteristics of individual well-logging probes can be summarized as follows:



	(grams/cc) Density	(km/sec) Velocity	Natural Radioactivity	Water Content
Halite	2.16	4.4 - 6.5	None	Very Low
Sylvite	1.99	4.6 - 6.5	High	Low
Anhydrite	2.96	4.1	None	Very Low
Carnallite	1.61	4.4 - 6.5	Low	High
Dolomite	2.87	3.5 - 6.9	None	Low
Gypsum	2.32	2 - 3.5	None	Intermediate
Shale	2.2 - 2.6	2.3 - 4.7	High	Intermediate - High

Figure 1.—Lithology and physical properties of an idealized evaporite sequence in the Paradox basin. The lithologic information is from Hite and Lohman (1973), and the physical property information is from Tixier and Alger (1970).

Density

The density probe consists of a gamma-ray source and one or more gamma-ray detectors. Gamma rays emitted by the source are scattered by the rock formation as an inverse function of the electron density of the rocks. The Compton-scattered gamma radiation that is measured at the gamma-ray detector on the probe is inversely proportional to the electron density of the rock. When two detectors are used to measure the scattered gamma radiation, the effects of the borehole conditions (rugosity and fluid density) on the calibrated density measurement can be compensated, and the computed density is approximately equal to the bulk density of the rocks. The apparent bulk density of halite is approximately 2.05 g/cm^3 in the three Salt Valley drill holes. The density of the interbed and caprock lithologies is a function of the porosity and grain density of the rocks. Clays and shales have low apparent bulk densities (2.2 to 2.6 g/cm^3), sandstone has intermediate apparent bulk densities (2.45 to 2.65 g/cm^3), and dolomite has a high apparent bulk density (2.7 to 2.9 g/cm^3). Potash minerals (carnallite and sylvite) have very low apparent bulk densities (less than 2.0 g/cm^3).

Resistivity

Resistivity is a measure of the ease that electrical current passes through a rock and is a function of porosity, fluid resistivity, and grain resistivity. Laboratory resistivity measurements show a wide range of resistivity values for evaporites. The apparent resistivity of clay is usually less than 10 ohm-m , shale has a resistivity of less than 50 ohm-m , sandstone has a resistivity between 50 and 200 ohm-m , and dolomite has a resistivity of more than 200 ohm-m . The DC resistivity of consolidated halite is generally greater than $10,000 \text{ ohm-m}$, which contrasts markedly with the resistivities of

the caprock and interbeds in the Paradox basin. In theory, resistivity should be an excellent indicator of resistivity contrasts. However, conventional resistivity probes are not designed to operate in holes drilled through evaporites. The resistivity contrast between the drilling fluid and the salt formation is approximately 200,000 to 1, resulting in a resistivity response that is dominated by the low resistivity of the drilling fluid. This response results in resistivity well-log measurements that lack detail in defining lithologies within the interbeds, as well as yielding apparent resistivity values that are several orders of magnitude different from the true resistivity of the salt. Conventional induction-logging tools are also inadequate for measuring the high resistivities found in an evaporite sequence.

Gamma ray

The gamma-ray probe measures the natural gamma radiation emitted by the rocks surrounding the borehole. The principal natural gamma-ray emitting minerals in the evaporite sequence are uranium and potassium-40. Halite has a nearly zero gamma-ray response, shale has a low to intermediate gamma-ray response, black shale has an intermediate to high gamma-ray response, and the potash minerals have very high gamma-ray responses.

Neutron

The neutron well-logging probe consists of a neutron source and a neutron detector located on the probe approximately 0.5 m from the source. The number of neutrons counted at the receiver is inversely proportional to the hydrogen content of the rocks surrounding the borehole, and is primarily a measure of the amount of water and hydrocarbons contained in the rocks. The neutron response is high in halite, intermediate in sandstone and dolomite, and low in carnallite and black shale.

Acoustic velocity

The acoustic-velocity probe consists of an acoustic source and two (or more) acoustic detectors. The interval transit time of a sonic wave emitted from the source is measured between two detectors. The inverse of the interval transit time (t) times the distance (in meters) between the two detectors is the acoustic velocity (m/s). Only the p-wave velocity is usually measured. The acoustic velocity is high for carnallite, anhydrite, and dolomite (approximately 5000 m/s), intermediate for halite (approximately 4500 m/s), and low for gypsum and shale (approximately 3000 m/s).

INTERPRETATION OF LITHOLOGIES

FROM BOREHOLE GEOPHYSICAL WELL LOGS AT SALT VALLEY

The complete borehole geophysical well-log measurements for the holes considered in this study are shown in the appendixes as follows: (1) the logs for DOE Salt Valley No. 1 (SV1) are in Appendix A, (2) the logs for DOE Salt Valley No. 2 (SV2) are in Appendix B, and (3) the logs for DOE Salt Valley No. 3 (SV3) are in Appendix C.

The response of the neutron, gamma-ray, density, and acoustic-velocity well logs in the halite, caprock, and interbed sections of drill hole SV3 is illustrated in figure 2. Halite is easily distinguished from the interbeds and caprock at Salt Valley. The high gamma-ray response in the interbeds and caprock is caused by potassium-rich clays and possibly uranium in the shaley interbeds, whereas the low neutron response indicates a general increase in

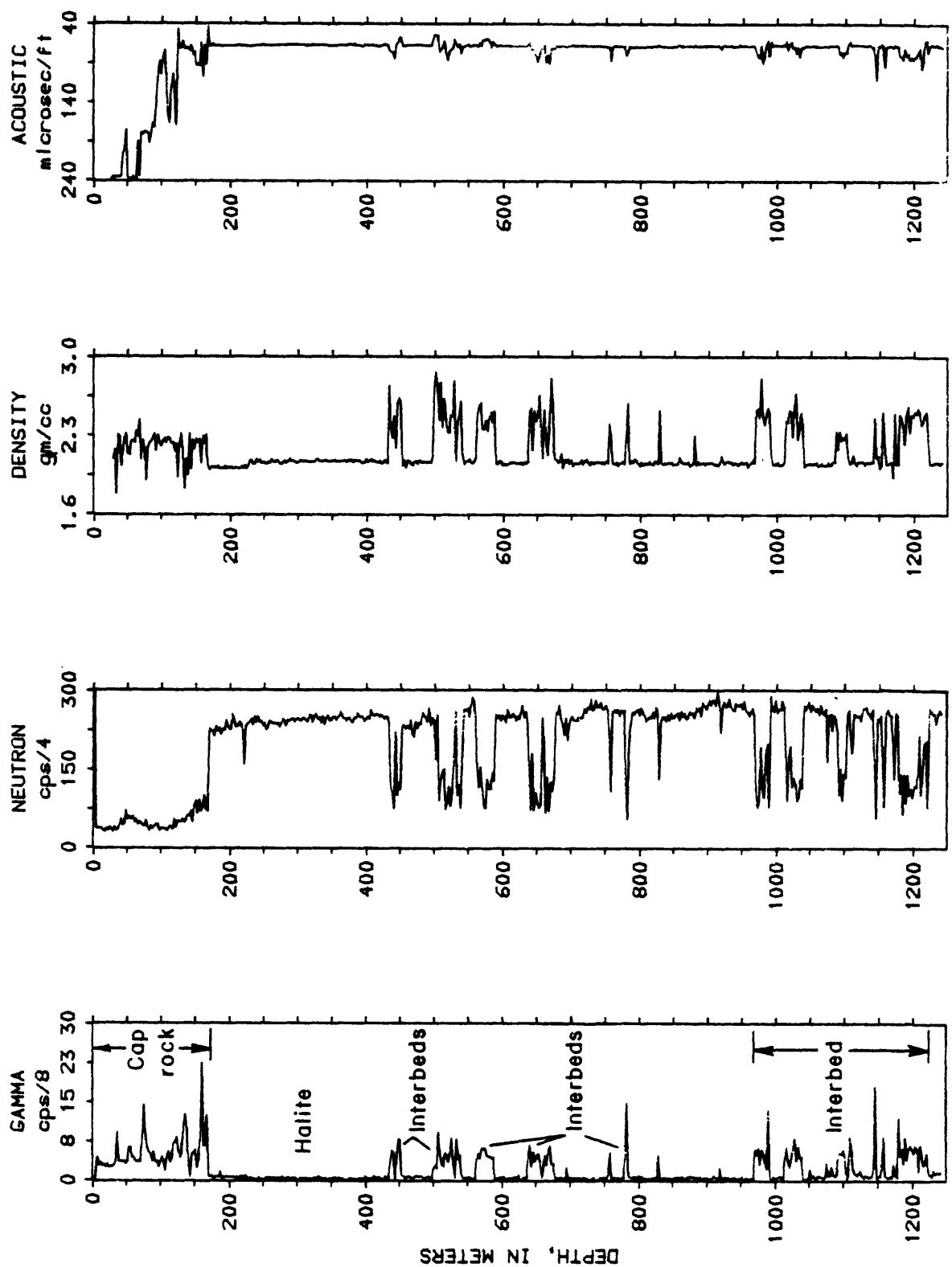


Figure 2.--Gamma ray (GAMMA), neutron (NEUTRON), compensated density (DENSITY), and acoustic-velocity (ACOUSTIC) well logs for drill hole SV3. The interbed, caprock, and halite intervals are indicated on the gamma-ray log. Units are counts/second (cps) for the gamma-ray and neutron logs, grams/cubic centimeter (g/cm^3) for the density log, and microseconds/feet (microsec/ft) for the acoustic log.

water in the interbeds and caprock. The density log shows the relatively high grain densities of the interbeds compared to the halite, whereas the acoustic log reflects the low p-wave velocity of the caprock and interbeds. The density, neutron, and acoustic log responses reflect the hydration of anhydrite to gypsum in the caprock.

An experiment using widely spaced electrode arrays was performed in the test well (SV3) at Salt Valley. Electrode configurations and the resulting apparent resistivities are shown in figure 3. Increasing the source-receiver separation increases the apparent resistivity. The widely spaced configurations also show more detail than the conventional long-normal resistivity. This paradox is a result of penetration of current beyond the invaded zone of the interbeds. If the electrode separation were increased further, the resolution of the interbeds would diminish, and the apparent resistivity would increase as the ratio of salt-to-interbed thickness increased. The intrinsic resistivity values of the evaporite layers can only be achieved by removing the effect of the borehole from the apparent resistivity response by detailed computer modeling.

High-frequency electromagnetic methods, such as radar, can be used in dry holes drilled into evaporites, and could be adapted to work in fluid-filled holes. More experimental work is needed to determine the usefulness of sub-radar-frequency electromagnetic measurements in salt environments. Figure 4 shows an uncalibrated experimental conductivity log that was made at Salt Valley by measuring the in-phase self-inductance of a single coil driven at a frequency of 1000 Hz. The quadrature component of this inductance signal is normally used to measure magnetic susceptibility and has been described by

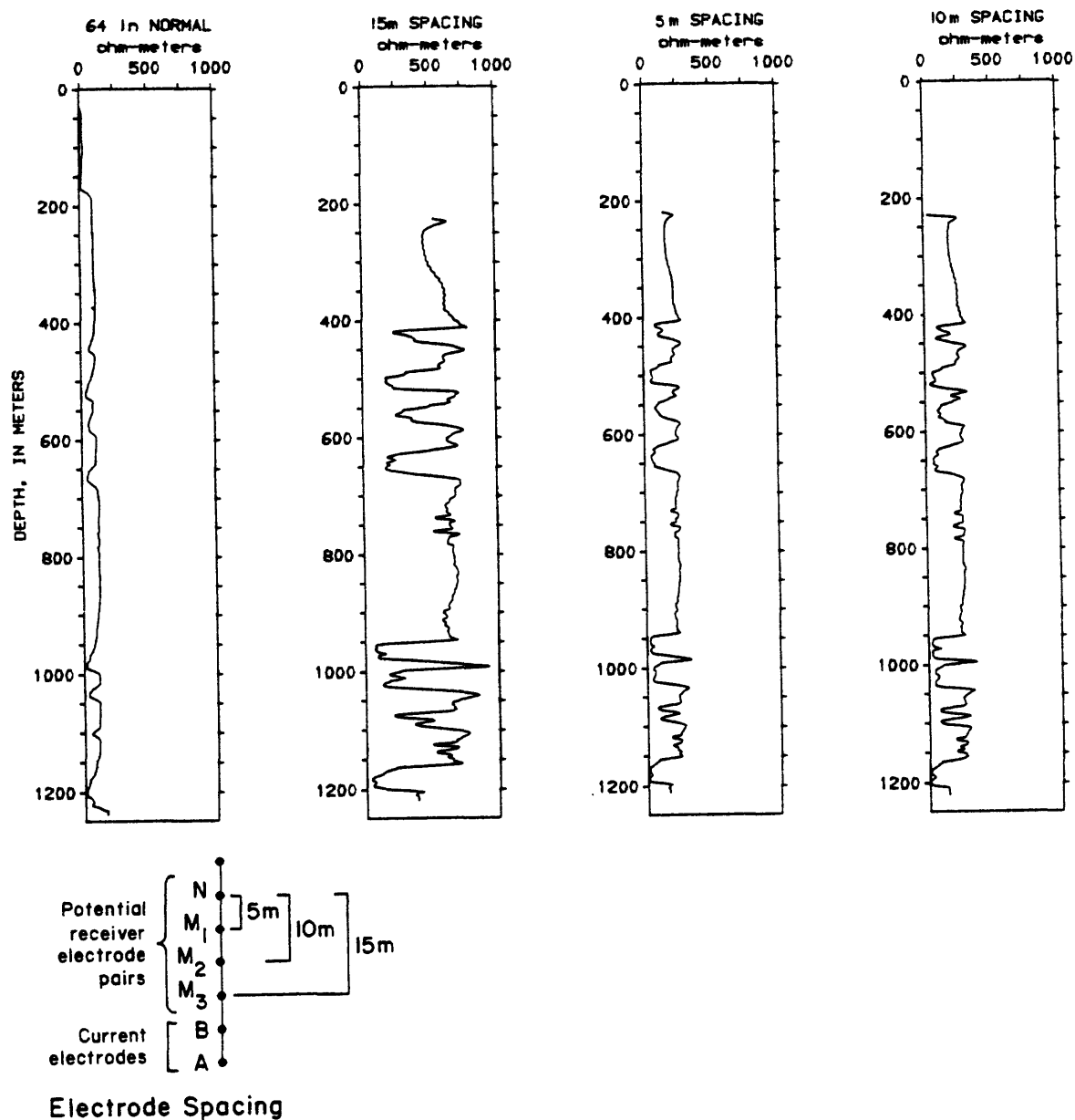


Figure 3.--DC-resistivity well-log responses for drill hole SV3. The long normal array (64 in) is the conventional 1.6 m logging array. Spacing for the other arrays are shown in the figure. Plot position for the widely spaced arrays is halfway between the potential electrodes.

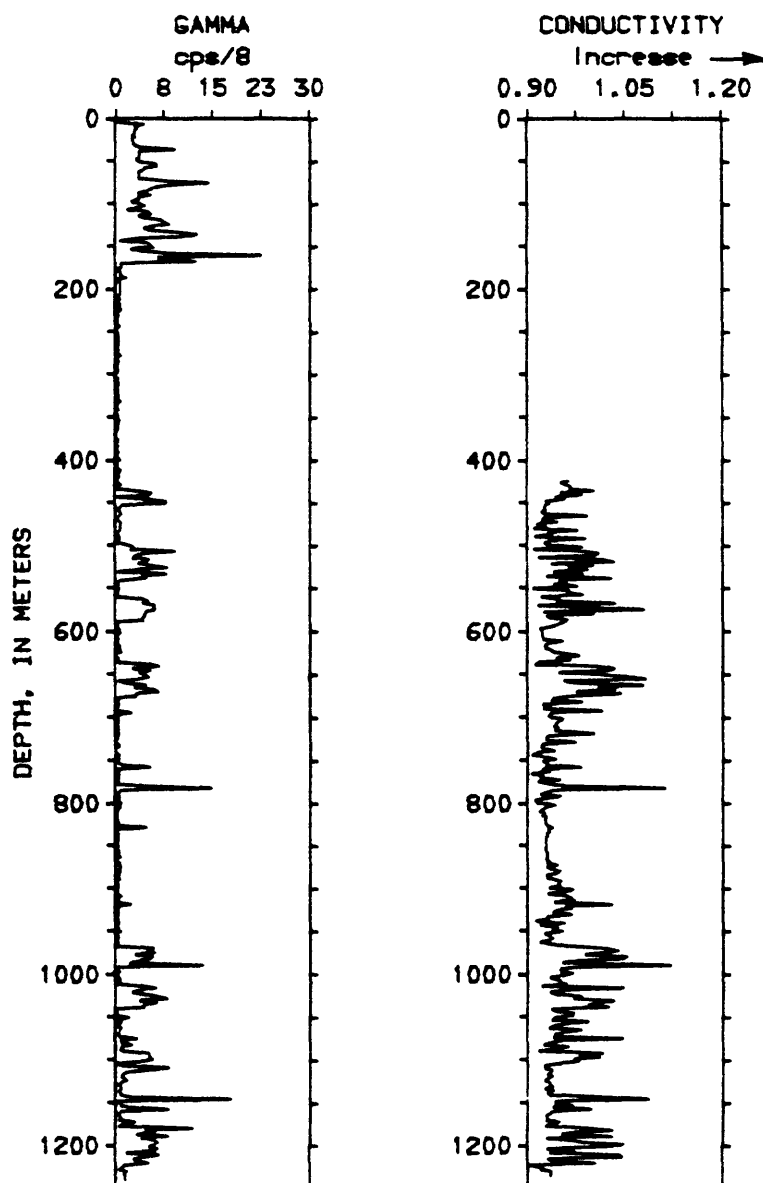


Figure 4.--Gamma-ray and conductivity well logs for drill hole SV3. Conductivity values are uncalibrated.

Scott and others (1976). The usefulness of this conductivity measurement is not yet fully established, but the measurements correlate with conductivity changes that would be expected in an evaporite sequence.

Figure 5 illustrates the well-log measurement response for a typical halite-interbed sequence from the well logs shown in figures 2 and 4. Carnallite can usually be distinguished from shale by its low density. Anhydrite can be distinguished from halite by its high density and the nearly constant acoustic velocity of halite. There are sections of the interbeds where multiple lithologies make it difficult to distinguish the mineralogic components of the section. This difficulty is clearly illustrated for depth intervals 1018 to 1025 m and 1030 to 1040 m. The presence of dolomite in shale and sandstone complicates the interpretation of geophysical well logs in evaporite sequences. Halite, shale, potash, and anhydrite can be easily identified by individual well logs as follows:

- (1) Anhydrite has a low gamma-ray count, high neutron response, high acoustic velocity, high density, and low conductivity.
- (2) Most black shales have a high gamma-ray response, low neutron response, intermediate densities, low acoustic velocities, and high conductivities.
- (3) Halite has a low gamma-ray count, high neutron response, low density, low acoustic velocity, and low conductivity.
- (4) The potash minerals at Salt Valley are carnallite and sylvite. Carnallite has an intermediate gamma-ray count, an intermediate neutron response, low density, high acoustic velocity, and high

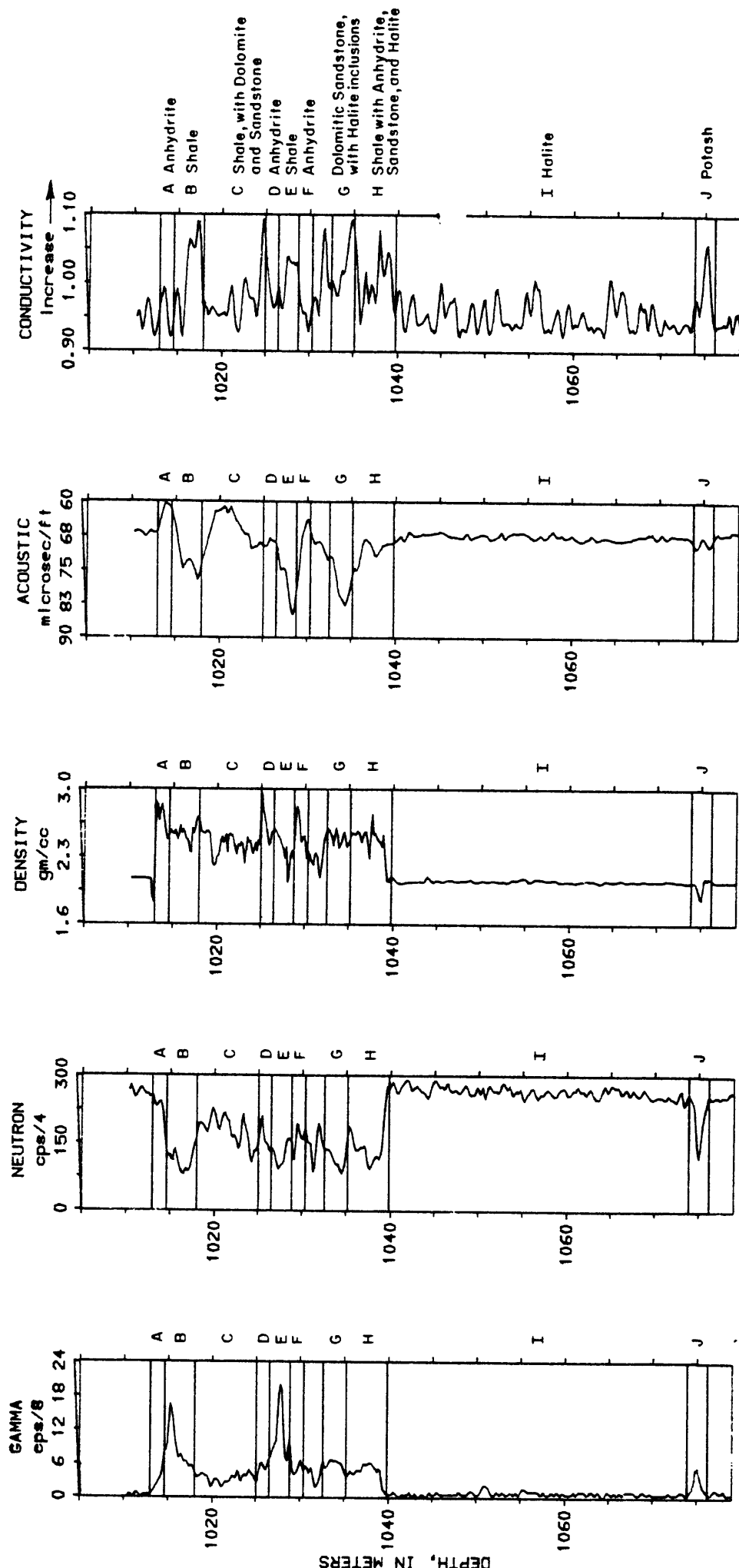


Figure 5.—Lithologies corresponding to response values for the gamma-ray, neutron, density, acoustic-velocity, and conductivity well logs.

conductivity. Sylvite has a high gamma-ray count, high neutron response, low density, high acoustic velocity, and low conductivity.

COMPUTER-ASSISTED INTERPRETATION

To overcome the ambiguity associated with individual well-log interpretation, several well logs must be simultaneously interpreted. A consistent interpretation of the well logs can be achieved by interpreting the digital well-log data. Computer-assisted interpretation of well logs involves the following procedure: (1) input of digital depth-well log response measurement data pairs into the computer, (2) assignment of value ranges of one or more geophysical well logs for a particular lithology, and (3) execution of the computer program to assign lithologies to depth intervals where the well-log measurements are within the specified ranges for a particular lithology. This interpretation procedure is necessarily subjective; it should be considered to be a preliminary interpretation that should be refined by visual interpretation of the geophysical well logs. A computer-assisted interpretation of drill hole SV3 is given in Appendix D. The lithologies shown in Appendix D were interpreted using the well-log response value ranges given in table 2. The well-log response measurements of the Salt Valley drill holes were digitized at depth intervals of 0.1524 m. Therefore, beds whose thickness is less than approximately 0.3048 m cannot be detected. Beds whose thickness is less than approximately 0.6096 m show no response on the lithologic well logs in Appendix D. However, the list of interpreted values, shown in Appendix D, does add information to the interpretation for thin beds.

The caprock lithology is complex, consisting of a heterogenous mixture of sandstone, shale, dolomite, and gypsum. Vertical and horizontal changes in the stratigraphy are difficult to define. The complex nature of the caprock is reflected in the geophysical well-log measurements. The gamma-ray, neutron, density, acoustic-velocity, and caliper well logs for the caprock depth intervals in drill holes SV1, SV2, and SV3 are shown in figures 6, 7, and 8, respectively. The interpreted lithology based upon the well-log responses is shown below the geophysical well logs. The lithologic well logs were interpreted using the well-log response value ranges given in table 2. The computer was programmed to assign a specific lithology to all depth intervals that contained well-log response values in a specified value range. The interpretation assumes that the only lithologies present in the section are those that are listed in the table. Other lithologies may be present but have not been considered in this interpretation. This interpretation should be considered as a first approximation of the lithology and not a final interpretation of the lithology. However, the well-log interpretation does indicate the following:

- (1) The gamma-ray well logs indicate the presence of more shale in drill hole SV1 than in drill holes SV2 or SV3.
- (2) The shale at a depth of 121 m in SV1, 103 m in SV2, and 135 m in SV3 may be a single, correlative, lithologic unit.
- (3) The neutron well logs indicate that the caprock in drill hole SV1 has a lower porosity than in drill holes SV1 or SV2.

Only the neutron and gamma-ray well logs were used in the interpretation. The caliper log shows that each of the holes has large changes in borehole

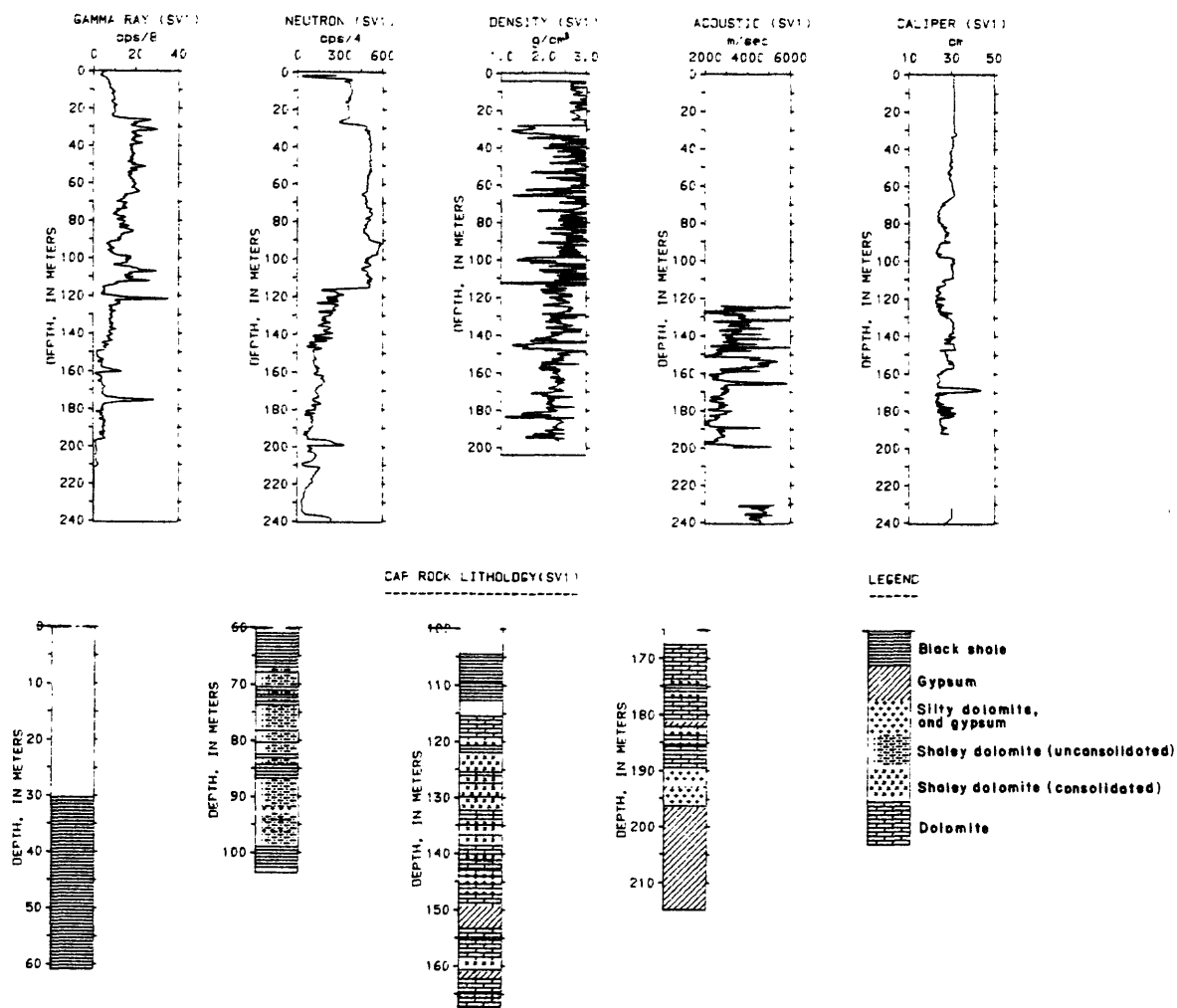


Figure 6.--Gamma-ray, neutron, density, acoustic-velocity, and caliper well logs for drill hole SV1. Lithologic interpretation for the caprock in SV1 based upon the information in table 1.

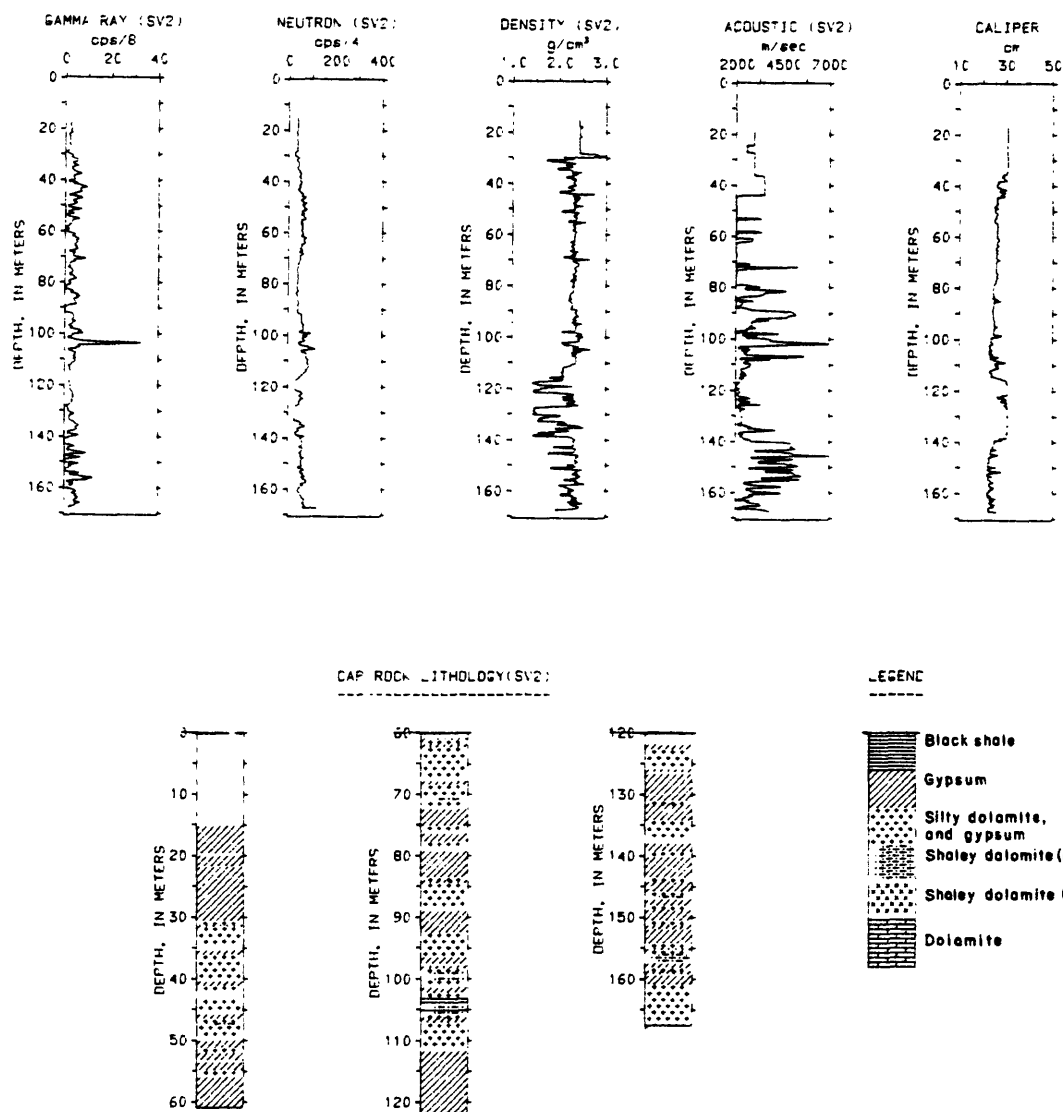


Figure 7.--Gamma-ray, neutron, density, acoustic-velocity, and caliper well logs for drill hole SV2. Lithologic interpretation for the caprock in SV2 based upon the information in table 1.

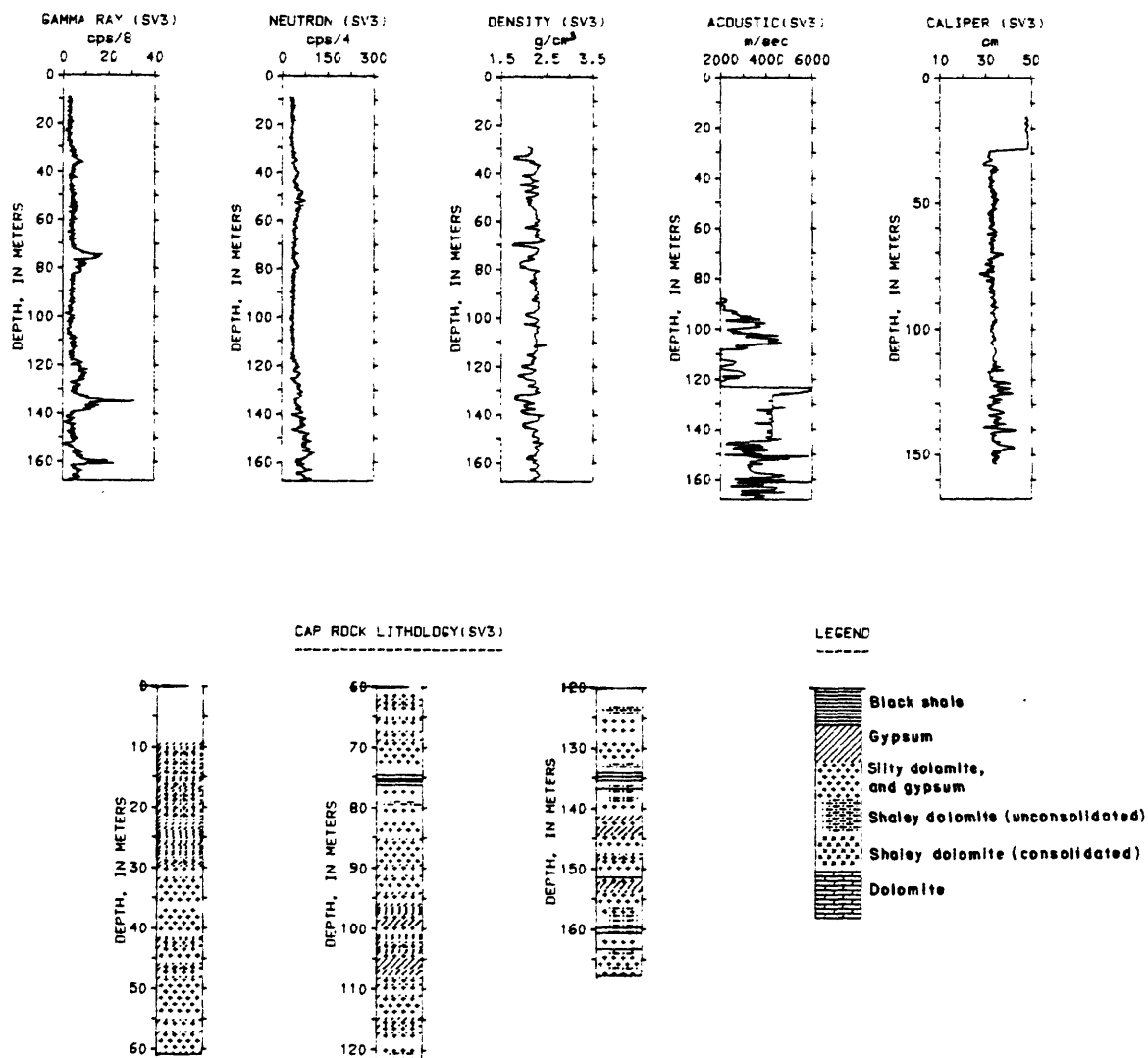


Figure 8.—Gamma-ray, neutron, density, acoustic-velocity, and caliper well logs for drill hole SV3. Lithologic interpretation for the caprock in SV3 based upon the information in table 1.

rugosity. These variations in borehole rugosity introduce errors in all of the logs except the gamma-ray well log. These errors are particularly pronounced on the acoustic velocity and density well logs.

Table 1.--Well-log response value ranges for interpreting lithologies in the halite-interbed sequence in drill hole SV3

Lithology	Gamma ray (cps)	Neutron (cps)	Density (gm/cm ³)	Acoustic velocity (microsec/ft)
Salt	0 to 3	225 to 300	2.0 to 2.1	--
Shale	13 to 50	0 to 150	2.2 to 2.6	--
Anhydrite	--	200 to 300	2.7 to 3.0	4500 to 6000
Dolomite	--	100 to 225	2.6 to 3.0	4500 to 6000
Sandstone	0 to 8	125 to 225	2.45 to 2.7	3000 to 4500
Sandstone and shale	7 to 15	50 to 200	2.2 to 2.6	2000 to 4500
Carnallite	--	0 to 150	1.6 to 2.05	--

Table 2.--Value ranges used for computer-assisted interpretation of interbed lithologies

Lithology	Gamma ray cps/8	Neutron cps/4
Black shale	15 to 50	0 to 1000
Gypsum	less than 3	0 to 1000
Silty dolomite and gypsum	3 to 8	less than 100
Dolomite (consolidated)	3 to 8	greater than 100
Shaley dolomite (unconsolidated)	7 to 15	50 to 125
Shaley dolomite (consolidated)	7 to 15	greater than 125

CONCLUSIONS

The lithologies present in an evaporite sequence (halite, anhydrite, potash, shale, gypsum, sandstone, and dolomite) show physical-property characteristics that are easily identifiable on conventional well logs. However, the evaporite sequence at Salt Valley is lithologically and structurally complex. More work needs to be done to quantitatively identify the mineralogic components within the complex interbed sequences. This is particularly true for the caprock; at the present time, interpretation of the caprock

lithology is little more than an educated guess. The lithology could be identified by conducting detailed chemical and petrographic analysis of core taken from the caprock.

The thin beds in the interbed sequence can be better defined by obtaining very closely spaced digital geophysical well-log measurements (a sample spacing of less than 2 cm). However, quantitative identification of mineralogic components within the interbed sequence may require the development and application of new borehole geophysical tools. Some tools that are presently used (such as acoustic velocity, neutron, and density) have been developed for use in oil exploration and may be redesigned to give the detailed information required for the nuclear waste program.

Borehole geophysical probes are needed to measure the large contrast of electrical properties (dielectric constant and resistivity) that are present between the individual lithologic components in an evaporite sequence. The single-coil induction probe that was tested at Salt Valley may be useful in determining the moisture content of halite. Both dry-hole and wet-hole radar, and subradar-frequency electromagnetic borehole probes need to be developed.

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APPENDIX A

Geophysical Well Logs from DOE Salt Valley No. 1 Drill Hole (SV1)

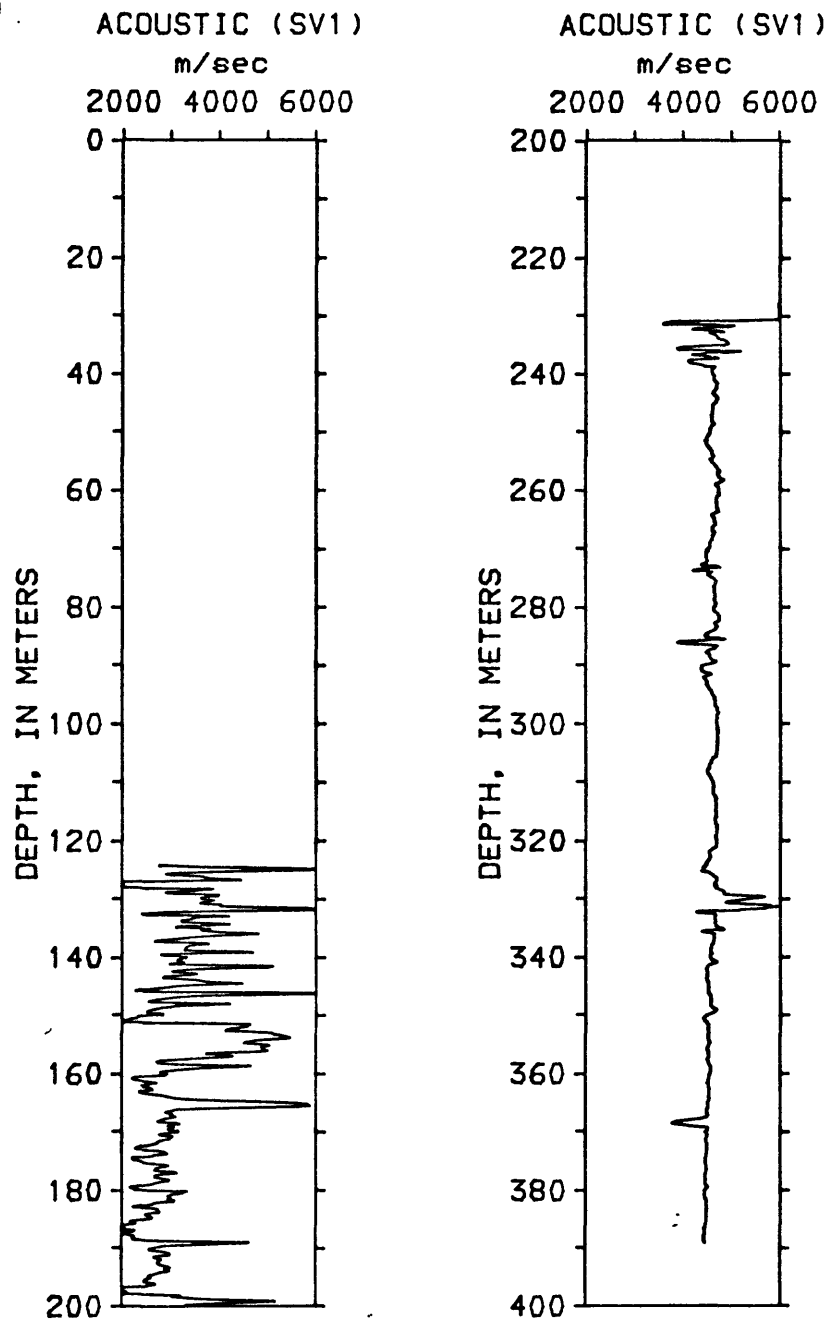


Figure A1.—Acoustic velocity well log for drill hole SV1. Units are in meters/second (m/sec).

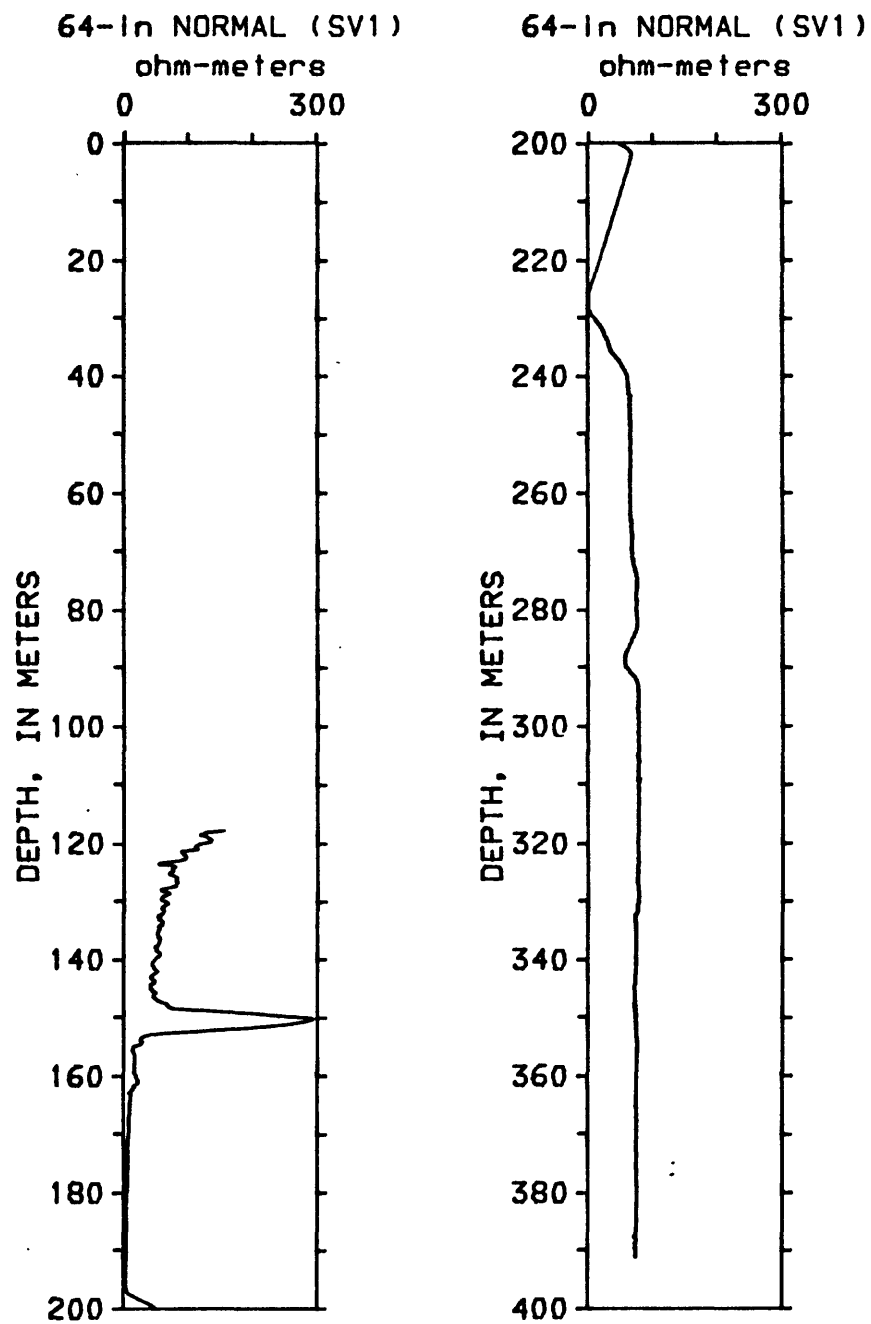


Figure A2.--Normal resistivity well log (64 in) for drill hole SV1. Units are in ohm-meters.

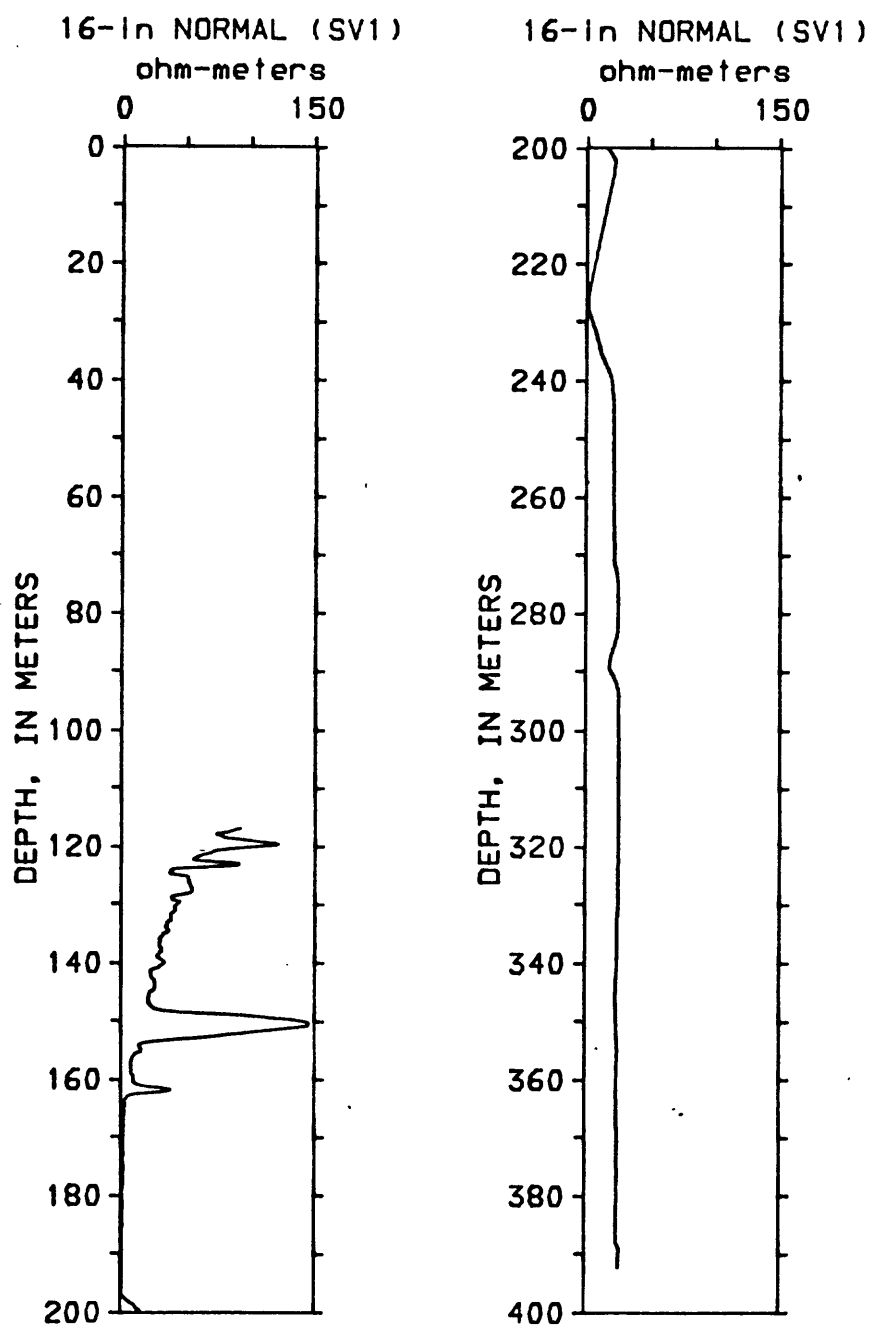


Figure A3.--Normal resistivity log (16 in) for SV1. Units are in ohm-meters.

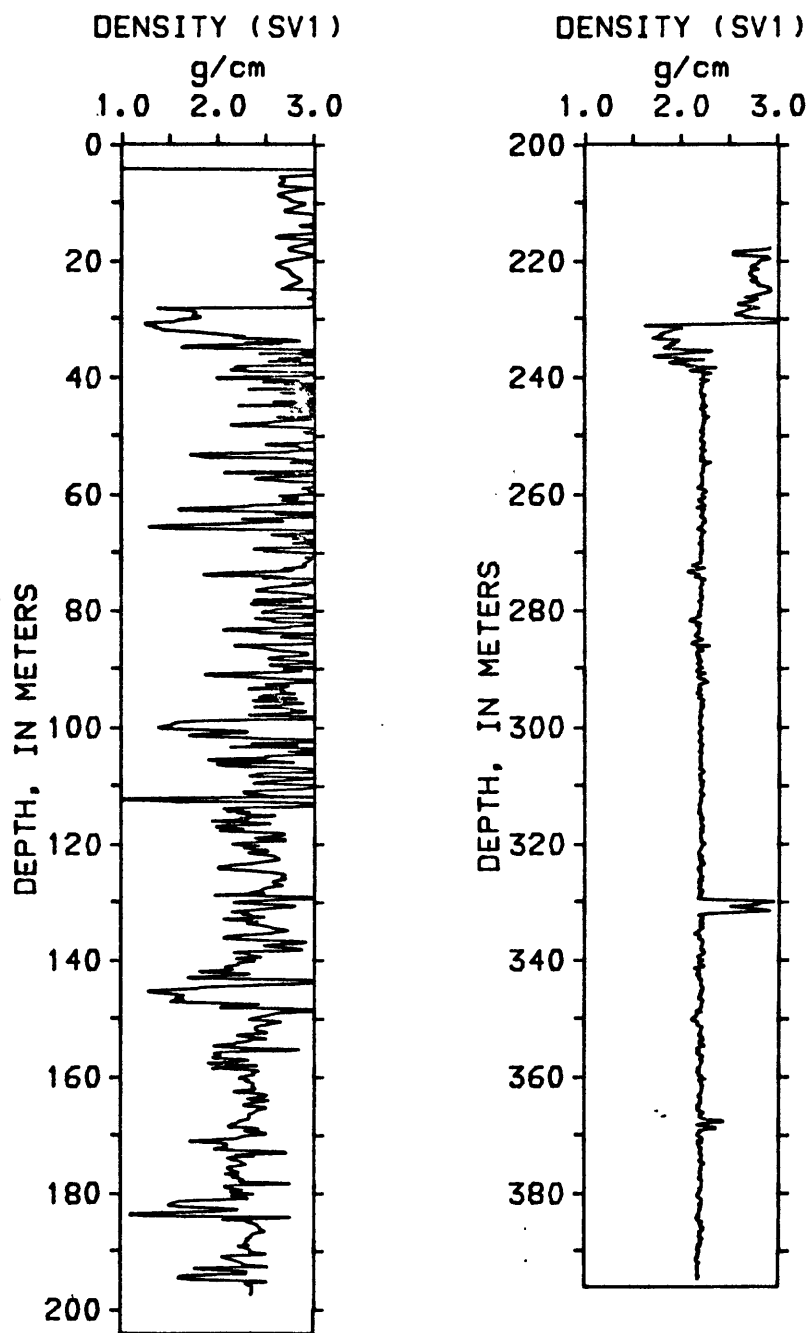


Figure A4.--Bulk density geophysical well log for drill hole SV1. Units are in grams/centimeter³ (g/cm³).

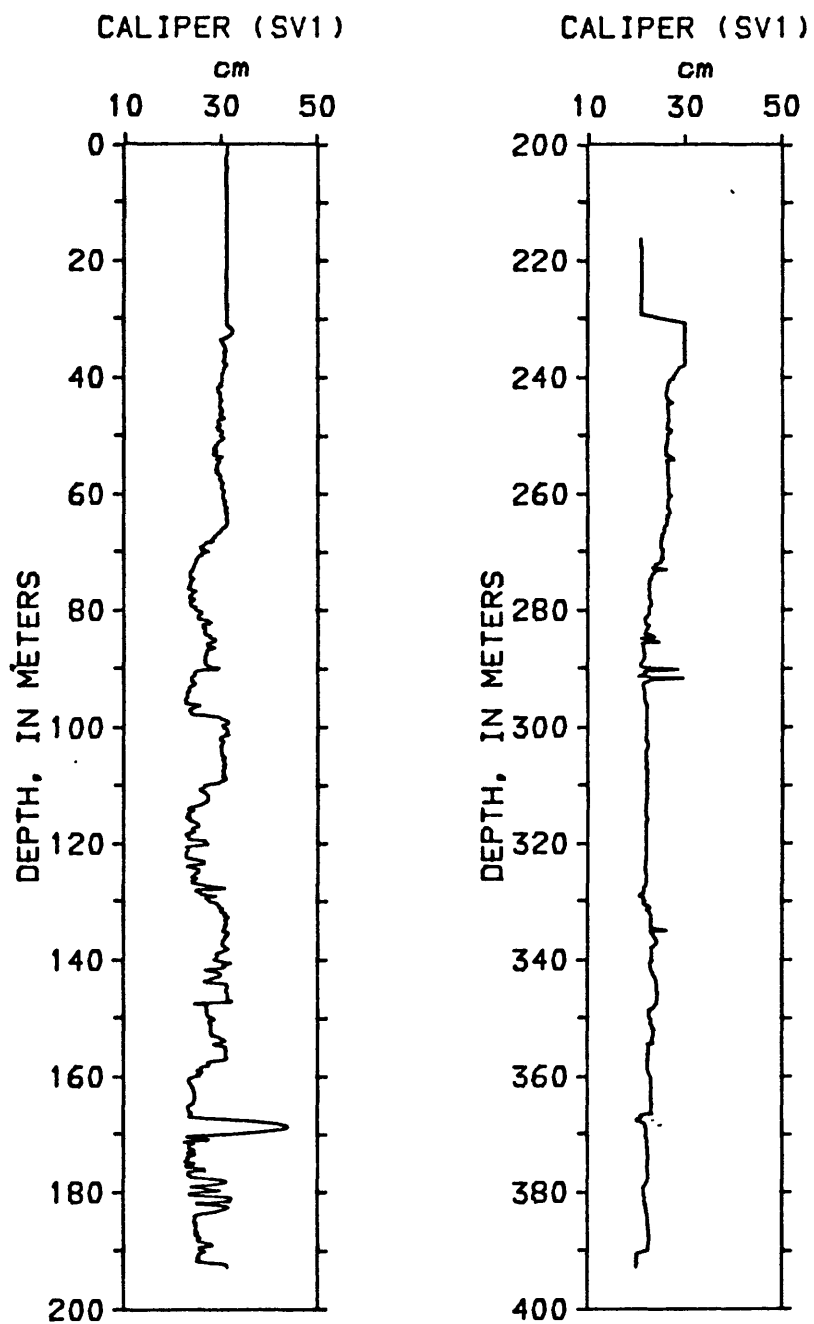


Figure A5.--Caliper well log for drill hole SV1. Units are in centimeters (cm).

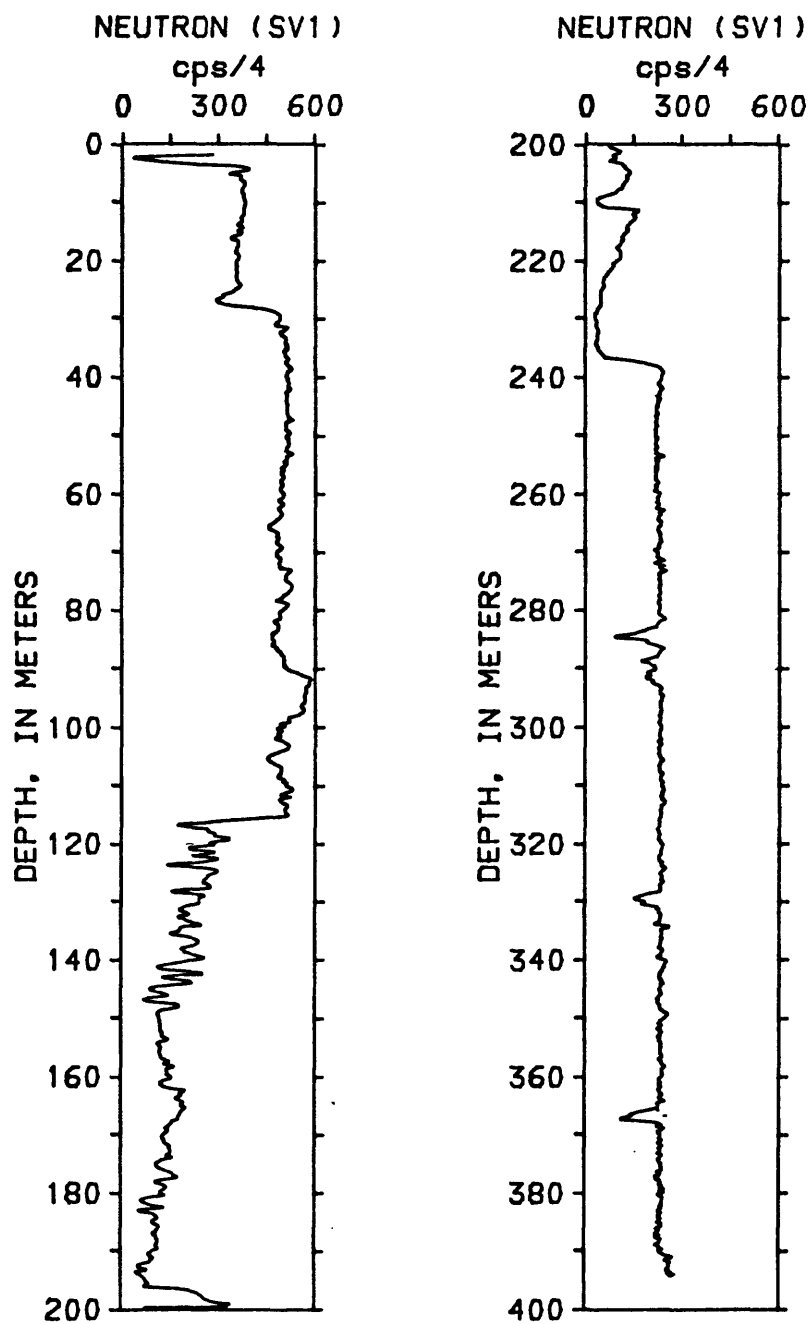


Figure A6.--Neutron well log for drill hole SV1. Units are in cycles/second (cps/4).

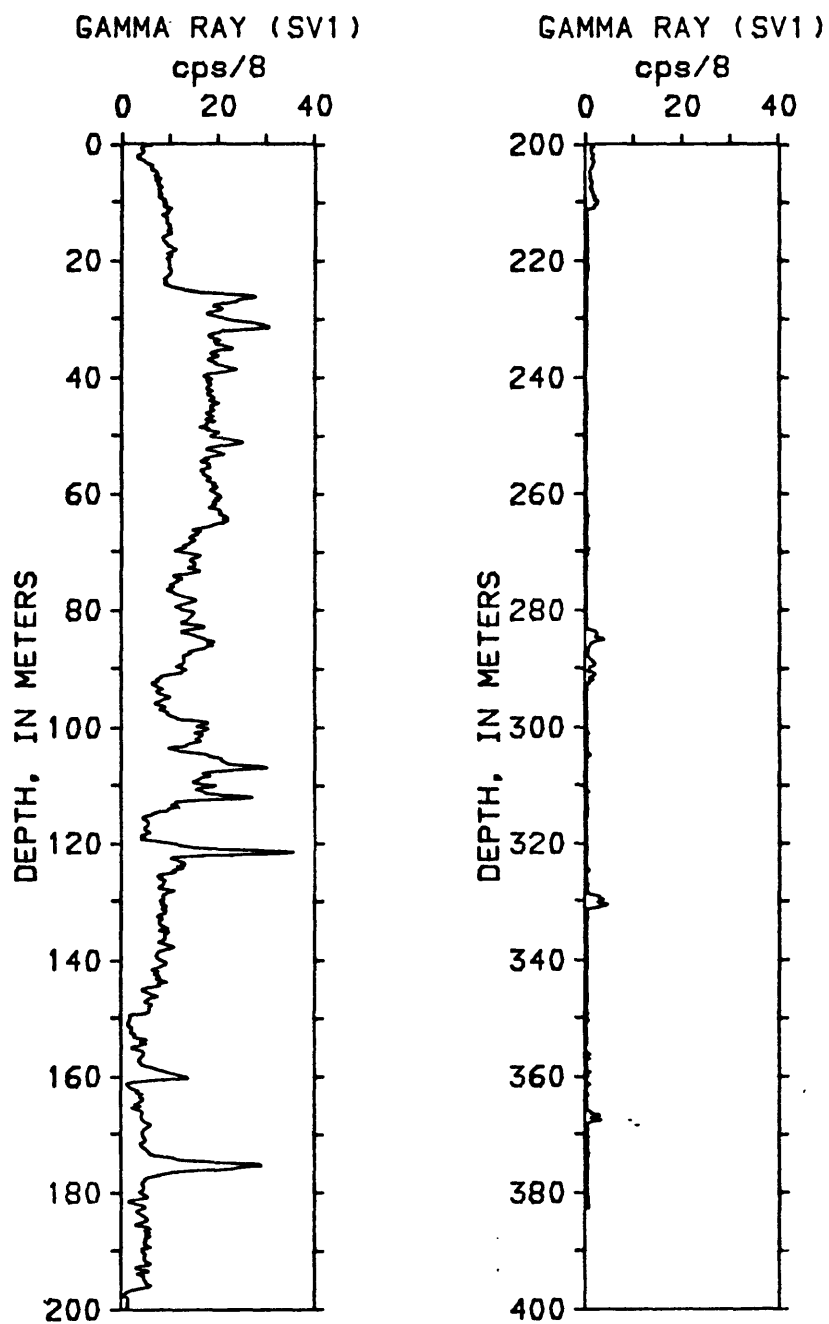


Figure A7.--Gamma ray well logs for drill hole SV1. Units are in cycles/second (cps/8).

APPENDIX B

Geophysical Well Logs from DOE Salt Valley No. 2 Drill Hole (SV2)

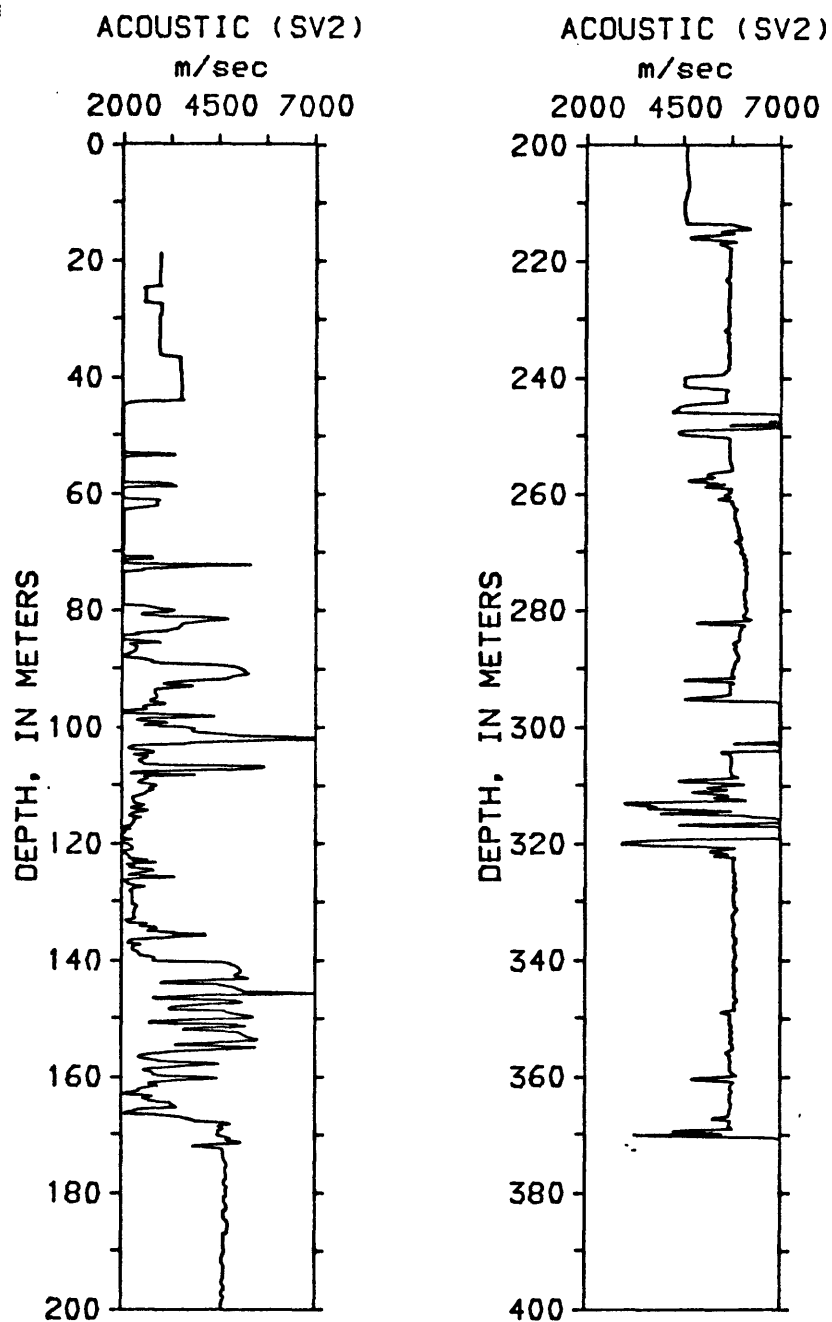


Figure B1.--Acoustic velocity well log for drill hole SV2. Units are in meters/second (m/sec).

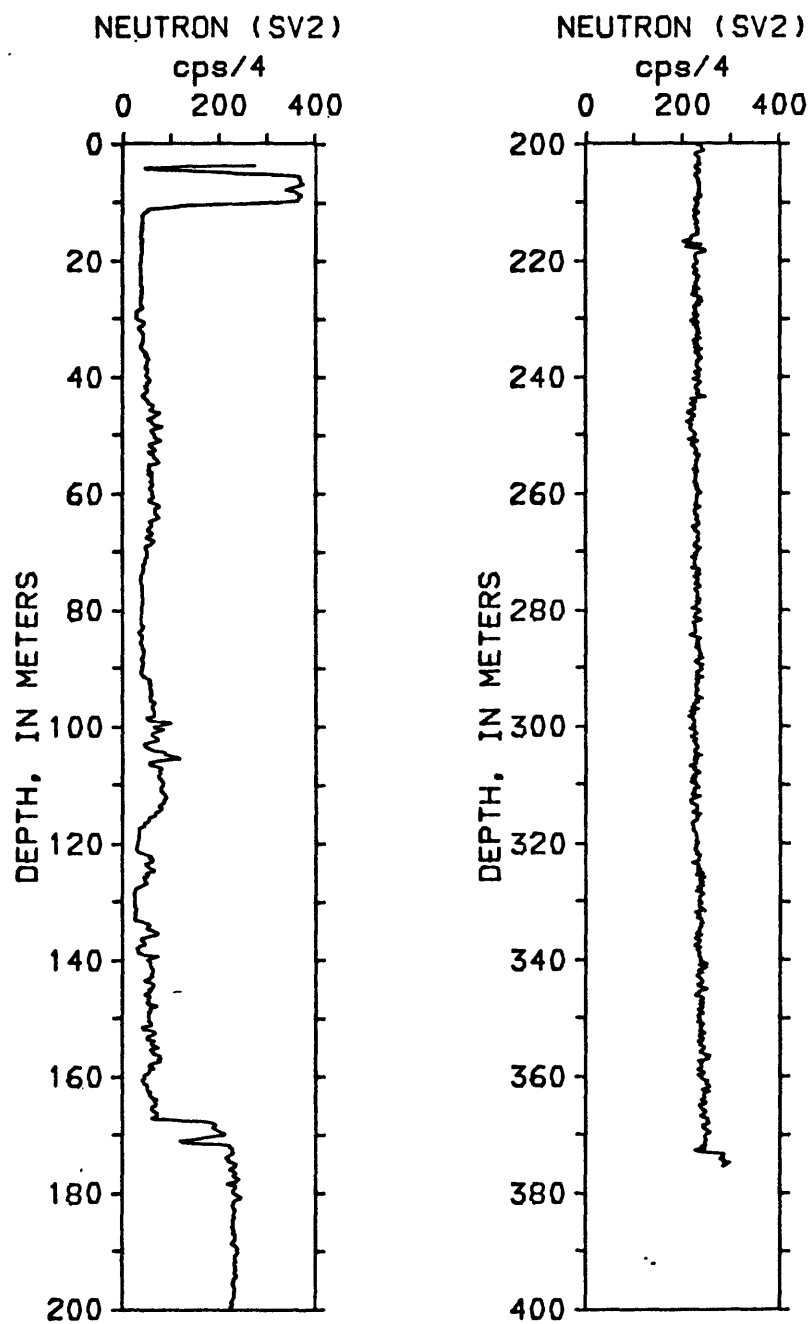


Figure B2.--Neutron well log for drill hole SV2. Units are in cycles/second (cps/4).

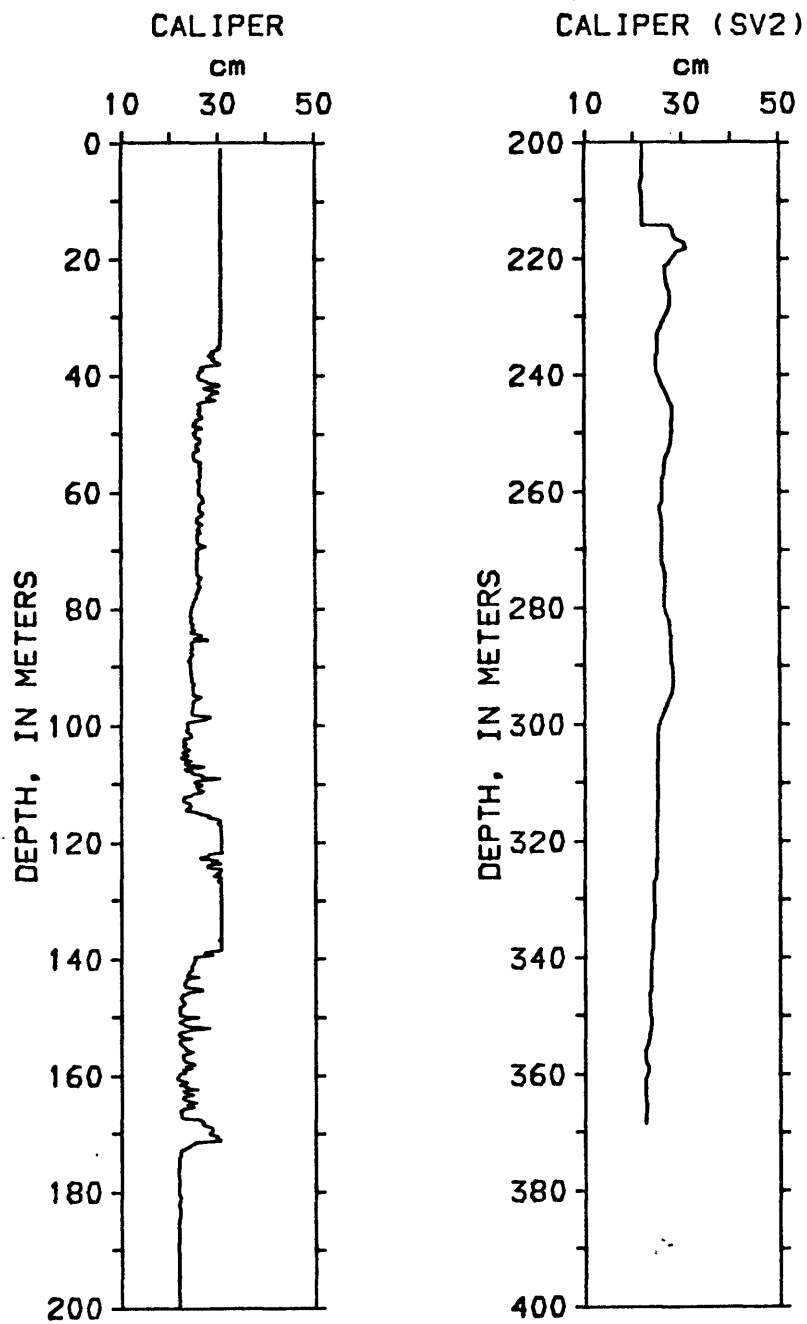


Figure B3.--Caliper well log for drill hole SV2. Units are in centimeters (cm).

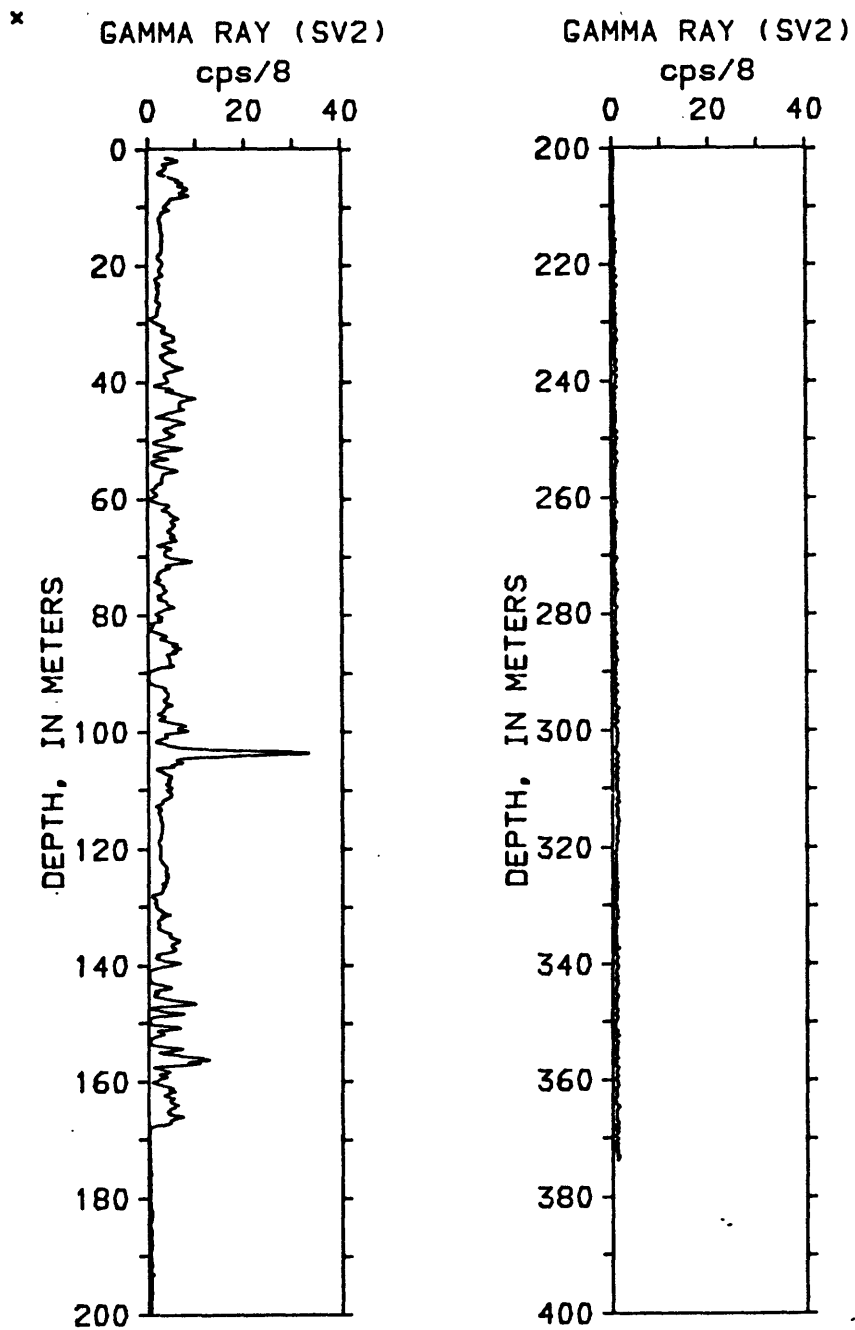


Figure B4.--Gamma ray well log for drill hole SV2. Units are in cycles/second (cps/8).

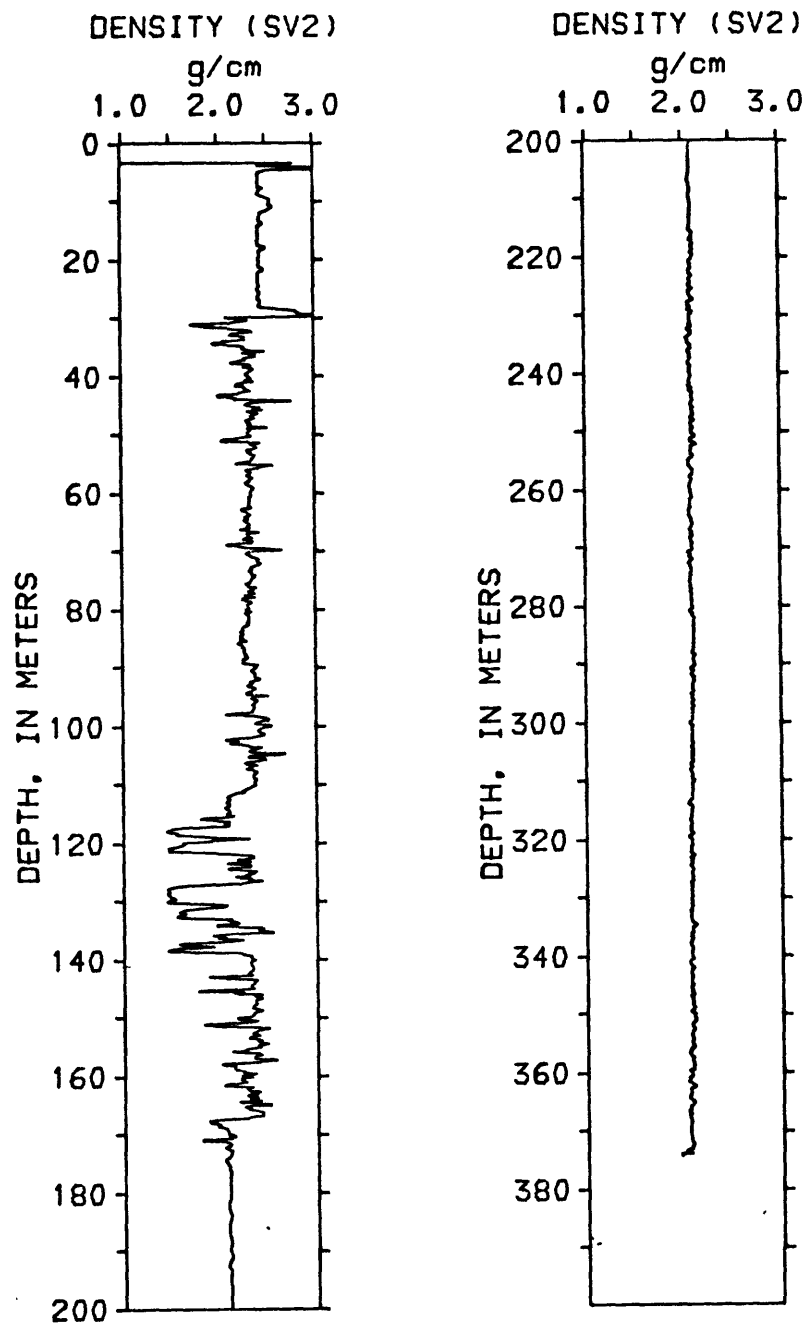


Figure B5.--Density well log for drill hole SV2. Units are in grams/centimeters³ (g/cm³).

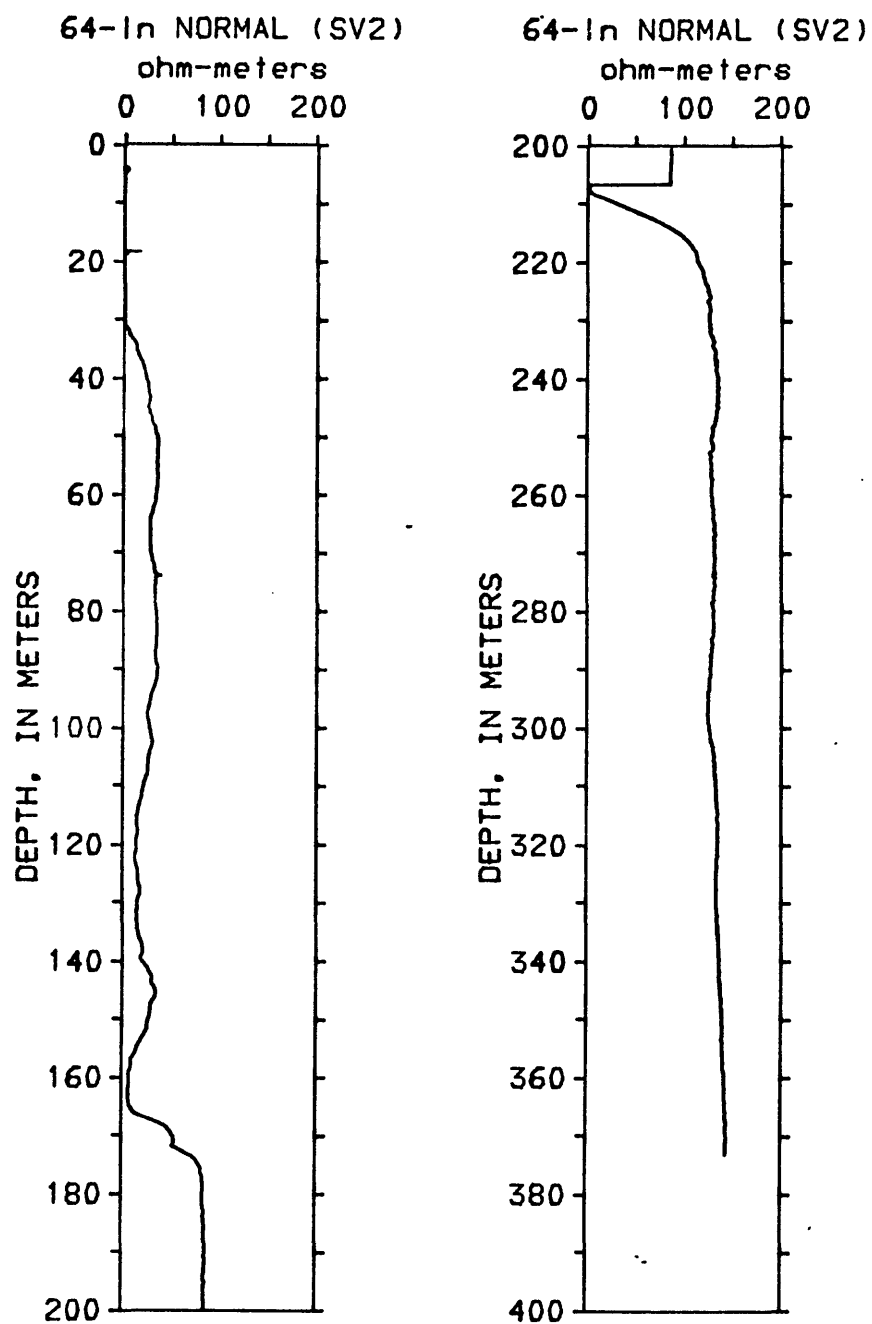


Figure B6.--Normal resistivity well log (64 in) for drill hole SV2. Units are in ohm-meters.

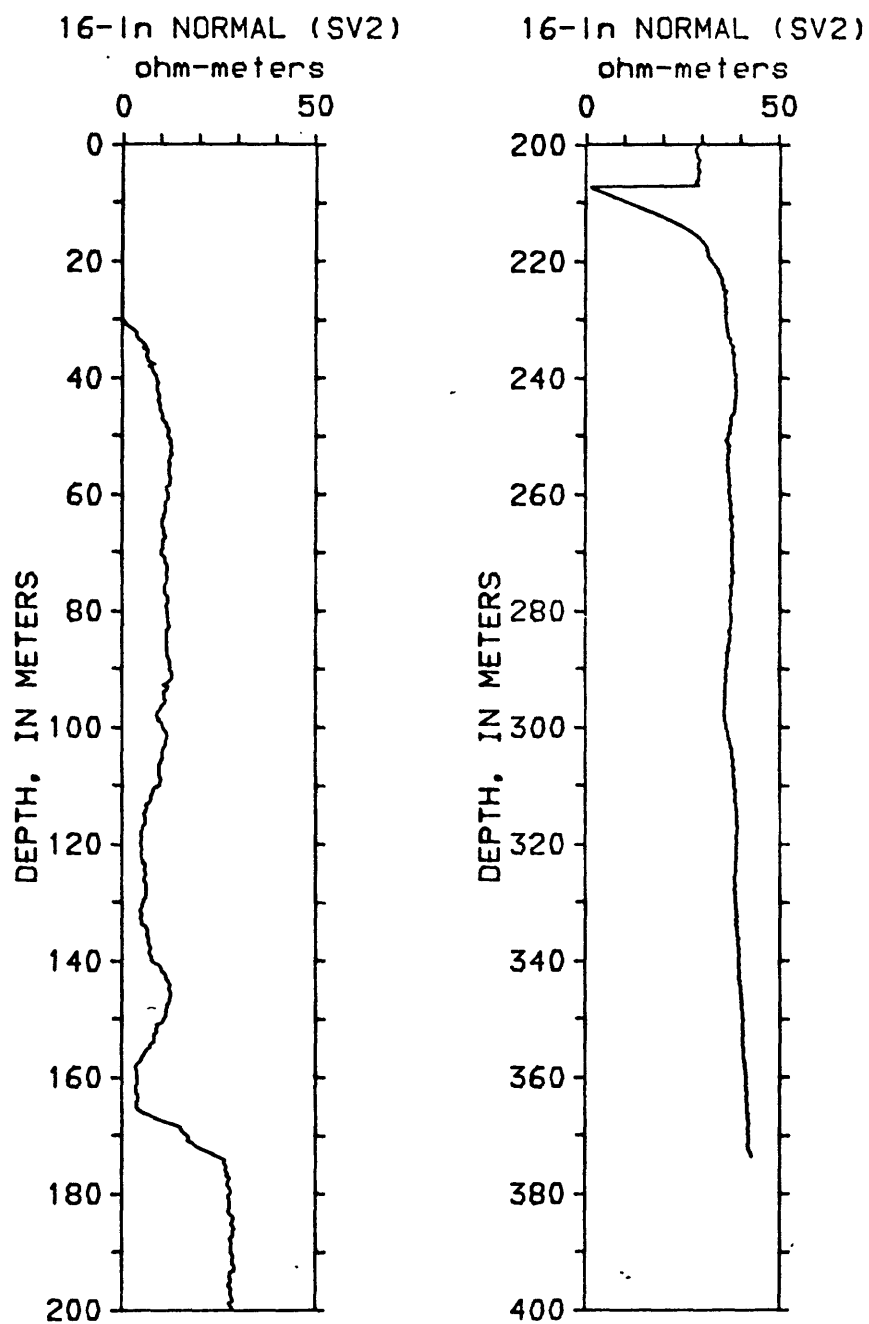


Figure B7.--Normal resistivity well log (16 in) for drill hole SV2. Units are in ohm-meters.

APPENDIX C

Geophysical Well Logs from DOE Salt Valley No. 3 Drill Hole (SV3)

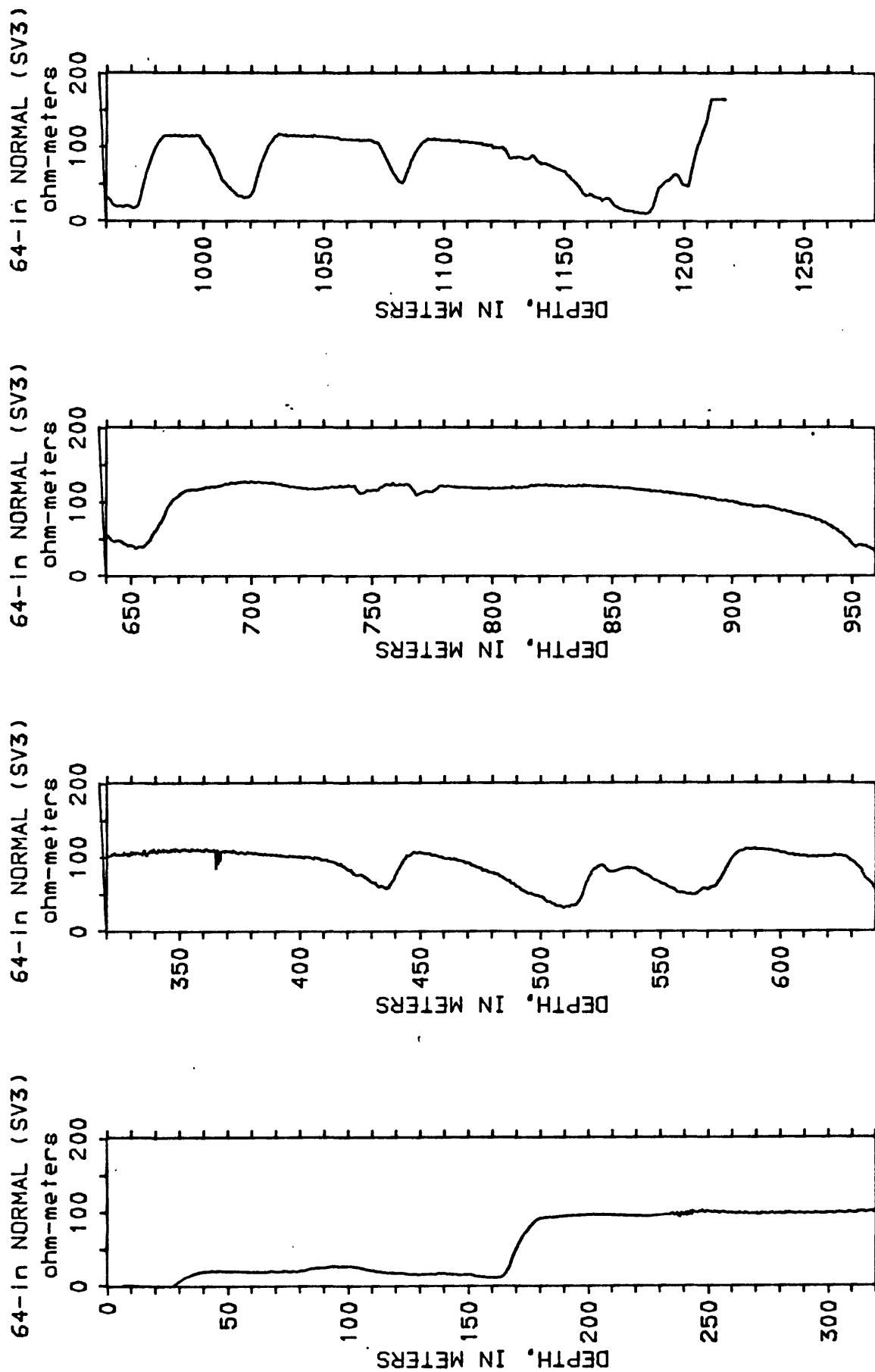


Figure C1.--Normal resistivity well log (64 in) for drill hole SV3. Units are in ohm-meters.

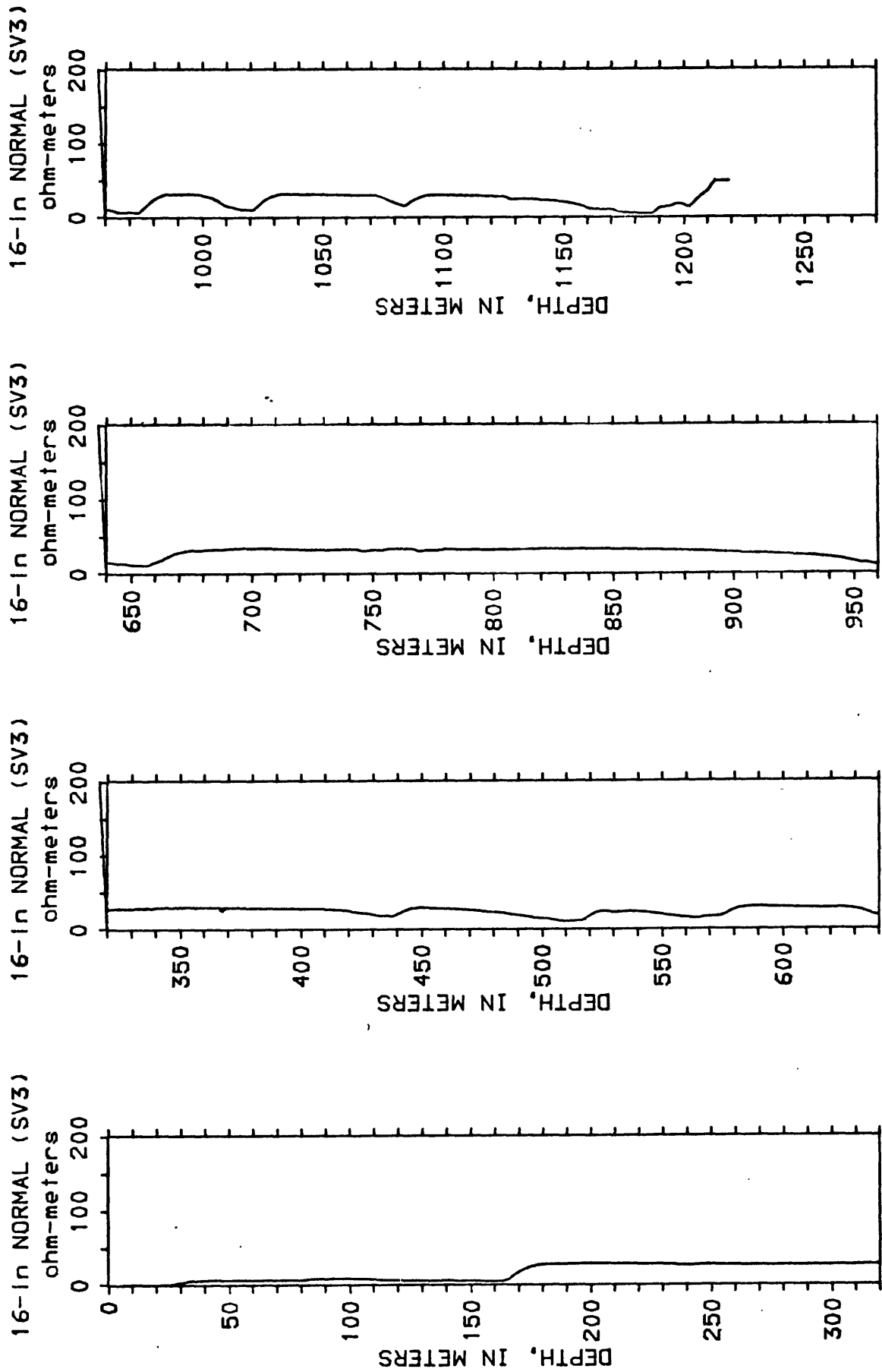


Figure C2.---Normal resistivity well logs (16 in) for drill hole SV3. Units are in ohm-meters.

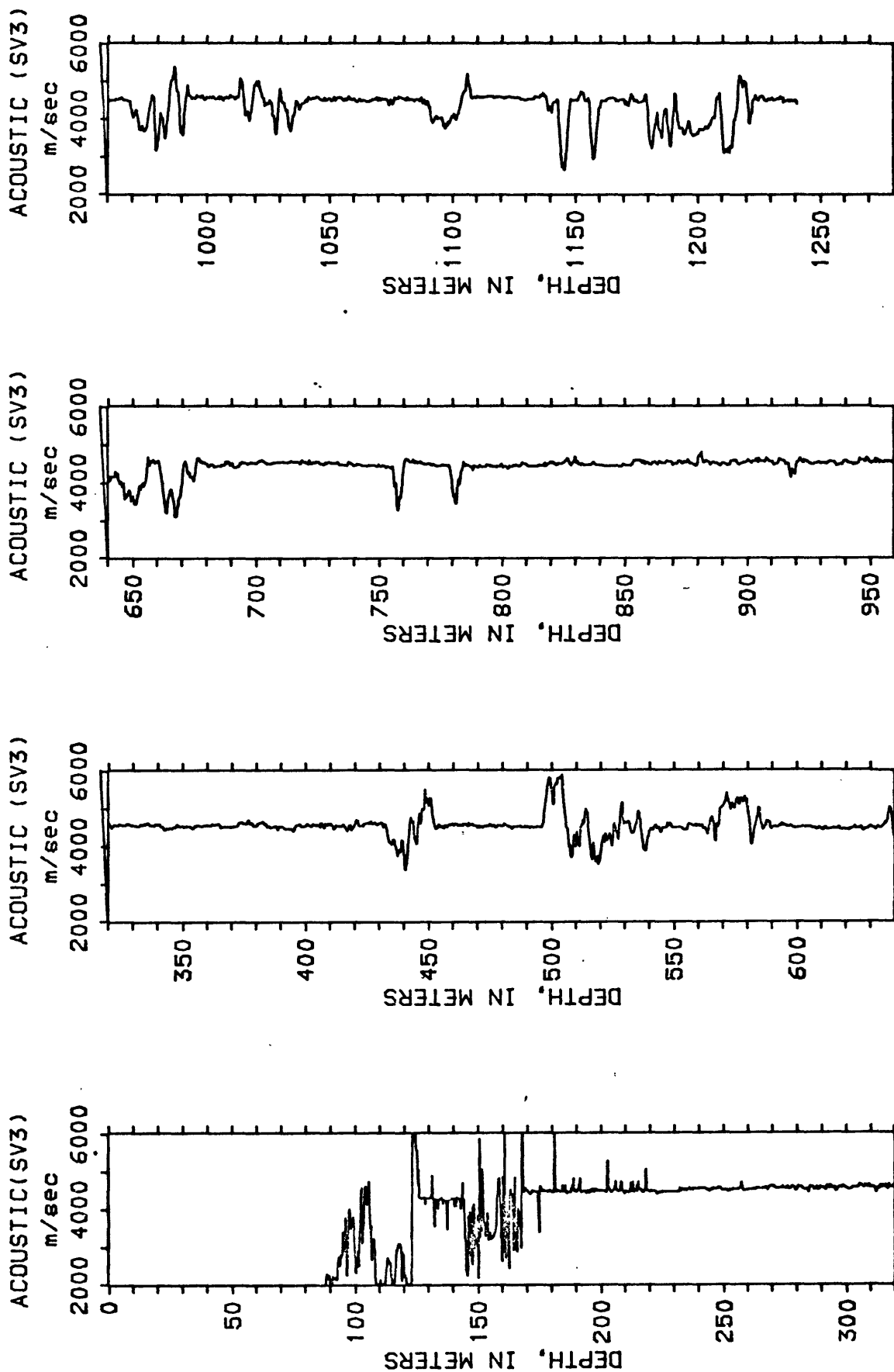


Figure C3.--Acoustic velocity well log for drill hle SV3. Units are in meters/second (m/sec).

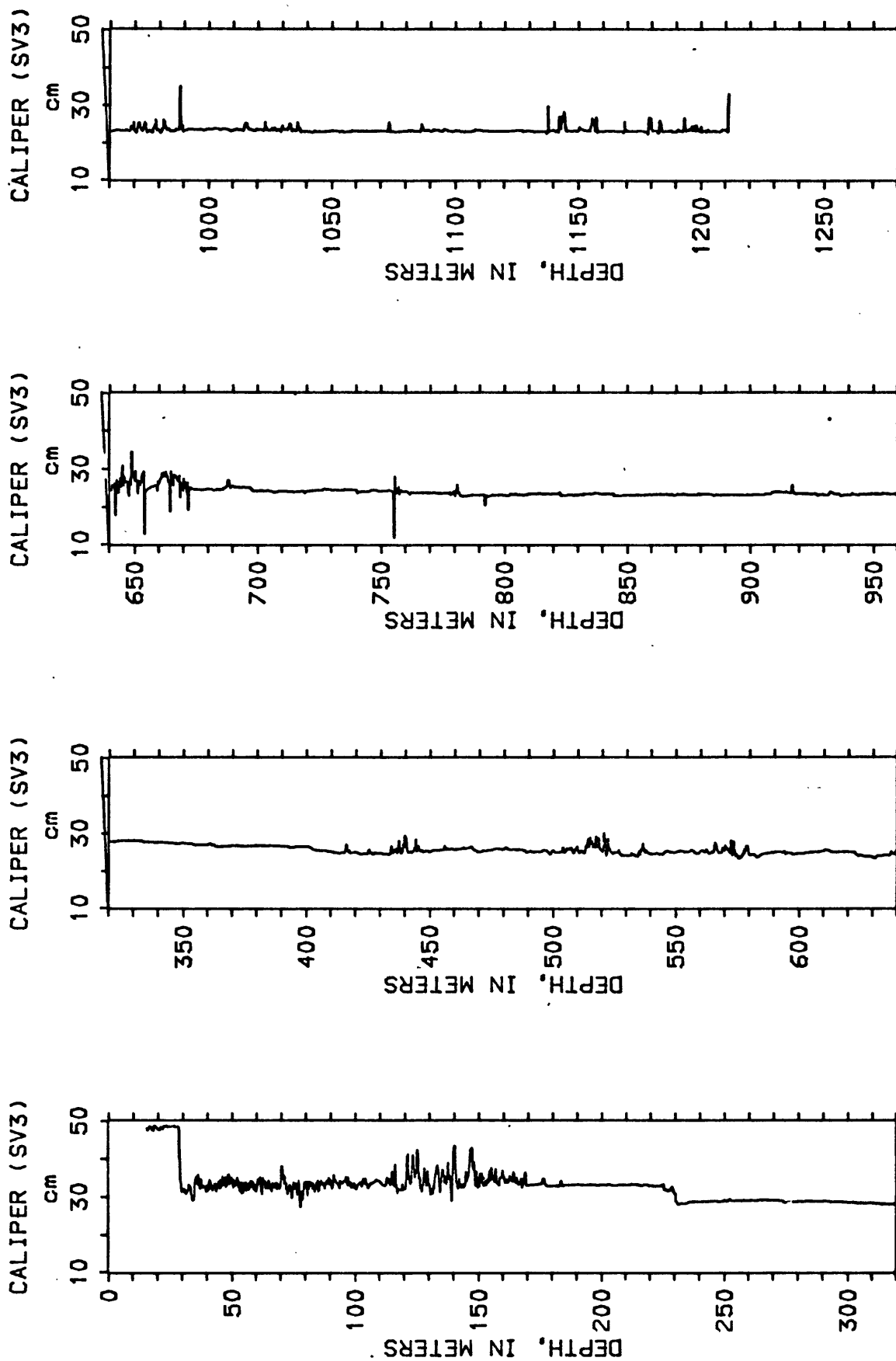


Figure C4.--Caliper well log for drill hole SV3. Units are in centimeters (cm).

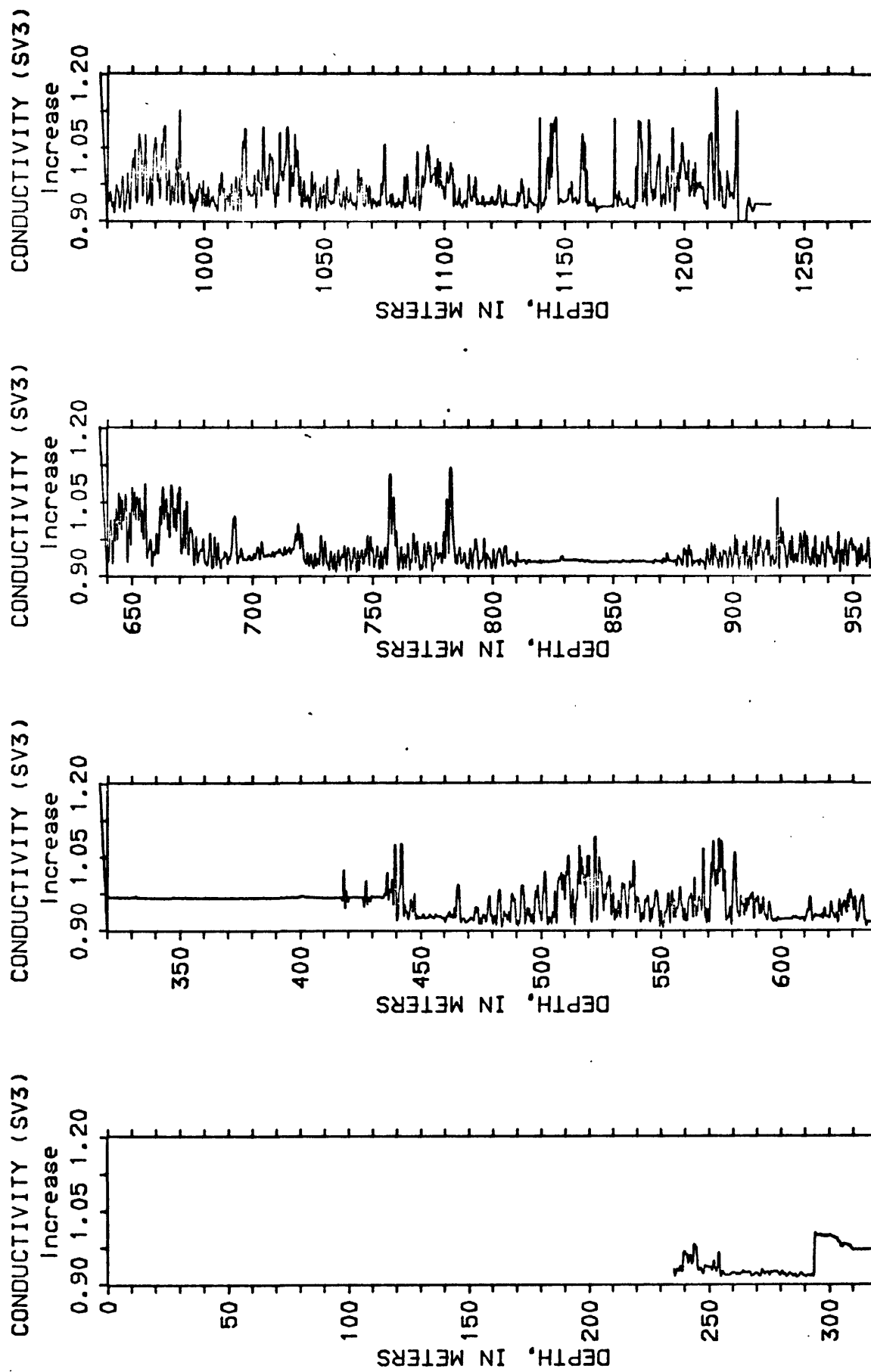


Figure C5.--Conductivity well log for drill hole SV3. Units are uncalibrated with increasing conductivity to the right.

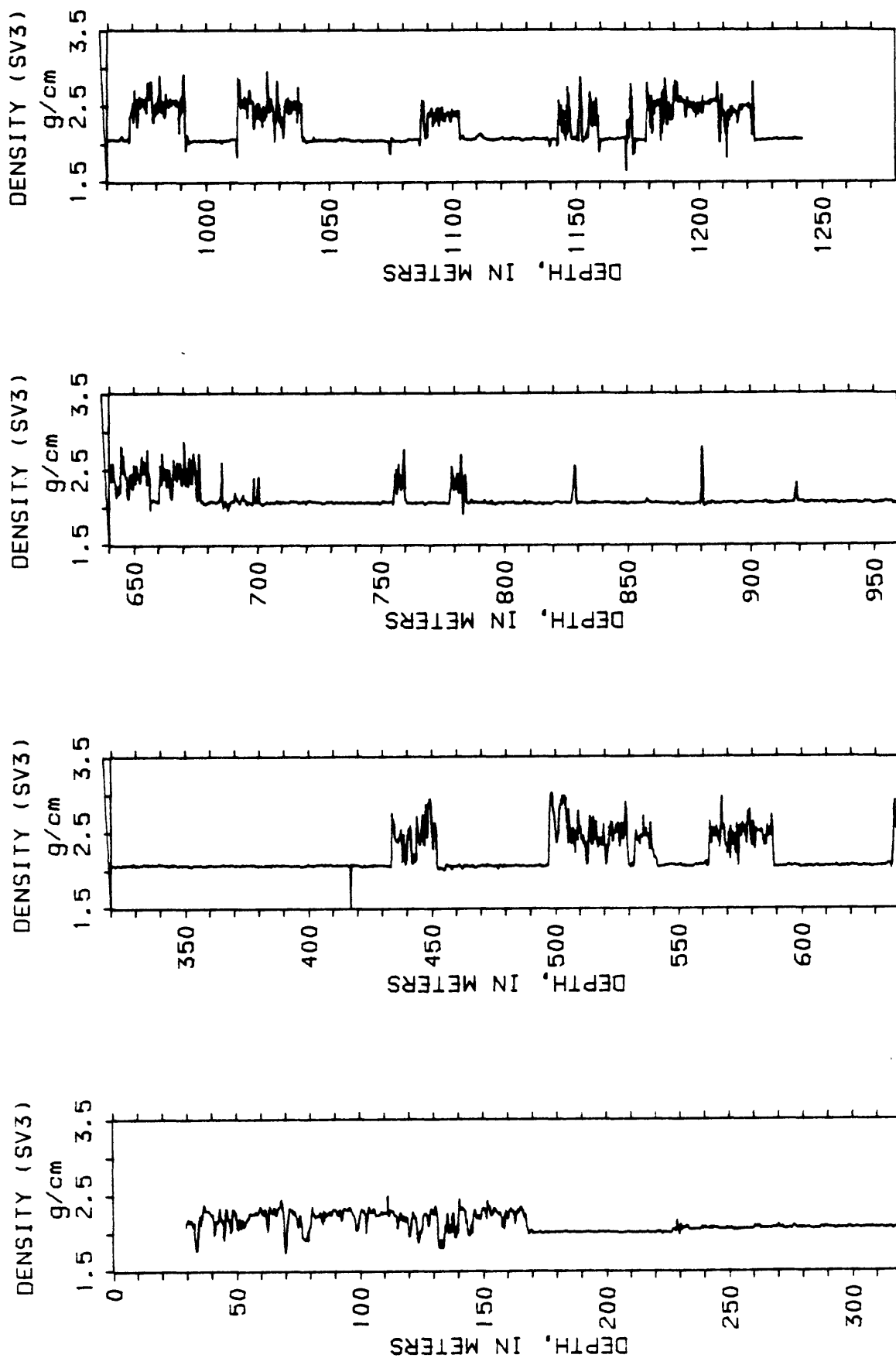


Figure C6.—Density well log for drill hole SV3. Units are in grams/cubic centimeter (g/cm³).

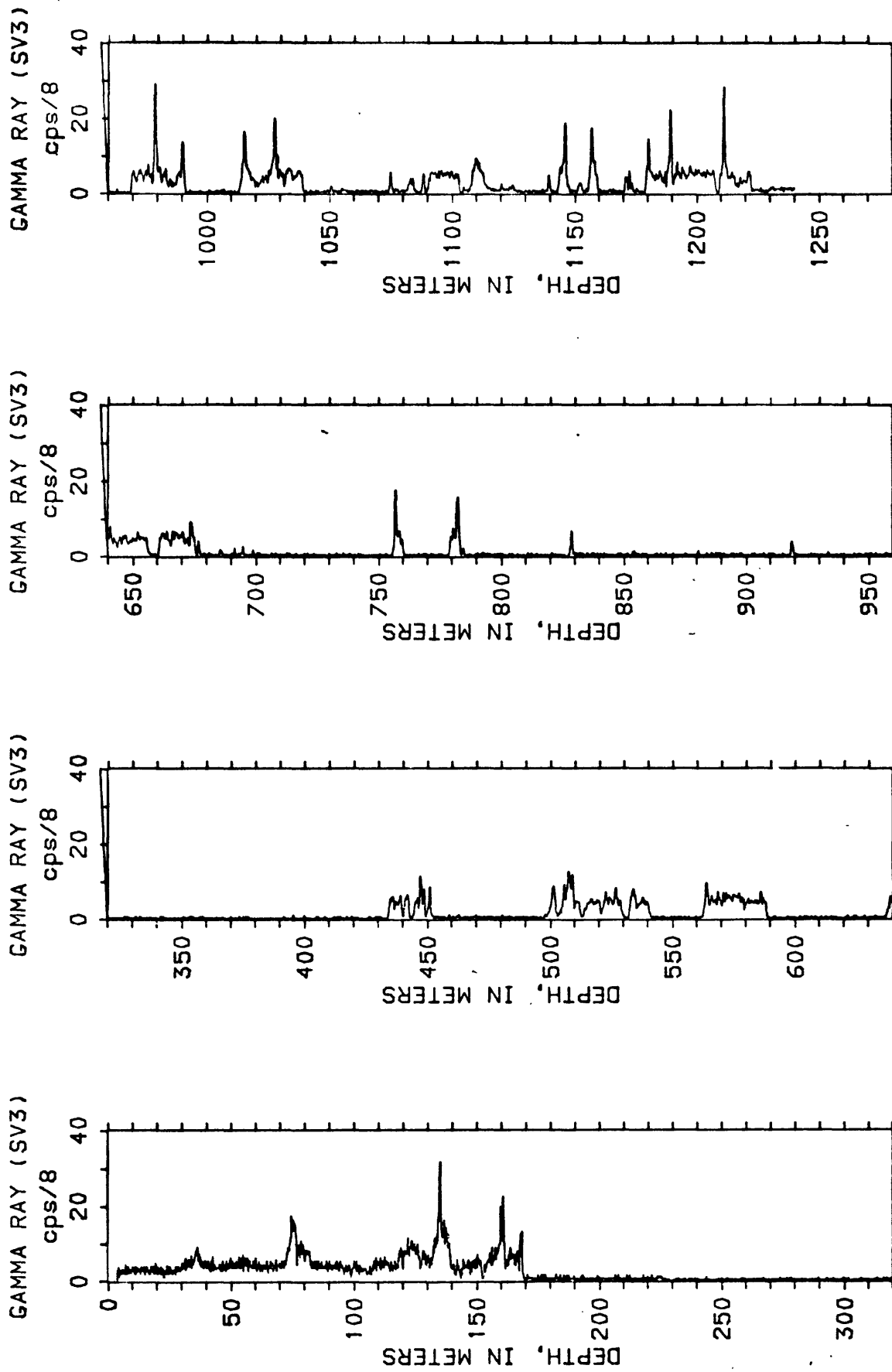


Figure C7.-- Gamma ray well log for drill hole SV3. Units are in counts/second (cps/8).

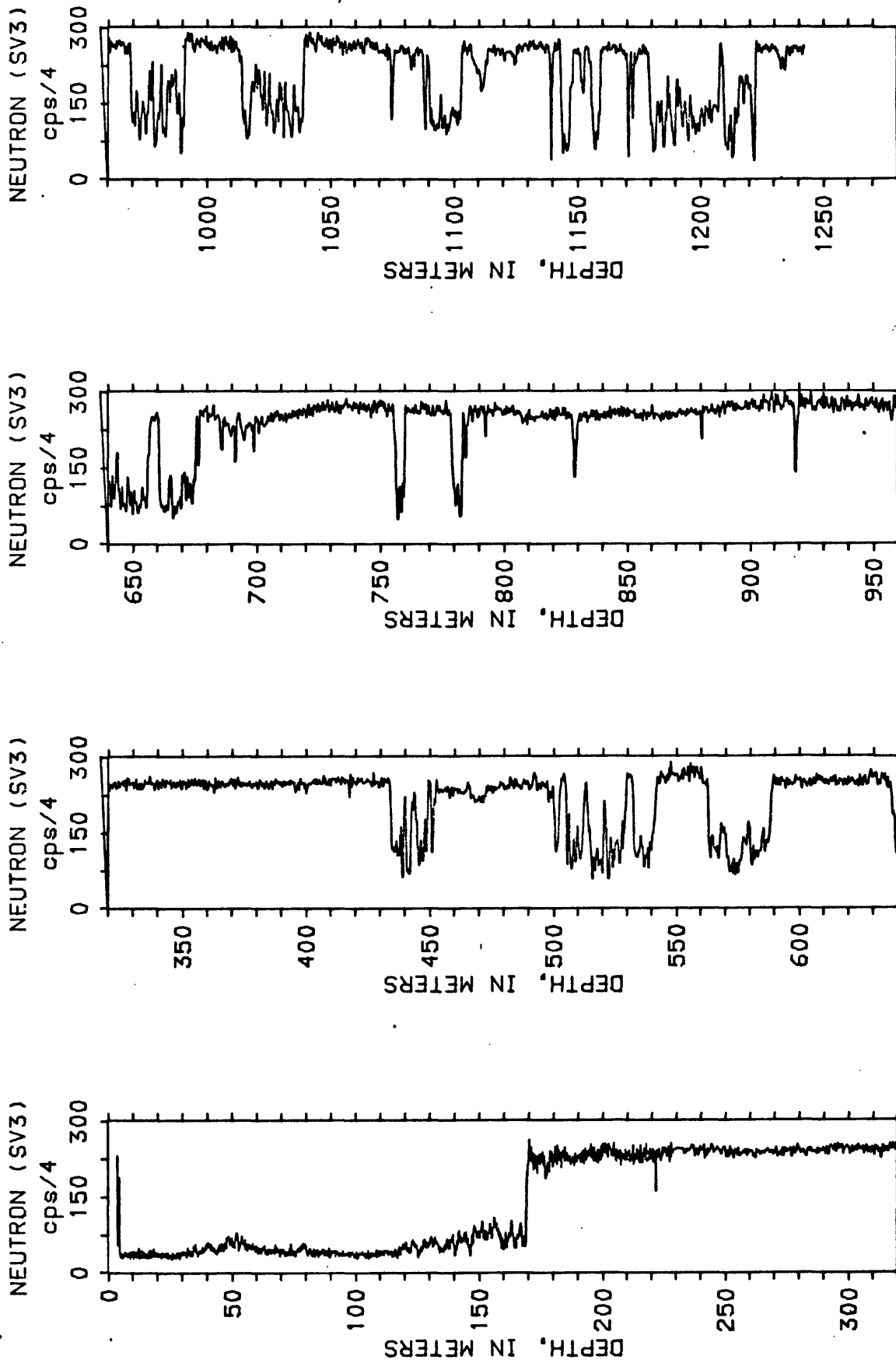


Figure C8.--Neutron well log for drill hole SV3. Units are in counts/second (cps/4)

APPENDIX D

Computer-Assisted Interpretation of Geophysical Well Logs from Drill Hole SV3

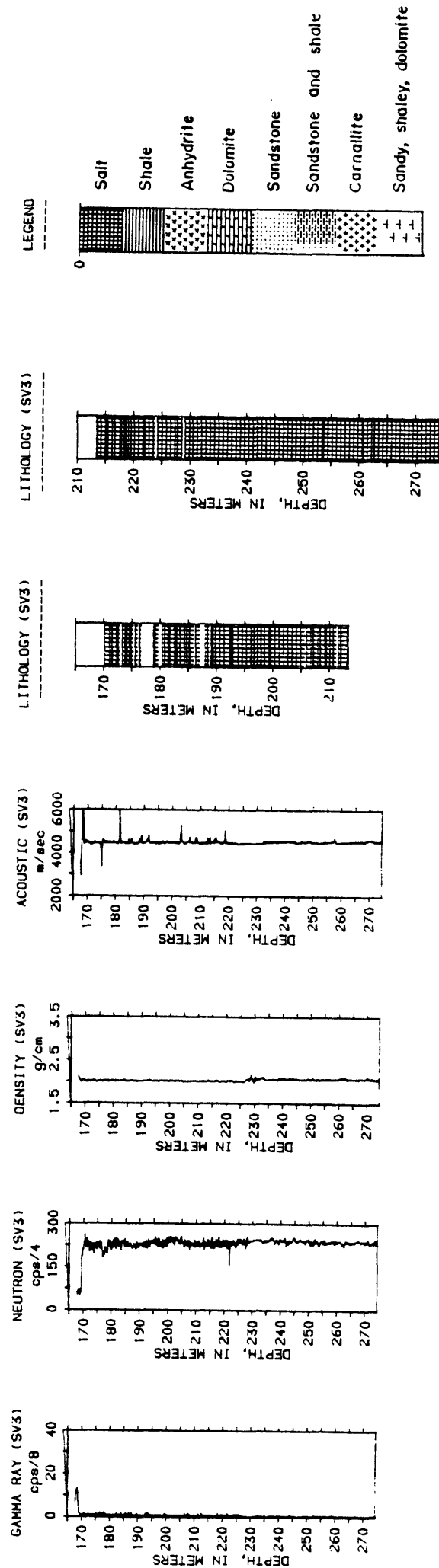


Figure D1.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 165-275 m in SV3.

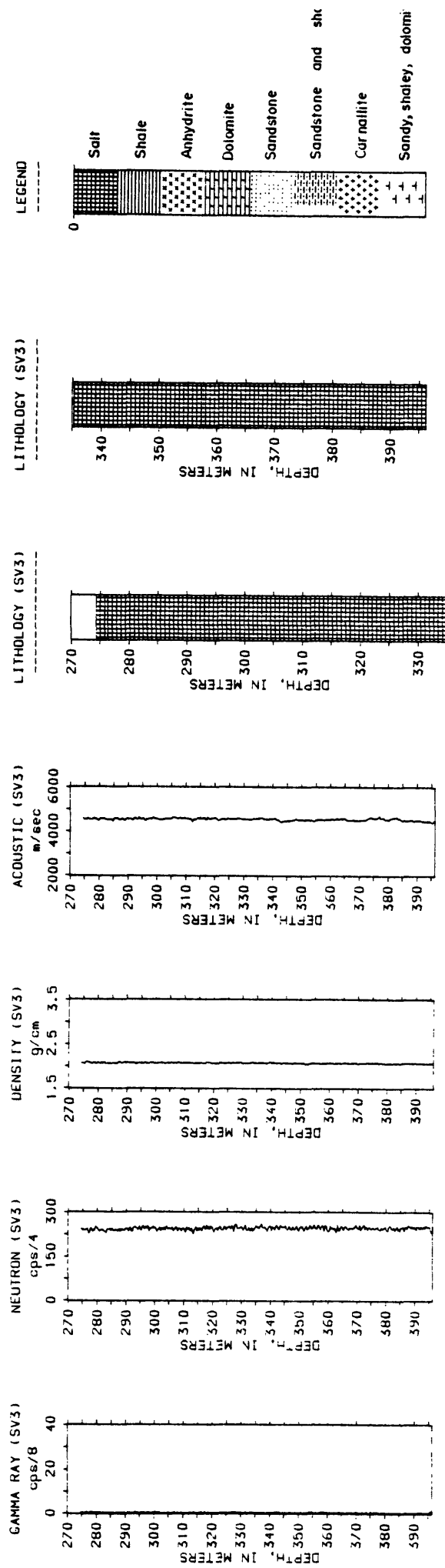


Figure D2.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 275-396 m in SV3.

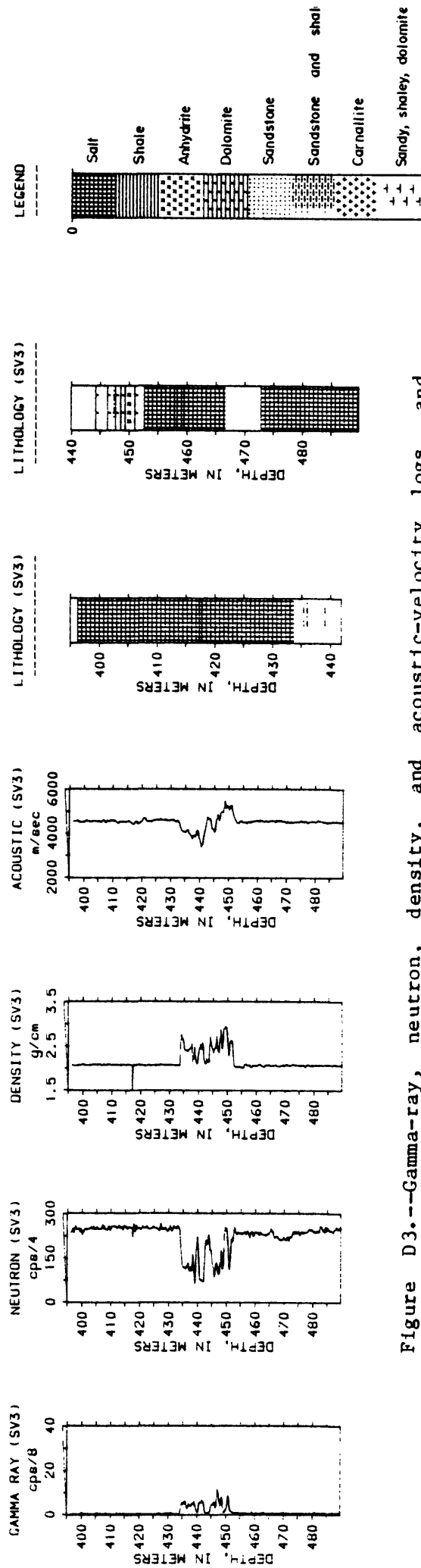


Figure D3.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 396-490 m in SV3.

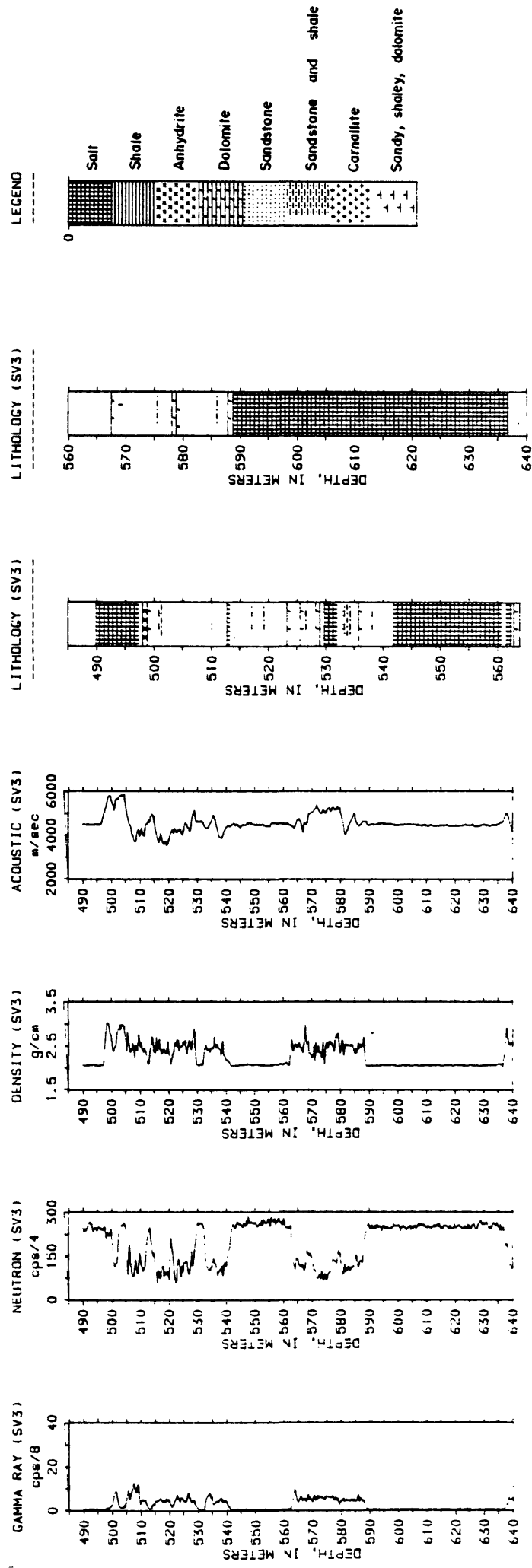


Figure D4.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 490-640 m in SV3.

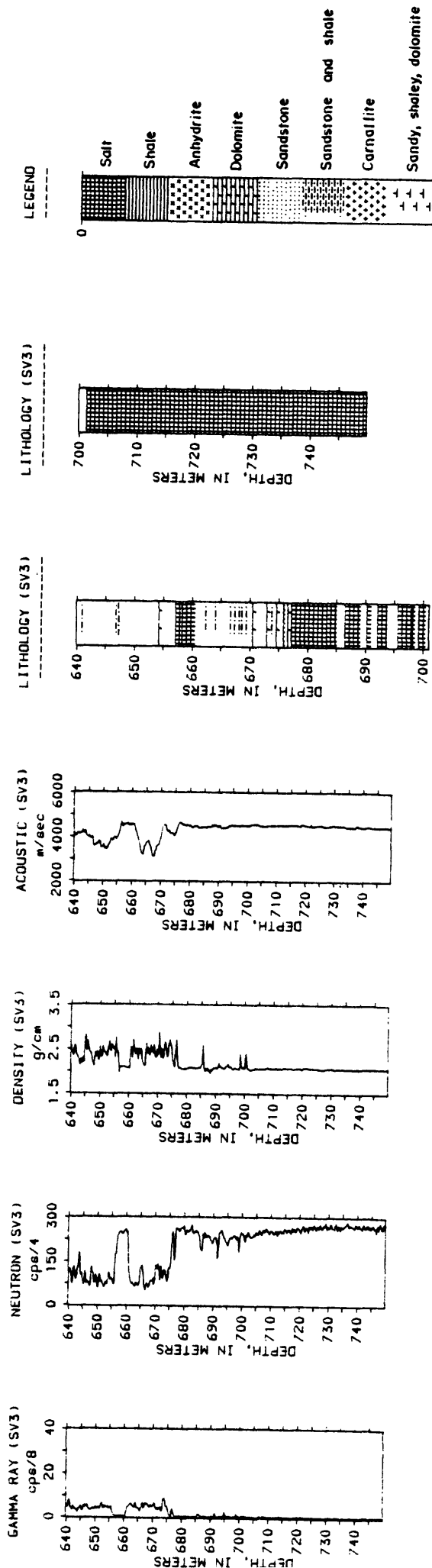


Figure D5.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 640-750 m in SV3.

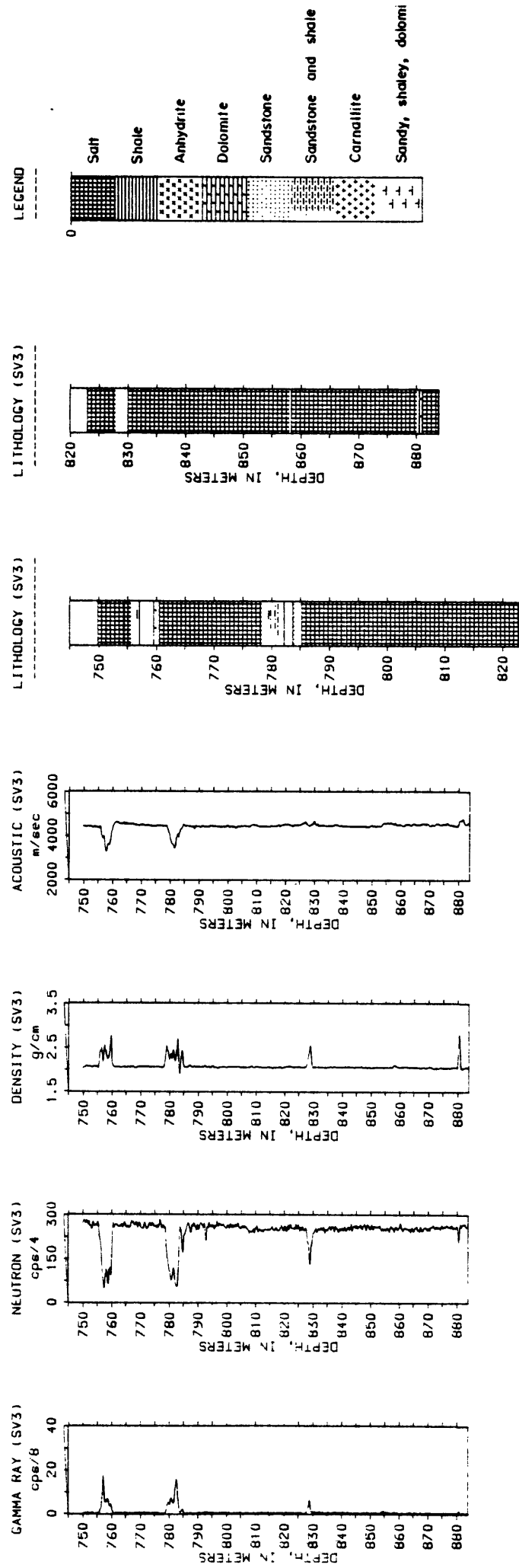


Figure D6.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 750-884 m in SV3.

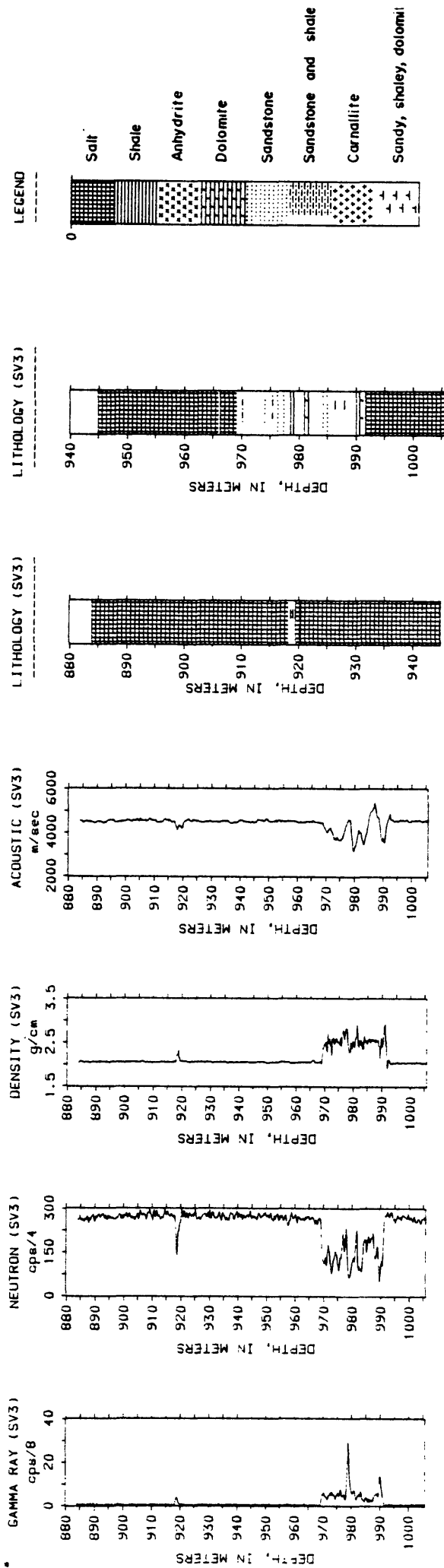


Figure D7.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 884-1006 m in SV3.

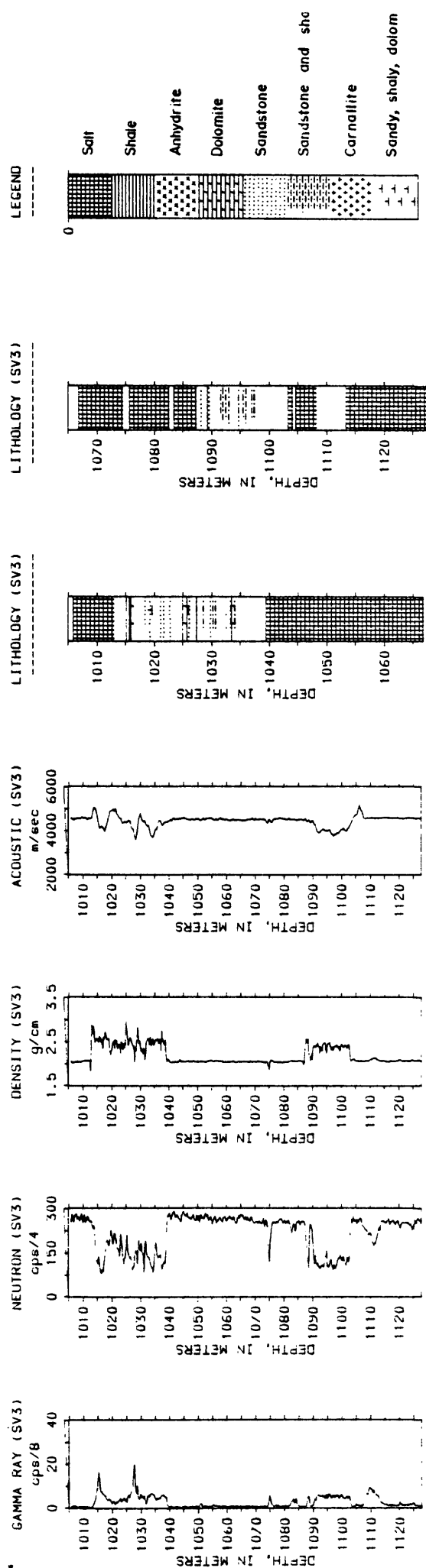


Figure D8. —Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 1006-1128 m in SV3.

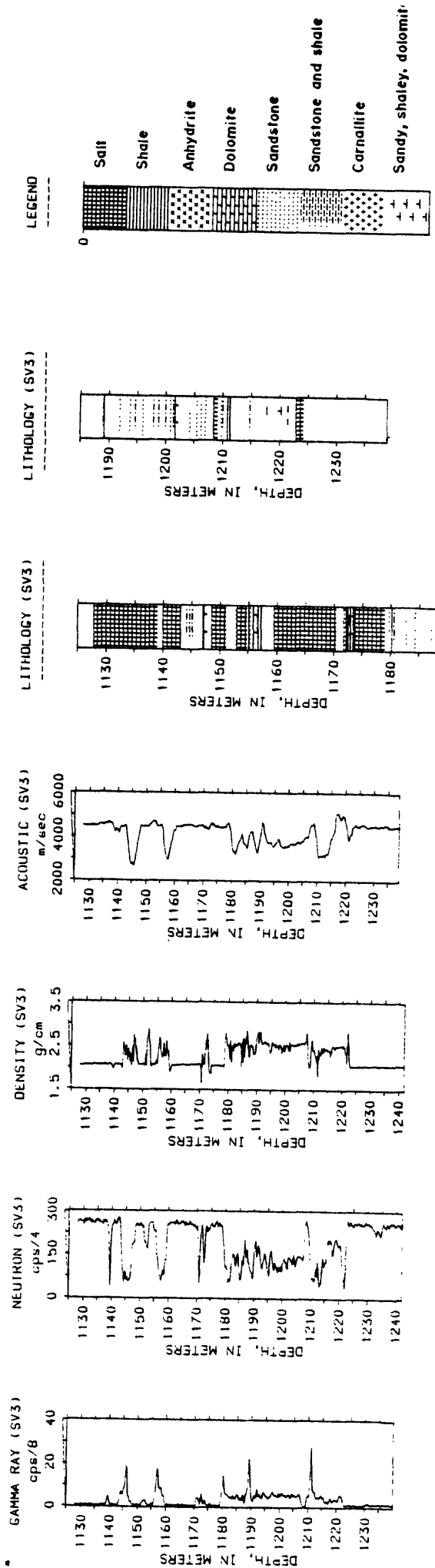


Figure D9.--Gamma-ray, neutron, density, and acoustic-velocity logs, and computer-assisted lithologic interpretation for the depth interval 1128-1242 m in SV3.

<u>Upper Depth</u>	<u>Lower Depth</u>
444.2	444.3
446.3	446.6
447.7	448.1
448.6	449.5
451.0	451.8
498.0	498.4
498.9	499.5
523.3	523.4
525.6	525.9
528.3	529.2
535.8	536.1
562.9	563.2
567.5	568.1
578.1	579.5
587.9	588.4
654.2	654.3
670.5	671.0
672.9	673.1
674.6	674.8
676.6	676.7
759.5	759.7
880.5	881.0
980.9	981.7
990.7	991.1
1015.8	1016.0
1025.0	1025.7
1033.5	1033.7
1146.9	1147.1
1147.2	1147.5
1155.9	1156.2
1172.2	1172.4
1172.5	1172.8
1173.0	1173.1
1201.6	1201.8

Table D1.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of dolomite.

<u>Upper Depth</u>	<u>Lower Depth</u>	<u>Upper Depth</u>	<u>Lower Depth</u>
434.3	434.9	1022.4	1023.0
438.7	438.9	1025.7	1026.8
501.6	501.9	1029.4	1030.2
509.7	510.5	1032.1	1033.1
513.7	514.1	1087.8	1088.4
514.4	514.7	1090.4	1090.5
515.1	515.4	1094.3	1094.8
527.9	528.2	1151.6	1151.8
532.6	533.0	1152.4	1152.8
637.4	637.7	1179.4	1180.0
638.3	639.3	1182.4	1183.5
641.8	642.0	1183.9	1184.5
656.2	656.5	1186.1	1186.2
660.7	661.1	1186.8	1187.3
685.6	685.9	1187.7	1188.2
969.7	969.8	1190.8	1191.1
970.6	970.7	1191.6	1192.0
973.6	975.0	1192.2	1192.5
975.9	976.4	1193.4	1194.5
977.0	977.4	1195.7	1196.7
978.2	978.5	1200.5	1201.3
983.8	985.5	1203.9	1204.5
1017.7	1017.8	1205.1	1207.6
1018.0	1018.6	1207.9	1208.0
1018.9	1019.3	1209.4	1210.0
1020.7	1021.2	1215.2	1215.5
1021.3	1022.1	1216.4	1216.5

Table D2.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of sandstone.

<u>Upper Depth</u>	<u>Lower Depth</u>	<u>Upper Depth</u>	<u>Lower Depth</u>
435.2	435.7	975.9	976.1
435.8	436.3	978.3	978.5
438.4	438.5	983.2	983.4
438.9	439.2	983.5	983.7
447.1	447.4	1025.9	1026.0
450.7	450.9	1027.1	1027.4
500.6	501.6	1028.3	1028.9
505.3	505.4	1030.0	1030.3
516.9	517.3	1030.5	1030.9
519.0	519.3	1031.2	1031.4
526.3	526.9	1033.1	1033.4
533.0	535.0	1033.8	1034.3
537.6	537.8	1091.3	1093.6
537.9	538.4	1094.0	1094.2
575.2	575.6	1094.5	1094.9
575.7	575.9	1095.2	1096.3
580.9	581.0	1096.8	1097.1
585.8	586.1	1097.2	1097.7
640.3	640.5	1097.8	1098.0
640.6	641.2	1143.9	1144.3
642.5	642.6	1144.5	1144.8
646.3	646.4	1144.9	1145.4
646.6	647.6	1156.4	1156.7
661.4	661.5	1179.8	1180.0
662.1	662.9	1180.4	1180.7
663.0	663.2	1181.6	1181.8
663.3	663.5	1185.5	1185.6
663.8	664.4	1187.1	1187.3
666.4	666.8	1188.4	1189.1
667.1	667.8	1189.7	1189.9
667.9	668.2	1194.5	1195.4
668.4	668.8	1197.7	1198.0
669.1	670.0	1198.6	1199.2
673.5	673.9	1199.5	1199.6
779.6	780.1	1199.8	1200.2
780.4	781.8	1201.2	1201.6
782.1	782.2	1201.8	1201.9
783.1	783.3	1209.8	1210.1
969.8	970.4	1210.5	1210.6
970.6	970.7	1214.6	1214.9
973.5	973.6	1221.3	1221.7
975.1	975.6		

Table D3.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of sandstone (dolomitic (?)), and shale.

<u>Upper Depth</u>	<u>Lower Depth</u>
444.8	445.1
448.1	448.6
450.6	450.9
500.1	500.7
506.1	506.7
527.9	528.2
568.1	569.2
569.3	569.8
579.7	580.1
585.3	585.8
676.7	677.1
756.5	756.6
779.3	779.5
828.5	828.8
918.5	918.6
918.9	919.1
971.5	972.1
985.4	985.7
986.1	986.3
987.8	987.9
988.7	989.2
1014.2	1014.6
1018.3	1019.6
1020.3	1020.7
1023.5	1023.9
1025.7	1025.9
1030.3	1030.8
1035.2	1036.0
1172.4	1172.5
1217.6	1217.8
1217.9	1218.4
1219.0	1220.4
1220.5	1220.8

Table D4.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of sandy and shaley dolomite (calcite cemented dolomitic sandstone (?)).

<u>Upper Depth</u>	<u>Lower Depth</u>
444.0	444.2
449.5	450.1
498.0	500.0
880.5	880.8
981.5	981.7
991.1	991.3
1013.1	1013.4
1013.6	1014.0

Table D5.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of anhydrite.

<u>Upper Depth</u>	<u>Lower Depth</u>
168.6	169.0
1074.8	1075.3
1139.4	1139.9
1170.5	1170.8

Table D6.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of carnallite.

<u>Upper Depth</u>	<u>Lower Depth</u>	<u>Upper Depth</u>	<u>Lower Depth</u>	<u>Upper Depth</u>	<u>Lower Depth</u>
170.2	170.9	208.4	209.2	657.1	658.0
171.1	171.4	209.5	209.6	658.3	660.4
171.5	172.2	210.1	210.6	675.8	676.0
172.3	172.5	210.7	211.2	677.2	685.0
172.6	172.8	211.6	211.9	686.5	689.1
173.4	173.5	212.1	212.8	690.3	690.9
173.8	174.0	213.1	213.5	692.1	693.7
174.1	174.4	213.6	214.1	695.6	698.1
174.6	174.7	214.2	215.0	698.2	698.5
174.9	175.2	215.1	215.3	699.3	700.4
175.7	176.0	215.4	216.0	701.3	755.5
176.4	176.6	216.2	216.3	760.6	778.2
178.9	179.0	216.7	217.4	783.7	783.9
179.2	179.6	217.6	217.7	785.3	792.7
180.4	180.5	217.9	218.2	793.0	827.8
180.8	181.3	218.3	218.5	830.1	858.0
181.4	181.6	218.6	218.9	858.4	880.0
181.8	182.5	219.1	219.4	881.1	914.3
182.7	182.8	219.5	219.9	914.6	918.1
183.0	183.4	220.2	220.8	919.5	920.3
183.6	184.6	220.9	221.5	920.4	965.9
184.8	185.0	221.7	221.8	966.3	969.1
185.3	185.9	222.0	223.7	991.8	992.4
186.3	186.9	224.3	227.5	992.7	1012.9
188.0	188.3	227.8	228.5	1039.5	1074.5
188.5	188.6	229.1	230.4	1075.7	1082.6
189.1	189.2	230.5	241.8	1083.5	1084.0
189.4	189.5	242.0	253.5	1084.3	1087.3
189.8	191.2	253.7	260.5	1089.3	1089.6
191.4	192.0	260.7	262.4	1103.3	1104.1
192.3	192.4	262.7	270.0	1104.7	1108.2
192.6	192.7	270.3	276.1	1113.4	1124.7
192.9	193.5	276.4	417.2	1124.8	1139.0
193.8	196.1	417.4	417.7	1140.0	1143.1
196.2	196.5	417.8	433.7	1148.6	1151.0
196.7	197.1	452.6	458.1	1153.0	1154.7
197.3	197.8	458.4	459.4	1155.1	1155.3
197.9	198.4	459.6	466.6	1159.6	1170.4
198.5	199.1	472.8	497.4	1171.7	1171.9
199.3	199.4	512.8	513.2	1173.4	1173.6
199.6	205.5	529.8	532.0	1173.7	1178.9
206.0	207.1	541.9	560.6	1208.5	1209.1
207.2	207.7	561.5	562.4	1222.9	1224.2
208.0	208.3	588.8	636.8		

Table D7.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of halite.

<u>Upper Depth</u>	<u>Lower Depth</u>
757.1	757.4
782.2	782.8
978.5	979.0
990.1	990.2
1015.1	1015.7
1027.4	1028.0
1156.7	1157.4
1180.3	1180.4
1189.1	1189.7
1210.9	1211.1
1211.4	1211.5

Table D8.--Depth interval in drill hole 3 chosen by the computer to contain the well log response values in Table 2 that are indicative of black shale.