Summary Report of the Investigation / Demobilization of Construction Dewatering Wells San Onofre Nuclear Generating Station Units 2 & 3

PREPARED FOR

SOUTHERN CALIFORNIA EDISON
P.O. BOX 800
ROSEMEAD, CALIFORNIA 91770

JULY 1979

Woodward-Clyde Consultants

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TABLE OF CONTENTS

TABLE OF CONTENTS (con't)

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0.0 EXECUTIVE SUMMARY

During decommissioning of the 12 construction dewatering wells and one test well at the SONGS Units 2 and 3 site (well locations shown on Figure 1), evidence of cavities associated with these wells was detected. The decommissioning procedure was then modified to include an evaluation of the possibility of cavities associated with these wells and an assessment of the effects of the detected cavities on adjacent Seismic Category I structures. The results of the field and laboratory investigative work and the analyses performed during the well investigation/demobilization effort are summarized in the accompanying report. In brief, the field work included: (1) drilling a total of 634 borings, some to the maximum depth of the wells (about 200 ft); (2) removal of the well casing and filter gravel (Figure 2) from the wellbore and subsequent filling of the wellbore with concrete at three of the wells; (3) exploration drilling and crosshole seismic surveys at four of the wells; (4) downhole inspection of 12 well casings by a bore hole television camera; and, (5) pressure grouting with cement grout around four wells close to Seismic Category I structures where cavities were detected. A summary of the investigation/demobilization work is presented in Table 1. This work led to the demobilization of all wells and to the detection of cavities at Wells 6, 7, and 8 and either small or possible small cavities at Wells 3, 5, and 10. The significant characteristics of these cavities are that they were sand-filled, limited in areal extent, rather lobate in shape (Figure 3), and are predominately located in the drawdown zone developed during construction dewatering. These observed characteristics are consistent with the mechanism of cavity formation postulated in Section 2 and Appendix A of the accompanying report.

The results of extensive exploration drilling and grouting programs indicate that all cavity areas are filled with sand or grout and contain no open voids. Analyses were performed to evaluate the maximum effects of the detected cavities on the performance of Seismic Category I structures, considering static as well as DBE-induced loading conditions. The results of these analyses indicate that maximum effects of any detected cavity on the adjacent Seismic Category I structures are very small and are well within the variation in design parameters used in initial design.

In conclusion, the findings of the investigations show no detrimental effect from the detected cavities to Seismic Category I structures. All on-site wells have been demobilized by backfilling with sand, gravel, and/or grout.

1.0 INTRODUCTION

1.1 Purpose and Scope

The purpose of this report is to summarize the investigation/demobilization work for the dewatering wells at the SONGS Units 2 & 3 site. Subsurface cavities were found at the location of some of these wells. Because these cavities represent an anomalous condition with respect to original subsurface conditions used to develop foundation design parameters, analyses were made to study the effects of these cavities on foundation design parameters for Seismic Category I structures and are documented herein.

1.2 Background

The construction dewatering system for the SONGS site consisted of 12 wells constructed at the site between June and August 1974 as located on the Site Plan, Figure 1. A test well, 3A, had been constructed earlier and pumped for a few days to develop design criteria for the 12 production wells. The production wells were in service between June 1974 and February 1978, and were utilized to facilitate site dewatering to allow construction to Elev. -35 ft (about 40 ft below the existing water table at the site.) A typical section for the 12 production wells is presented on Figure 2. Significant features of the wells are: (1) the wellbore for each well is 30 in. in diameter and is drilled to a depth of about 200 ft; (2) the well casing extends to the full depth of the wellbore and is a 14-in. diameter steel casing with the lower 110 ft louvered; (3) the annular area between the wellbore and casing contains a gravel filter; and (4) a 1500 gpm turbine pump was used in the dewatering operation with the bottom of the pump bowl assembly located between Elev. -80 to -90 ft (110 to 120 ft below the ground surface.)

An indication of a possible cavity was first noted during the initial demobilization of Well 6 in May of 1977. The subsequent investigation and demobilization of each well at the site is outlined chronologically in Table 2. The work described in Table 2 comprises a series of investigative techniques and demobilization procedures developed specifically for the site conditions at each well and within the logistic constraints imposed by adjacent construction. One or more of three basic investigation/ demobilization procedures were used: (1) drilling exploration and pressure grouting of the area around the well; (2) the airlift cleaning of the gravel pack and the removal of the well casing, followed by the placing of measured volume of concrete in the wellbore; and, (3) the exploration drilling of the area around the well, supplemented by crosshole seismic measurements to provide closure, and followed by additional borings, as required. Other field measurements were also made during the course of the exploration work, including downhole-TV monitoring of the well casings and caliper and/or sonar measurements of cleaned well bores and cavities.

1.3 Organization of the Report

This report has been organized in five sections, providing a summary of the field and laboratory work completed to demobilize the wells and define subsurface conditions adjacent to the wells, and of the analyses completed to evaluate the effects of cavities, if present, on adjacent structures. Specifically, the study is introduced in Section 1. The mechanism of cavity formation is summarized in Section 2. The investigation/ demobilization procedures are described in Section 3 and the results of the investigation are contained in Section 4. The results of the analysis of cavity stability and the effects on structures are discussed in Section 5. Factual data and details of field procedures and of analyses are included in Appendices A through G.

2.0 MECHANISM OF CAVITY FORMATION

The mechanism of cavity formation together with the results of a laboratory testing program to study the initiation and progression of piping are described in Appendix A. Basically, the information in Appendix A supports the fact that the dewatering wells were designed to prevent subsurface erosion if all components of the well remain intact: the louvers were sized to retain the filter gravel and the filter gravel was adequately graded to retain the native sand. Because cavities were detected at some of the wells, it appears likely that for some of the wells the components did not remain intact. The key element was assessed to be the absence of the filter gravel locally in the well annulus. This absence may have been due to the arching in the annulus between the casing and the wellbore, compaction and/or settlement of the gravel under hydraulic gradient, and/or the erosion of the gravel through holes in the casing caused by corrosion. Though gravel erosion through holes in the casing appears to be the most likely cause of loss of the gravel filter, there is not sufficient evidence to state definitively which of the above causes or combination of causes may be responsible.

With the filter gravel absent locally along the wellbore, the erosion of the native San Mateo sand can occur when the flow gradients are sufficiently high. For the native sands, which have cohesion due to their gradation and efficient packing (they stand in near-vertical cliffs 100 ft high), the gradient which will erode them is probably much greater than for truly cohesionless sands. Thus, as discussed in detail in Appendix A, subsurface erosion features in the native sand are expected to have a limiting stable size. Further, it is expected that the cavities found will be rather lobate, as shown in Figure 3(a). The series of sketches shown on Figure 3 show schematically the mechanisms leading to the likely cavity configuration. The mechanism depicted on Figure 3 indicates the cavity will most likely form in the vicinity of the drawdown zone where the gradients are highest and confinement is relatively low. Also in this zone, alternate sequences of wetting and dewatering are expected when pumping is stopped and restarted. Because some of the cavity-infill sand is pumped out through the well casing, the cavity is expected to be funnel-shaped near the wellbore narrowing to about the well diameter below the drawdown zone where gradients become small. Though this mechanism does not preclude the possibility of deeper cavities, it indicates that they would be limited in size and would most likely be part of a more shallow cavity. Also, as indicated in Appendix A, the native San Mateo sand is very dense (mean dry density of 123 pcf), and because the infill sand will achieve a lower density (estimated maximum dry density of 105 pcf), it is expected that 15 to 20% bulking will be associated with the above described phenomenon. It is expected, therefore, that the stabilized cavity will be full or nearly full of infill sand as shown on Figure 3(d). The results of the laboratory piping test described in Appendix A support the key elements of the above described mechanism.

3.0 INVESTIGATION/DEMOBILIZATION PROCEDURES

3.1 Well Cleaning, Inspection, and Measurements

Well cleaning, inspection, and measurements were accomplished using the technique described in Appendix B. Well cleaning was used for two purposes: (1) if initially decommissioned, to clean the inside of the well casing; and (2) to clean the filter gravel from the annular area between the wellbore and the well casing to facilitate the removal of the well casing for full inspection of the wellbore. The cleaning procedure was an airlift technique and is described in detail in Appendix B. Volumes and types of material removal were monitored during the cleaning operation for evaluation.

Visual inspection of well casings and wellbores was facilitated by the use of a bore hole television from which 28 videotapes were obtained. The purpose of this work was: to log the inside of the in-place well casing; to check the condition of the well casing and to view various operations being performed in the wells; to log sections of the annulus between the wellbore and casing; to check for possible cavities in the well face; and, to monitor an exploration hole drilled into the cavity at Well 6. A complete summary of the television logs with pertinent observations is presented in Appendix B.

Wellbore and cavity measurements were facilitated by the use of a mechanical (dog-leg) and a sonar caliper. These calipers and their use are described in Appendix B. Measurements ranging from the 30-in. wellbore diameter up to 20 ft in the case of the cavity at Well 6 were made using these calipers. Before the measurements could be made on a cavity, however, it was necessary to first remove the cavity-infill sand using the airlift.

Borehole inclinometers, were used to measure the inclination of the well casings. This was an important aid in interpreting the observations during exploration drilling, for example, when a drill hole might have encountered the wellbore or well casing. These inclinometer measurements are described in Appendix C under exploration drilling.

3.2 Exploration, Drilling, and Grouting

The investigations at each well were planned to explore the relevant conditions at that location. Preliminary boring layout was based on the results of the initial investigations within the wellbore. New data were continuously analyzed, and the results were used to modify the investigation to assure complete areal coverage for exploration and grouting. The details of the program of drilling and grouting are summarized in Appendix C.

Four kinds of drilling programs were conducted during the investigations:

1. Exploratory Drilling: Initial drilling program to obtain preliminary information on conditions surrounding the wells.

2. Deep drilling: Borings drilled to about 200 ft. Program to (a) ensure, by closely-spaced holes, that all cavities larger than 3 ft in width immediately adjacent to and within the full depth of the well would be located; (b) locate the maximum depth of a cavity; and, (c) provide additional subsurface information for the design of the grouting program.

3. Exploration/Grouting: Borings drilled to between 50 and 120 ft deep. Program to (a) locate any shallow cavities or zones of disturbed material and delineate their extent and shape; (b) investigate the properties of the cavity-infill materials; (c) provide access for grouting; and (d) provide a check on the effectiveness of the grouting program while it was still in progress. Both vertical and angle holes were drilled during this investigation.

4. Deep Drilling/Crosshole Seismic: Borings drilled to about 200 ft. to (a) provide holes outside the disturbed zone for crosshole seismic investigation; (b) identify possible cavities with crosshole seismic measurements; and (c) to investigate some areas where crosshole seismic data were interpreted as being anomalous.

The details of the programs of drilling and grouting are summarized in Appendix C. Additional data are provided in previously submitted reports for a specific well or wells as follows:

- Bechtel report entitled, "Deep Exploration Drilling Program, Dewatering Well No. 6," February 1979
- Bechtel report entitled, "Exploration/Grouting Program, Dewatering Well No. 6," February 1979
- Bechtel report entitled, "Deep Exploration Drilling Program, Dewatering Well No. 7," June 1979
- Bechtel report entitled, "Exploration/Grouting Program, Dewatering Well No. 7", 2 Volumes, June 1979
- Bechtel report entitled, "Deep Exploration Drilling Program, Dewatering Well No. 8", August 1978
- Bechtel report entitled, "Shallow Exploration/Grouting Program, Dewatering Well No. 8", August 1978
- Woodward Clyde Consultants report entitled, "Exploration/ Demobilization of Wells 4 and 5", July 1979

Soil samples were obtained for laboratory testing and standard penetration tests were performed at regular intervals to further interpret visual material classifications. Gyroscopic and slope-indicator surveys were performed on many of the bore holes to determine the location of the bore hole with depth to aid in the interpretation of bore hole data and to verify the closure spacings of the holes.

Grout was placed in the cavities and drill holes using both gravity and pressure-injection methods. Gravity grouting was used primarily to fill any large open cavity spaces emptied by airlifting, and to help stabilize the upper portions of the cavities. It was also used to backfill wells where the well casing had been removed and the wellbore measured, and around the PVC casing in bore holes being prepared for the crosshole seismic surveys.

The pressure grouting program followed gravity grouting of the open cavity spaces at the top of the cavities (created by the emptying of the cavity-infill sand with the airlift). Its objectives were to fill any remaining voids and to provide for nominal densification of the cavity-infill materials. Grouting was done in stages on a grid pattern around the known or suspected cavity locations to ensure complete filling of the cavities.

3.3 Laboratory Testing

Laboratory tests were conducted on samples obtained during drilling exploration to define the grain size distribution of the San Mateo sand in the vicinity of the dewatering wells, to evaluate the adequacy of the filter gravel, and to study the characteristics of simulated cavity-infill material. Over 750 gradation tests were performed on samples, with over 100 of these representing the cavity-infill material. The results of these tests, as presented graphically in Appendix D, show that the cavity-infill material is slightly more coarse-grained than the surrounding native soil. This indicates that some of the fines may have been pumped out of the cavity as the infill material was being deposited.

Tests were also performed on the effectiveness of the filter material to prevent piping of the San Mateo sand as summarized in Appendix D. These tests substantiate the fact that the filter material used, if in place, is adequate to prevent piping of the native soils.

Permeability tests were also performed on simulated samples of cavity-infill material. The interpretation of these data, as discussed in Appendix D, indicate a permeability of the cavity infill soil to be on the order of 0.1 cm/sec.

3.4 Crosshole Seismic Surveys

Crosshole seismic surveys were performed at the site to aid in the interpretation of exploration drilling, as described in Appendix E. Specifically, the primary purpose of the crosshole seismic measurements was to provide closure information between borings, and to guide the location of additional borings as required, to verify the presence or absence of cavity.

The principal of operation is illustrated in Figure 4. A source of seismic energy (the hammer) is placed in one bore hole and several detectors (geophones) are lowered to the same elevation in adjacent bore holes. A recorder at the ground surface records the seismic energy received by the geophones. The waveform characteristics are interpreted as described in Appendix E, and anomalies found in the data are used to identify zones where additional drilling might be advisable.

The interpretations are made regarding the relative effects upon a waveform of the San Mateo sand and the cavity-infill material. These interpretations are applicable only when the same hammer source is used in materials with similar properties. Calculations show that the poroelastic properties of the cavity-infill sand are such that it should, for the source frequencies used, attenuate a P-wave rather efficiently and attenuate a S-wave relatively poorly. However, a cavity which is large compared to the crosshole distance should strongly attenuate both waves. The poroelastic properties of the undisturbed native sand are such that it should not, for the source frequencies used, greatly attenuate either the P-wave or the S-wave. The crosshole technique (field procedures and interpretation) was first calibrated on the cavity at Well 3 previously detected by exploration drilling.

4.0 WELL INVESTIGATION/DEMOBILIZATION RESULTS

4.1 General

The scope of the well investigation/demobilization work at each well varies and was mostly dependent upon the proximity of the well to Seismic Category I structures. At the wells where a cavity was detected, the program was directed at defining the size, and location of the cavity and ensuring backfill with grout. The investigation/demobilization procedures used at the wells are discussed in the subsections that follow. For discussion purposes, the wells have been grouped in accordance with the similarity in investigation/demobilization procedures utilized. The maintenance requirement at each well during operation was rated by reviewing the operating records. The rating is relative to the average maintenance at all wells. The results of these ratings are presented in Table 3 and form the basis for all comments on well maintenance.

4.2 Wells 1, 2, 3A, and 9

Wells 1, 2, and 9 were intermittently pumped for a total of about 950, 735, and 475 operating days, respectively. Wells 2 and 9 required relatively high maintenance to keep them in operation; the maintenance level at Well 1 was about average when compared with the level at other wells. The investigation/ demobilization of these three wells involved the following four steps: (1) airlifting the material from the annular space between the well casing and the side of the wellbore, and measuring the volume of soil removed; (2) removing the well casing and inspecting its condition; (3) measuring the diameter of the wellbore with a mechanical caliper; and, (4) demobilizing the well by filling the wellbore with gravity grout and measuring the volume of grout placed. The results of these measurements and observations are summarized on Table 4. The wellbore diameter after cleaning measured in substantial agreement with the original drilled diameter of 30 in. Also, calculations show that the volume of gravel removed is comparable to the volume of grout placed.

These measurements evidence the absence of any cavity at these wells.

Well 3A was the test well used to develop design criteria for the dewatering well system. It was operated for only a few days during the pumping test and was not operated during the actual dewatering of the site. The television log of the wellbore revealed 6 ft of sediment in the bottom of the well. It is probable that this material fell into the well during construction. Also, the television log revealed the casing to be slightly encrusted for the most part with some enlarged louver openings through which the filter gravel could be observed to be intact. Based on these observations and considering the limited use of the well, it was concluded that no cavities could have developed. The well was demobilized by filling the casing with gravity grout.

4.3 <u>Wells 6, 7, and 8</u>

The investigation/demobilization of Wells 6, 7, and 8 involved by far the most intensive effort because not only are they all close to Seismic Category I structures, but cavities were detected in all of them. A comprehensive description of the details of the investigation/demobilization work completed at these wells is provided in a series of six reports (BPC 1978a*, b; 1979a, b, c, d), with a summary of pertinent data presented in Appendices B and C. These wells were intermittently pumped for a total of about 545, 565, and 650 operating days, respectively. All required high to very high maintenance during operation. In fact, after about seven months of operation, sand and gravel were found to completely fill the Well 7 casing. The sand and gravel were bailed out and a smaller 10-in. diameter slotted well casing was inserted into the 14-in. casing. Thereafter, the well was returned to normal operation.

* see References at end of report

The cavity in Well 6 was outlined by exploratory drilling, further defined by airlift cleaning and caliper measurements, and ultimately established by exploration drilling and grouting (BPC February 1979a, b). The cavity at Well 7 was detected and partially defined by airlift cleaning the annular area between the casing and the side of the wellbore, and established by exploration drilling and grouting (BPC June 1979c, d). The cavity at Well 8 was detected by airlift cleaning the inside of the casing (initially demobilized by sand filling), further defined by airlift cleaning the annular area between the casing and the side of the wellbore, and ultimately defined by exploration drilling and grouting (BPC August 1978a, b). The locations and graphic logs of all borings (139 borings for Well 6, 233 borings for Well 7, and 195 borings for Well 8) are included in Appendix C.

Based on interpretation of the data collected during the investigation/demobilization work, simplified plan views and cross-sections of the cavities at Wells 6, 7, and 8, were prepared as shown in Figures 5, 6, and 7, respectively. These figures put the general size and configuration of the cavities at Wells 6, 7, and 8 after demobilization (present condition) and their proximity to Seismic Category I structures in perspective. It is significant to note that initially the cavities at Wells 6, 7, and 8 were sand-filled, subsequently they were partially emptied using an airlift, and finally they were filled with sand, gravity grout, and pressure grout. No attempt has been made to delineate the sand and grout comprising the cavity infill here, because that information has been provided in the aforementioned BPC reports. Wells 6, 7,and 8 have been demobilized by the drilling and grouting operations.

4.4 <u>Wells 4 and 5</u>

Wells 4 and 5 were intermittently pumped for a total of about 680 and 625 operating days, respectively. Well 4 required relatively low maintenance and Well 5 high maintenance during operation. Television logs of the well casing indicate the casings at both wells to be encrusted. A small hole was noted in the Well 4 casing and several corrosion holes were seen in the Well 5 casing. The investigation/demobilization of Wells 4 and 5 has been documented in detail in the WCC July 1979 report and summarized in the acompanying Appendix E. In brief, the investigation/demobilization of these wells was accomplished in three stages as follows: (1) at Well 4 direct observation of an excavation extending to approximately Elev. -8 ft (depth of 34 ft) indicated no cavity near Well 4 to that elevation, and at Well 5 exploration drilling revealed a small cavity extending from about Elev. +3 ft to Elev. -25 ft, which was subsequently stabilized by drilling and pressure grouting to Elev. -30 ft (depth of 60 ft below plant grade); (2) drilling exploration was completed at both Wells 4 and 5 extending to the full depth of the wells; and (3) 4-in. diameter plastic (PVC) casing was grouted into these exploration borings and a crosshole geophysical survey was performed to provide closure between borings to assess the need for further exploration drilling. The observations from Step 1 indicated that either no cavity exists (Well 4) or the small stabilized cavity is present (Well 5). The depths investigated at this stage were about 40 and 60 ft below grade for Wells 4 and 5, respectively. The logs of borings drilled in Step 2 showed only native soil and the results of Step 3 confirmed closure between the borings. Specifically, it is concluded that no cavities extend beyond Boundary A shown on Figure 8 for depths of 40 to 200 ft at Well 4. Further, based on the interpretation made on transects crossing the area bounded by Boundary A, it is concluded that no cavities of structural significance exist within Boundary A on Figure 8. Similarly, for Well 5, it is concluded that no cavity extends beyond Boundary B shown on Figure 9 for depths of 60 to 200 ft, and no cavities of structural significance exist within Boundary B. It was, therefore, concluded that no further drilling was required at

Wells 4 and 5. Both wells were demobilized by filling with sand, gravel, and concrete.

4.5 Wells 3 and 10

Wells 3 and 10 were intermittently pumped for a total of about 710 and 1175 operating days, respectively, with average to very low maintenance. The television logs for both wells indicate the casings were heavily encrusted. The investigation/demobilization work completed for Wells 3 and 10 was similar to that completed for Wells 4 and 5 in that the primary investigation of the area was completed by exploration drilling with secondary closure provided by the crosshole seismic measurements.

A cavity was first detected at Well 3 during the airlift cleaning of the annular space between the well casing and the side of the wellbore. This cavity was subsequently defined by exploration drilling and was noted to extend to a maximum depth of about 55 ft as indicated on Figure 10. The details of the investigation/ demobilization work described above are presented in the WCC July 1979 report and summarized in the acompanying Appendix E. The portion of the well below a depth of 55 ft was investigated by deep drilling and crosshole seismic measurements. Anomalous data was noted at a depth of 95 ft. All other data below 55 ft indicated closure between borings. The 95-ft depth was investigated by two additional borings in which native soil was logged below 55 ft. Because these data could, at worst, be interpreted as a cavity smaller than the cavity above a depth of 55 ft, and because Well 3 is not located near Seismic Category I structures, no further investigation was necessary.

The details of the investigation/demobilization of Well 10 is documented in Appendix E. In summary, the work completed included exploration drilling extending to depths of about 200 ft followed by the crosshole seismic measurements and additional drilling. The initial drilling indicated native San Mateo sand.

Anomalies were, however, interpreted in the crosshole seismic data at depths of 50 ft and between 150 to 165 ft. Because of these anomalies, three additional borings were drilled. All of these borings indicated native San Mateo sand. Interpretation of these data indicate the possibility of cavities at the depths noted above, but it is felt that these cavities, if they exist, would be smaller than the one detected at Well 3. Because Well 10 is not located near Seismic Category I structures, no further exploration was necessary. Wells 3 and 10 were both demobilized by backfilling with sand, gravel, and concrete.

4.6 Wells 11 and 12

These wells were located outside of the plant area and their distance from Seismic Category I structures precludes the possibility of any cavities associated with these wells affecting such structures. Therefore, no investigation/demobilization work was carried out on these wells.

5.0 ANALYSIS OF CAVITY STABILITY AND EFFECTS ON STRUCTURE

5.1 Cavity Geometry, Characteristics, and Proximity to Structures

As indicated in the foregoing sections, the most significant cavities as far as size and proximity to structures are those detected at Wells 6, 7, and 8. As shown in Figure 5, the cavity at Well 6 is located to the east side of the north end of the Auxiliary Building and south of the Unit 2 Fuel Handling Building. The cavity does not extend beneath either structure and is small in plan area compared to the plan area of either adjacent structure. Similarly, Figure 6 shows the cavity at Well 7 to be located to the east of the south end of the Auxiliary Building and north of the Unit 3 Fuel Handling Building. The cavity does extend slightly under the Auxiliary Building but does not extend under the Unit 3 Fuel Handling Building. As was the case for Well 6, the cavity is small in plan area compared to the plan area of either adjacent structure. The cavity at Well 8 is shown on Figure 7 to be located to the southeast of the Unit 3 Containment Structure and extends slightly under the edge of the structure terminating at the tendon gallery. As was the case for the cavities at Wells 6 and 7, the plan area of the cavity is small compared to that of the adjacent Containment Structure. A portion of a tunnel structure is located over the cavity at Well 8, see Figure 7. As discussed previously, observations in the field indicate all detected cavities to be full of sand and/or grout.

The proximity to structure and size of all other cavities detected at the site (small shallow cavity at Well 5, small shallow cavity at Well 3, and possible small cavity at Well 10) were not considered to have any measurable effects on adjacent structures as further discussed below.

5.2 Evaluation of Cavity Stability

A mechanism may be postulated for the earthquake behavior of a cavity wherein the excess pore water pressure developed in the walls of the cavity due to seismic shaking could cause the wall material to collapse and simulate cavity-infill soil. In examining this mechanism, it is noted that the native San Mateo sand is very dense (100% relative density) and is characterized by a very efficient grain packing. Further, experience in the field and the results of laboratory tests shows that the native soil fails by particulating grain-by-grain; and, in doing so, bulks and increases in volume by about 20%. Since the cavity is full of sand and/or grout, bulking is resisted by the existing soil in the cavity and the expansion of the cavity by wall failure is expected to be self-stabilizing. Seismic shaking may, however, cause liquefaction of the cavity-infill material, which will generate an excess pore water pressure in the cavity-infill soil. The dissipation of this excess pore water pressure into the adjacent native soil tends to reduce the stiffness of the native soil.

An analysis of this phenomenon was made for the cavity at Well 8 and documented in the WCC 25 August 1978 report and is summarized in the accompanying Appendix F. The results of the analyses are shown in plan for the cavity at Well 8 in Figure 11. These results are documented in the 25 August 1978 report as being conservative because the analysis assumes the cavity to be more than 25 times greater in size than the known size of the cavity (the response model is plane strain with absorbing boundaries at the width of the containment structure). Specifically, Figure 11 shows the footprint of the cavity at Well 8, and the maximum extent of contours of equal pore pressure ratio (pore pressure/confining pressure) of 1.0 and 0.3 during or after the Design Basis Earthquake. The higher the pore pressure ratio, the lower the effective confining pressure. This is important because the stiffness of the soil is proportional to the effective confining pressure (FSAR Figure 3.7-12). Thus, the soil within the 1.0 contour would exhibit very low stiffness, while the soil near the 0.3 contour would exhibit about 80% of its original stiffness. It should be noted that these reductions were found to represent a transient condition, and the soil was found to stabilize to the pre-earthquake condition within about an hour after the Design Basis Earthquake.

The results of the analysis of the Well 8 cavity were extrapolated to the Well 6 and 7 cavities as discussed in Appendix F. The results are shown on Figure 12 for Wells 6 and 7.

5.3 Analysis of Effects of Cavities on Structures

The cavities at Wells 6, 7, and 8 were evaluated to determine the effects on adjacent Seismic Category I structures as documented in the WCC 25 August 1978 report and in Appendix G. Specifically, the following cases were assessed: the combined effects of the Wells 6 and 7 cavities on the Auxiliary Building; the individual effects of Well 6 cavity on the Unit 2 Fuel Handling Building; the combined effects of the Wells 7 and 8 cavities on the Unit 3 Fuel Handling Building; and, the effects of the Well 8 cavity on the Unit 3 Containment Structure. These assessments were made by calculating the potential reduction in stiffness or support characteristics of the foundation material caused by an adjacent cavity. The calculation was facilitated by making conservative assumptions regarding the interrelationships between the geometry and spatial location of the cavity and the body of soil dominating the support of the structure, as documented in Appendix G. For the static analyses, the area enclosed within each cavity (Figures 5, 6, and 7 for Wells 6, 7, and 8 cavities, respectively) was conservatively assumed to have no stiffness at all. For the seismic analysis, the area within the 1.0 pore pressure contour (Figure 11 for Well 8, and Figure 12 for Wells 6 and 7) was also assumed to exhibit no stiffness, and the area between the 0.3 and 1.0 contours was assumed to exhibit an appropriately reduced stiffness as discussed in Appendix G. The results of these analyses have been summarized on Table 5.

The dynamic response analyses originally performed for the design of SONGS Seismic Category I structures were made assuming a ±30% variation in stiffness parameters. The maximum reduction in stiffness for any of the structures as calculated by the analyses of cavity effects is substantially below that variation, and is therefore well within the margin of safety for the design. The static settlements of the Unit 3 Containment Structure, the Auxiliary Building, and the Units 2 and 3 Fuel Handling Buildings were estimated to be less than 1/2 inch. Assuming this settlement to increase in proportion to the changes indicated on Table 5, the maximum 8% change in settlement is calculated to be less than a 1/10-in. increase.

A second analysis of the effect of the cavities on the settlement of the structures was made by calculating the potential change in volume of the soil beneath the Containment Structure due to the drainage of excess pore pressures. Specifically, this volume was calculated by multiplying volumetric strains reported by Lee and Albaisa (1974) by the volumes of soil enclosed by contours of constant pore pressure within the soil dominating the support of the structure as defined in Appendix G. The maximum potential settlement of the structure due to this phenomenon was then calculated by assuming the structure to tilt to accommodate this change in volume with no settlement on the side of the structure away from the cavity, and maximum settlement on the side of the structure near the cavity. This settlement was also calculated to be less than 1/10-in. for all structures affected by the cavities at Wells 6, 7, and 8. The factor of safety against bearing failure for the structure is in excess of 100 (Section 2.5.4.10.3 of the FSAR). A maximum 8% reduction in this factor would still yield a factor of safety of greater than 100.

The effect of the cavity at Well 8 on the tunnel structure was based on the results of the pore pressure dissipation analyses presented above. This was done by conservatively assuming that the tunnel would be unsupported in the area of the cavity within the maximum extent of the 0.5 pore pressure ratio contour at any point below the tunnel, as indicated on Figure 13 by the cross-hatched area. The tunnel was then checked for its spanning capabilities by BPC. These calculations indicated that the tunnel can span, unsupported, the cross-hatched area on Figure 13.

Because of the small potential effects of the cavities at Wells 6, 7, and 8 on the adjacent structures, and because of the relatively small sizes and greater distances of cavities or possible cavities from structures at Wells 3, 5, and 10, no specific analyses were completed at the latter locations. These cavities or possible cavities, in fact, lie outside the soil dominating the support of the nearest Seismic Category I structures and have no measurable effect on such adjacent structures.

TABLE 1
SUMMARY OF INVESTIGATION/DEMOBILIZATION OF
DEWATERING WELLS

Well Number	Description of Investigation/Demobilization
1,2,9	Annulus airlift cleaned, well casing removed, wellbore measured, and wellbore filled with concrete.
3A	Test well--only operated a few days, casing inspected, and filled with concrete.
3,10	Shallow investigation at Well 3 by borings identified and delineated a small cavity. Borings and crosshole seismic measurements made to bottom of both wells. Results of investigations, and analyses considering the distance to Seismic Category I structures, show no cavities of structural significance at either well. Well casings filled and capped.
4,5	Shallow investigation at Well 4 by open excavation detected no cavity. Shallow investigation at Well 5 using borings and pressure grouting detected and delineated a small cavity. Deep drilling and cross-hole measurements made to bottom of both wells. Results of investigation show no cavities of structural significance exist at either well. Well casings filled and capped.
6,7,8	These wells primarily investigated by deep drilling and exploration/grouting in detected cavity areas. Filled cavities were detected and delineated for further evaluation of effects on adjacent structures. Well casings were filled.
11,12	Located outside plant area at considerable distance from Seismic Category I structures. Therefore, no investigation work carried out on these wells.

TABLE 2

CHRONOLOGICAL SUMMARY OF
INVESTIGATION/DEMOBILIZATION WORK FOR EACH WELL

Well No.	Date	Exploration/Demobilization Work Completed
1	June to July 77	TV log inside 14-in. casing.
	Jan 78	Airlift gravel pack; remove casing; run mechanical caliper survey; and, backfill by gravity grouting. Well demobilized.
2	July 77	TV log inside 14-in. casing.
	Aug 77	Airlift gravel pack; remove casing; run mechanical caliper survey; and, backfill by gravity grouting. Well demobilized.
3	July to Aug 77	TV log inside 14-in. casing.
	Mar 78	Wire brush 14-in. casing and TV log; airlift gravel pack to 55 ft.
	Apr 78	Attempted mechanical and sonar survey from the cleaned well annulus.
	Apr to Oct 78	31 exploration borings.
	Aug to Nov 78	Crosshole seismic survey.
	Dec 78	Demobilized by filling the well casing with gravel, sand, and concrete.
3A	July to Aug 77	TV log inside 14-in. casing.
	Sep 77	Well demobilized by gravity grouting inside 14-in. casing.

Well No.	Date	Exploration/Demobilization Work Completed
4	Aug 76	Initially decommissioned by backfilling with sand inside 14-in. casing.
	Oct 77	Construction excavation made to Elev.-8 ft placed 102 yds concrete backfill, Elev. -8 ft to Elev. +5 ft. 42-in. diameter working casing set around the 14-in. casing extending from Elev. -7 ft to Elev. +26 ft and excavation backfilled to Elev. +26 ft.
	Mar 78	Airlift sand from inside 14-in. casing.
	Mar to Apr 78	Wire brush 14-in. casing and TV log from inside the casing.
	Oct to Dec 78	8 exploration borings.
	Nov to Dec 78	Crosshole seismic survey.
	Dec 78	Demobilized by filling the well casing with gravel, sand, and concrete.
5	Dec 76	Initially decommissioned by backfilling with sand inside 14-in. casing.
	Sep to Oct 77	Construction excavation made to Elev. +6 ft for Electrical Tunnel. Shallow drilling program (19 borings) drilled from Elev. +6 ft. Backfill 9 holes with sand and pressure grout 10 holes. 30-in. diameter steel casing driven into wellbore to Elev. -30 ft prior to pressure grouting. Shallow pressure grouting program (29 grout locations).
	Oct 77	42-in. diameter CMP access casing placed and area backfilled to Elev. +30 ft.
	May 78	Airlift sand within 14-in. casing from Elev. +6 ft to Elev. -120 ft; TV log to Elev. -120 ft.
	Sep to Oct 78	4 exploration borings.
	Oct 78	Crosshole seismic survey.
	Jan 79	Demobilized by filling the well casing with gravel, sand, and concrete.

Well No.	Date	Exploration/Demobilization Work Completed
6	May 77	Initially decommissioned by backfilling with sand inside 14-in. casing. Gravel pack settled 30 to 40 ft.
	May to June 77	7 exploration borings.
	June to Aug 77	Airlift sand from inside 14-in. casing; gravel pack removed from annulus; series of TV logs; pull 150 ft of casing; and, make a number of mechanical caliper surveys. Initial detection of cavity at Well 6 and condition report to the NRC.
	Oct 77	TV log in open wellbore with "side-looking" lens.
	Nov 77	Sonar caliper measurements.
	Dec 77	36-in. casing initially driven to a depth of 108 ft. Roof of cavity emptied by airlifting collapsed during casing driving operation.
	Dec 77 to May 78	28 exploratory borings; series to TV log; and, sonar caliper measurements from drill holes. In Feb 78 36-in. casing redriven to a depth of 118 ft (driving terminated due to break in casing at 60 ft) nominal air lifting and repair of 36-in. casing attempted.
	Apr 78	Gravity grout backfilling of cavity previously emptied by airlifting.
	May to Oct 78	26 borings; deep exploration program.
	July to Oct 78	74 borings; exploration/grouting program.
	May 78	36-in. casing filled with sand and concrete cap placed, well demobilized.
7	June to July 77	Airlifted material from inside 10- and 14-in. casings pulled about 136 ft of 10-in. casing. Series of TV logs inside 14-in. casing and the remaining 10-in. casing.
	July to Nov 77	Airlift gravel pack from annulus to about Elev. -84 ft; limited sonar survey.

Well No.	Date	Exploration/Demobilization Work Completed
	Jan to Apr 78	54 exploratory borings.
	Apr 78	Cavity previously emptied by airlifting was filled as follows: (a) sand placed around well casing, (b) gravity grout placed below water table through access holes and (c) loose sand placed above water table on west side.
	July to Sep 78	34 borings; deep exploration program.
	Oct 78	Excavated 10 ft around well area and backfilled with 257 yds of fillcrete.
	Oct 78 to Feb 79	142 borings; exploration/grouting program.
	Mar 79	Excavation of fill area adjacent to auxiliary building and backfilled with 192 cu yds of fillcrete, well demobilized.
8	Apr 77	Initially decommissioned by backfilling with sand inside 14-in. casing.
	Aug to Nov 77	Airlift to clean inside 14-in. casing and the gravel pack in the annulus. 42-in. CMP access casing placed to a depth of 15 ft. 142 ft of 14-in. casing removed.
	Sep 77	39 exploration borings.
	Oct to Nov 77	Gravity grout of cavity previously emptied by air-lifting through exploration borings, pressure grouting of area below concrete, drive 20-in. casing to 120 ft.
	Dec 77 to Mar 78	27 exploration borings.
	Feb 78	Airlift to attempt to clean remainder of well; mechanical caliper measurements; and, 2 TV logs.
	Mar 78	Gravity grouting of cavity previously emptied by airlifting.

Well No.	Date	Exploration/Demobilization Work Completed
	Mar to Jul 78	Construction excavation made to Elev. +7 ft for Electrical Tunnel, 19 borings, deep exploration program.
	May to Aug 78	Backfill 20-in. casing with sand, 108 borings, shallow exploration/grouting program. Well demobilized.
9	July to Aug 77	Series of TV logs. Airlift 46 ft of material in casing and gravel pack from the annulus. 196 ft of casing removed. Mechanical caliper survey and well demobilized by gravity grouting.
10	July 77	TV log inside 14-in. casing to 196 ft.
	May 78	Wire brush 14-in. casing and TV log to 197 ft.
	Nov to Dec 78	7 exploration borings and crosshole seismic survey
	Jan 79	Well demobilized by filling the well casing with gravel, sand, and concrete.
11	July 77	TV log inside 14-in. casing. No further investigation work done. Well outside plant area.
12	------	No investigation work done. Well outside plant area.

TABLE 3

SUMMARY OF WELL MAINTENANCE

Well No.	Date Well Pumping Stopped[1]	Total Operating Days[2]	Maintenance Rating[3]	Remarks
1	02 Nov 1977	950	Average	
2	10 Nov 1976	735	High	
3	19 Jan 1977	710	Very low	
3A	N/A	N/A	N/A	Test well only operated a few days
4	29 Jun 1976	620	Very low	
5	15 May 1976	625	High	
6	04 Jun 1976	545	High	
7	12 Aug 1976	565	Very high	About 7 months after start up the well filled with sand to about 100 ft and was bailed. A new 10-in. well casing was inserted to allow continued operation of the well.
8	05 Jun 1976	650	High	
9	29 Nov 1975	475	High	
10	14 Feb 1978	1175	Low	
11	24 Mar 1977	950	Average	
12	14 Feb 1978	1285	Low	

Notes:

1. It is assumed that all wells began pumping on 1 August 1974 and pumped intermittently through to this date.

2. Total number of operating days obtained from daily logs by adding the number of days the well was in operation beginning on 1 August 1974 through to date the well was finally stopped (Note 1 above). Because this is only a rough estimate, the number of days have been rounded to the nearest five.

3. A subjective, normalized rating based on a review of the maintenance records for the well. The rating is normalized with respect to the average level of maintenance for all wells.

TABLE 4
SUMMARY OF MEASUREMENTS FOR WELLS 1, 2, AND 9

Well	Condition of Well Casing[1]	Calculated Diameter of Well (Inches)		
		Mechanical Caliper[2]	Volume of Material Airlifted[3]	Volume of Gravity Grout Placed[4]
1	Moderately to very heavily encrusted. No corrosion holes.	34.6	35.0	35.0
2	Very heavily encrusted throughout. One corrosion hole, approximately 1 in. x 2 in. at 115 ft.	33.1	33.4	34.0
9	Heavily encrusted throughout. No significant corrosion or enlargement of louvers.	32.8	32.8	33.2

NOTES:

[1]Based on TV inspection of well casing in-place and direct inspection upon removal.

[2]This calculated diameter represents the average diameter based on direct mechanical caliper measurements, see Table B-4.

[3]This calculated diameter represents the average diameter based on a calculation using the depth of the well and the volume of material removed from the annular space between the well casing and the side of the wellbore plus the volume accomodated by the well casing, see Table B-1.

[4]This calculated diameter represents the average diameter based on a calculation using the depth of the well and the volume of gravity grout placed to fill the wellbore, see Table C-2.

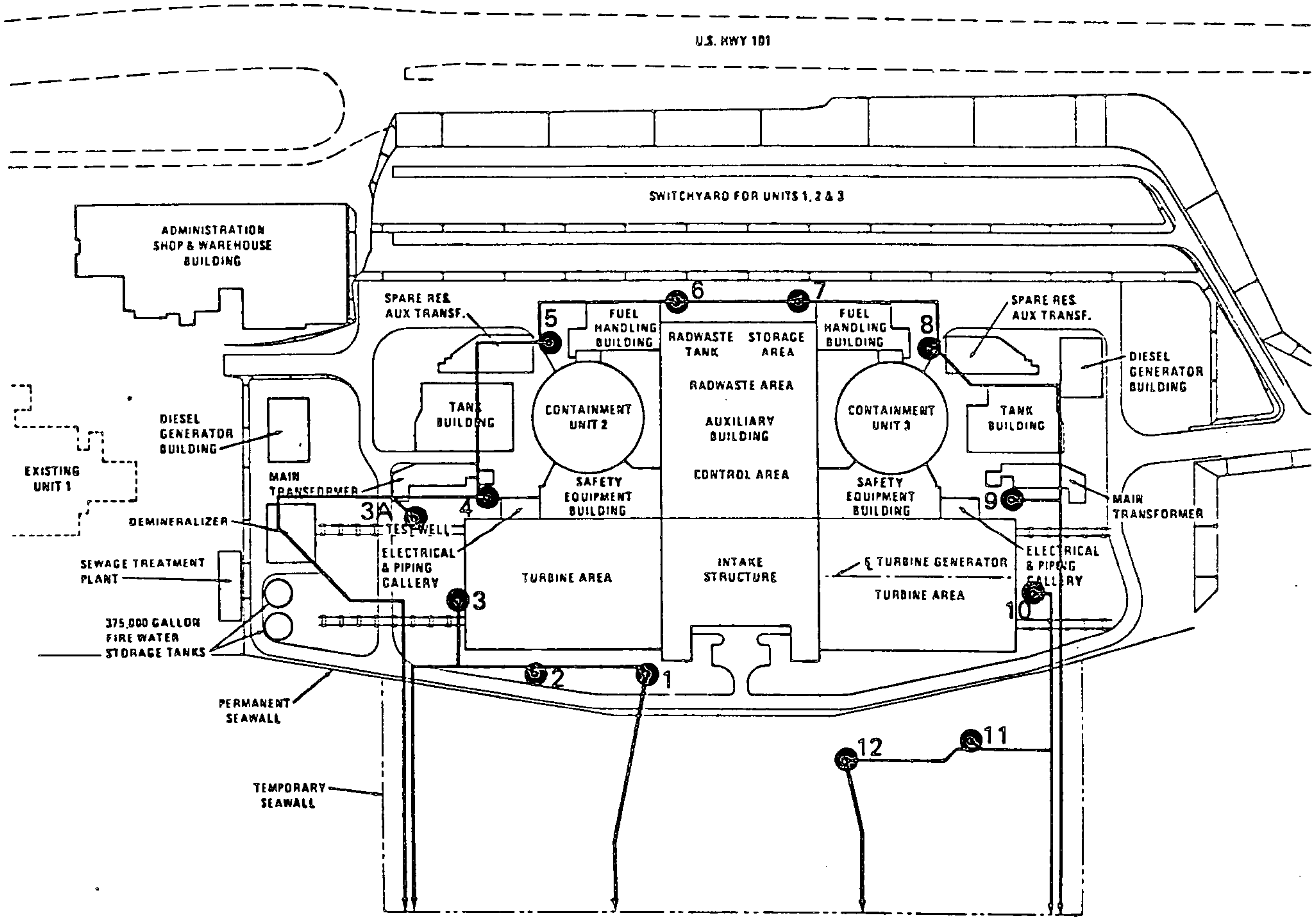
TABLE 5

SUMMARY OF MAXIMUM EFFECTS OF CAVITIES ON STRUCTURES

Structure	Well No.	Maximum Decrease of Dynamic Stiffness* (percent)		Maximum Increase in Settlement of Structure (percent)	
		Translation	Rocking	Total Vertical	Differential
Containment Unit 3	8	4	5	4	5
Auxiliary Units 2 and 3	6,7	2	2	2	2
Fuel Handling Unit 2	6	<1	3	<1	3
Fuel Handling Unit 3	7,8	<1	8	<1	8

* Affecting dynamic response of the structure during earthquake shaking.

SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 & 3
PLOT PLAN



Project: SONGS 2 & 3 Project No. 411301	PLOT PLAN SHOWING LOCATION OF DEWATERING WELLS	Fig. 1

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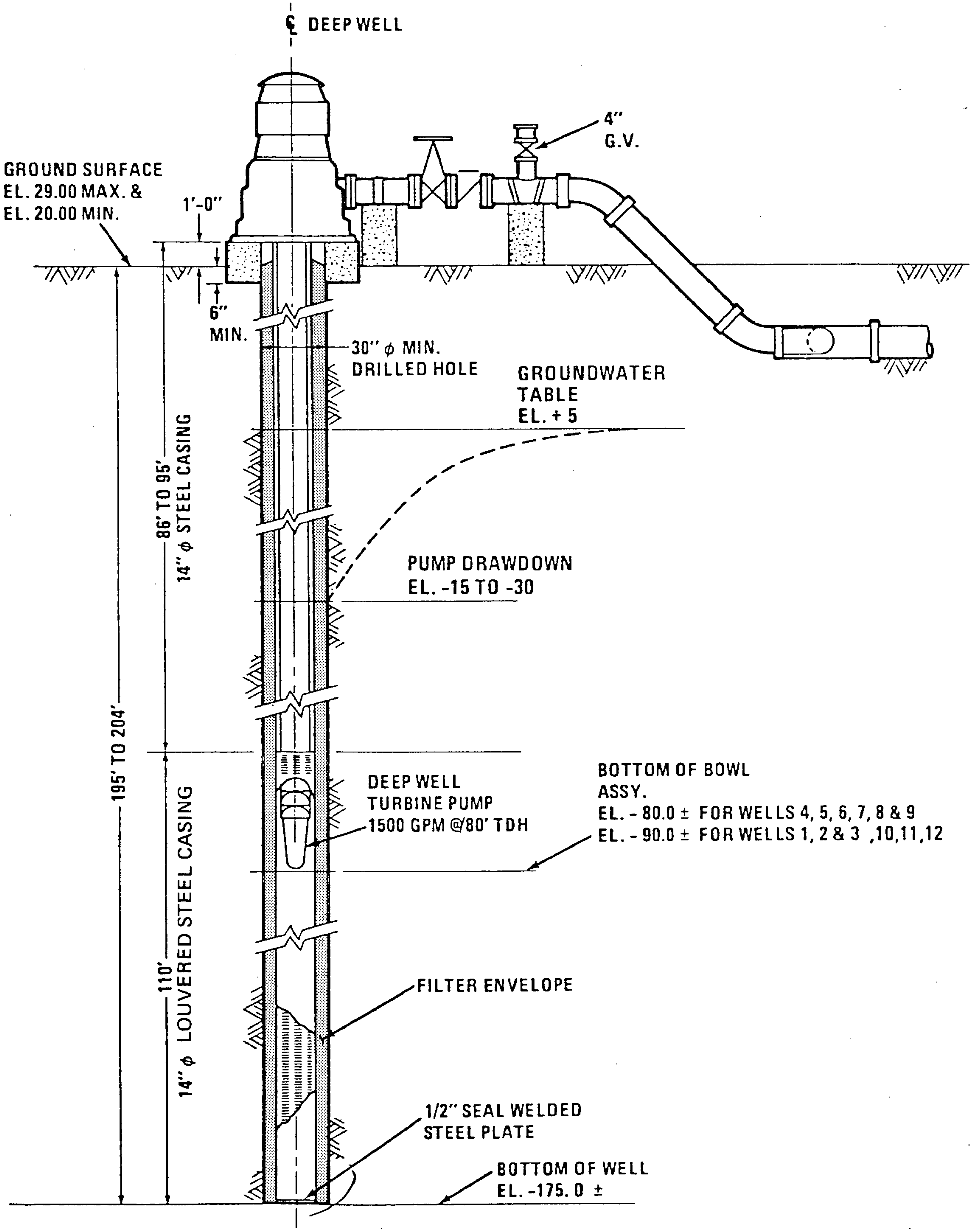

Project: SONGS 2 & 3 Project No. 41130I	TYPICAL SECTION; 30-INCH DIAMETER DEEP WELL	Fig. 2

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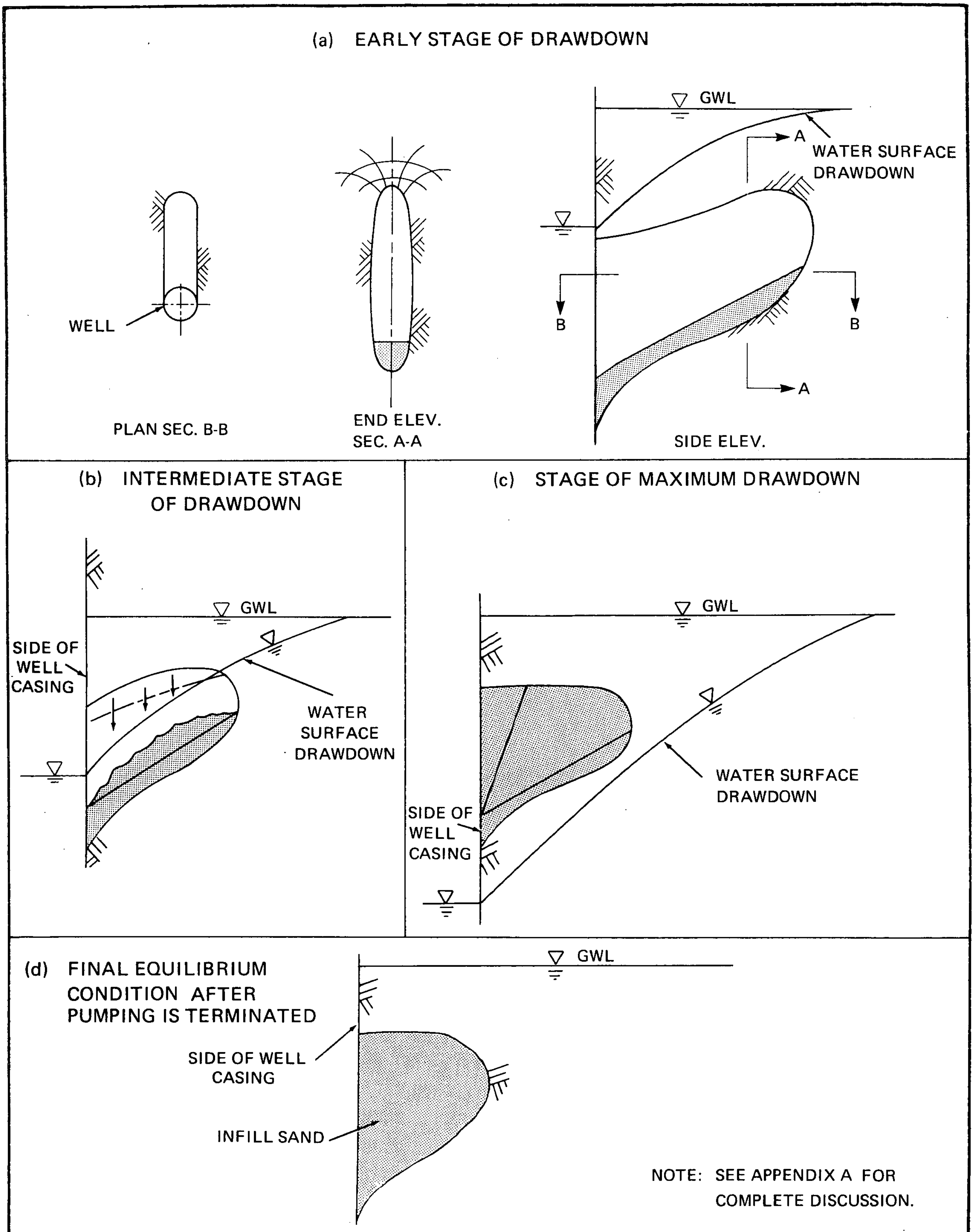

Project:	SONGS 2 & 3	LIKELY CONFIGURATION OF CAVITY	Fig.
Project No.	411301		3

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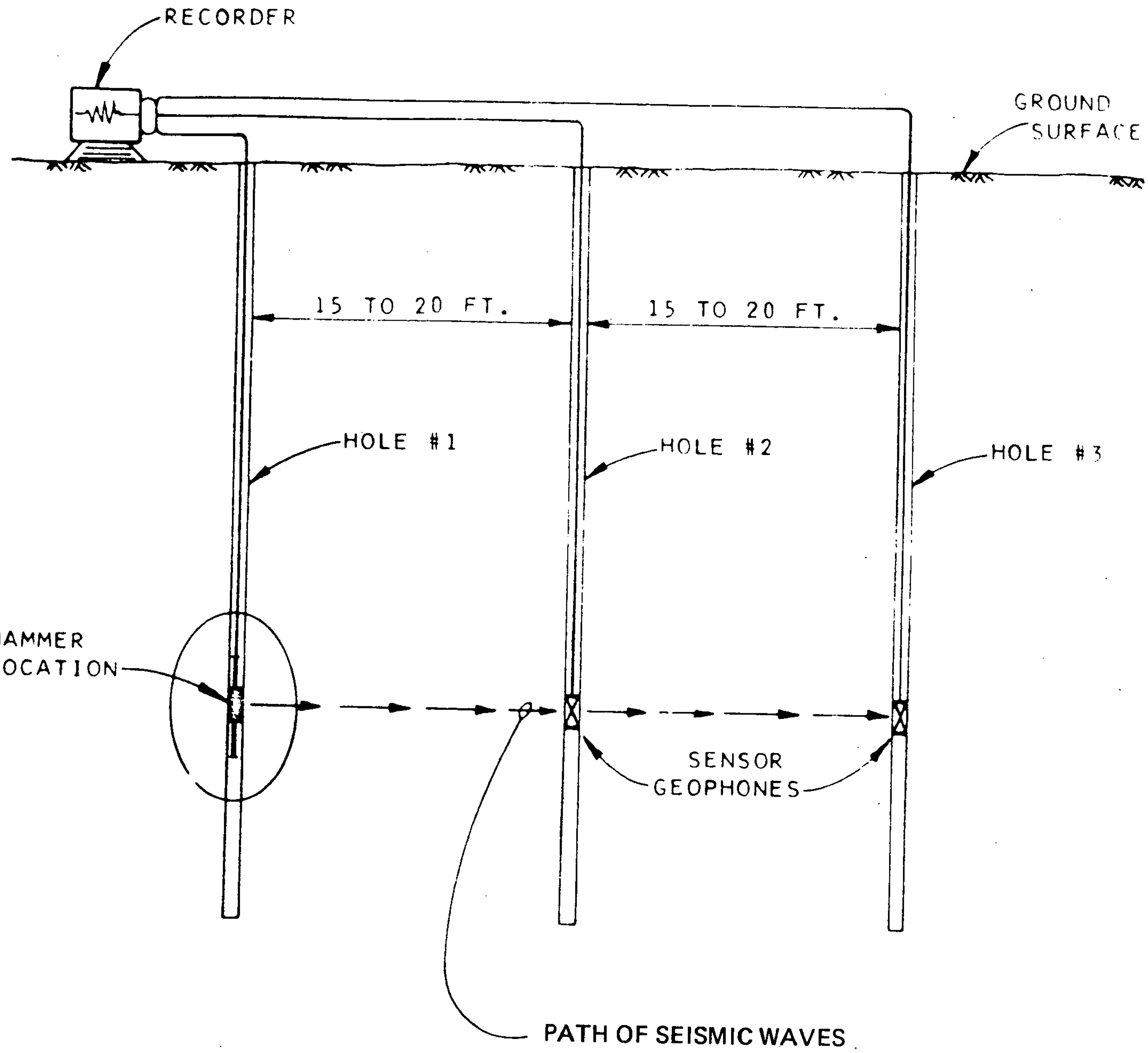

Project:	SONGS 2 & 3	ARRANGEMENT OF INSTRUMENTS FOR CROSSHOLE SURVEY	Fig. 4
Project No.	411301		

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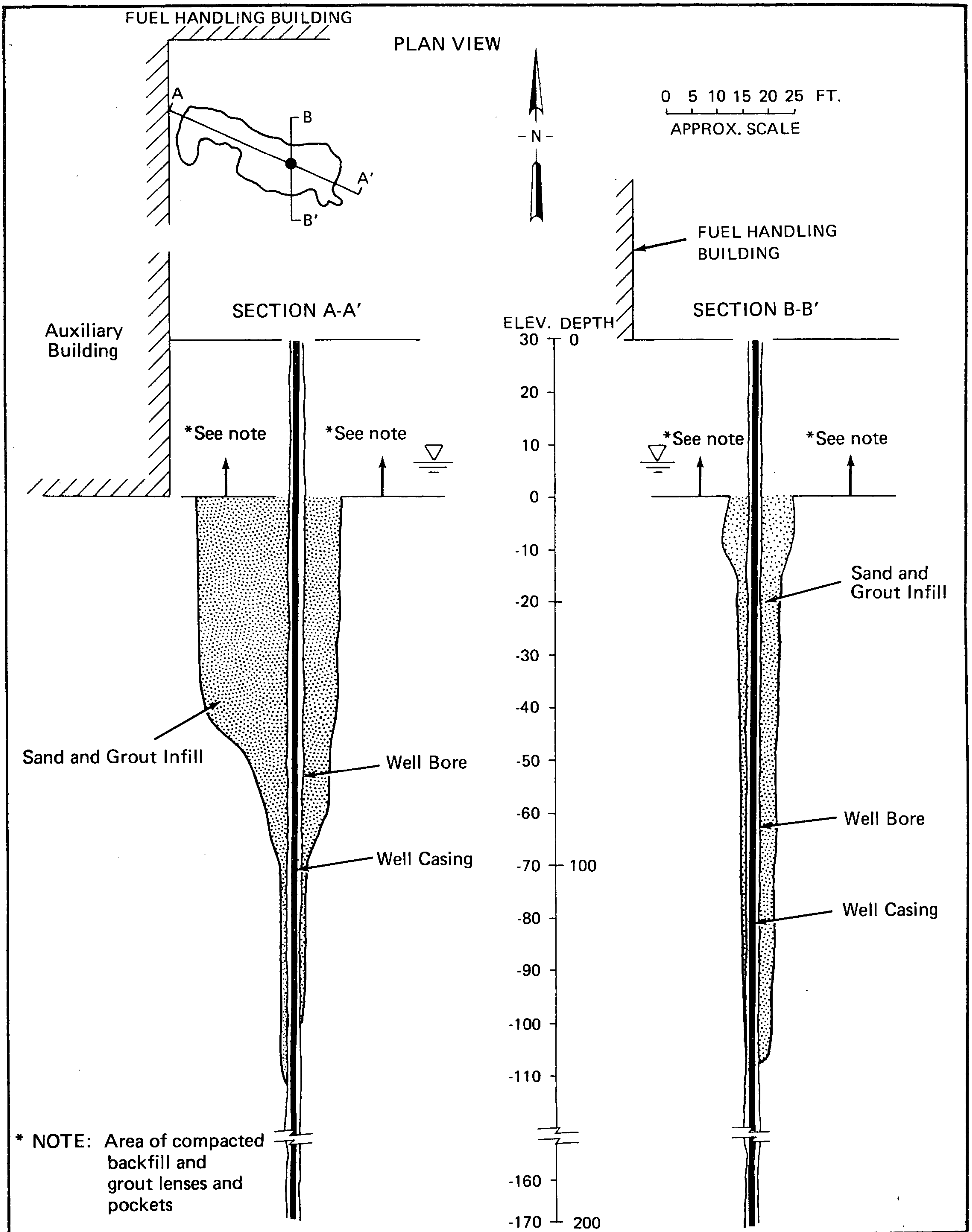

Project: SONGS 2 & 3 Project No. 411301	PLAN AND SECTION VIEWS OF WELL NO. 6	Fig. 5

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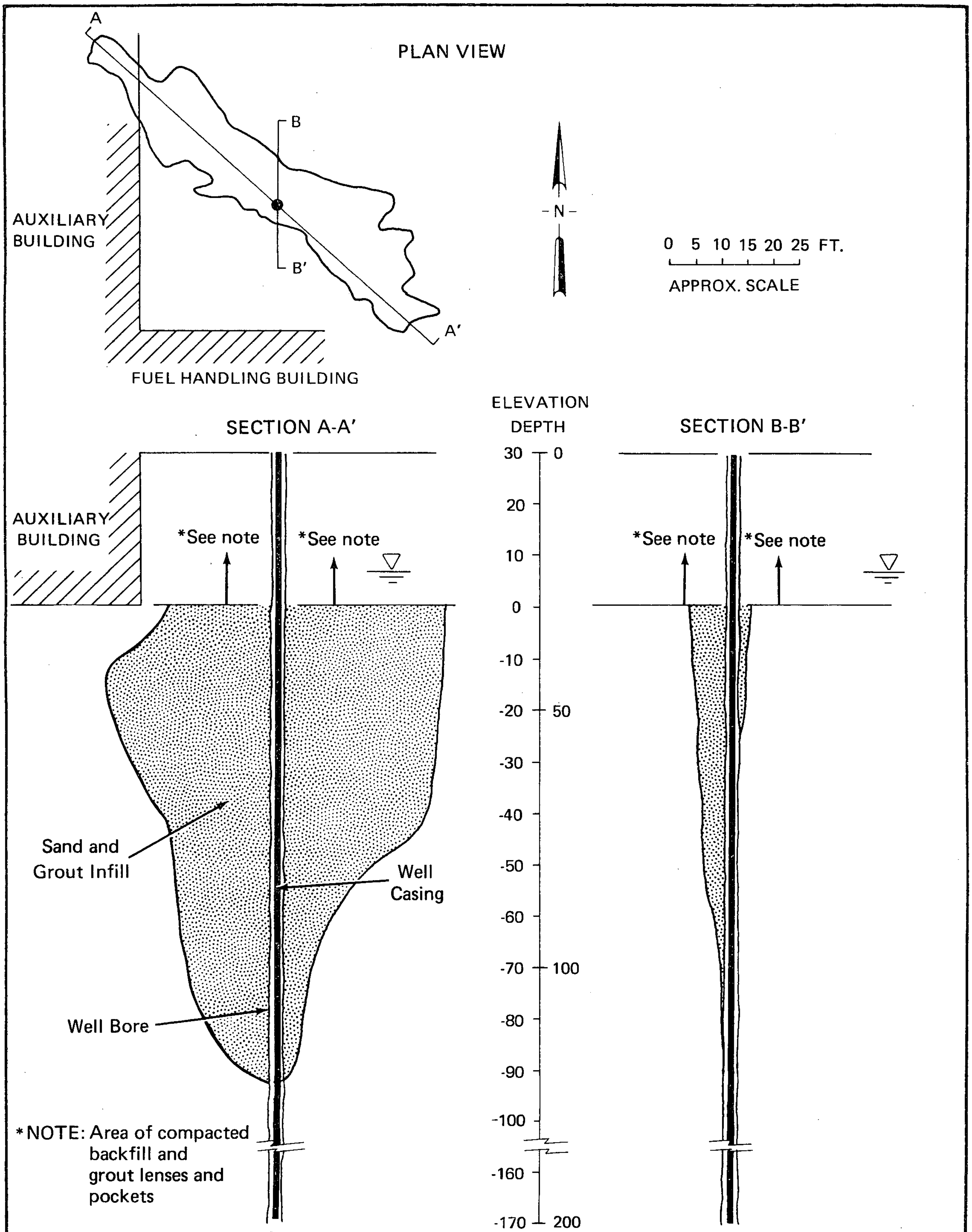

Project:	SONGS 2 & 3	PLAN AND SECTION VIEWS OF WELL NO. 7	Fig.
Project No.	411301		6

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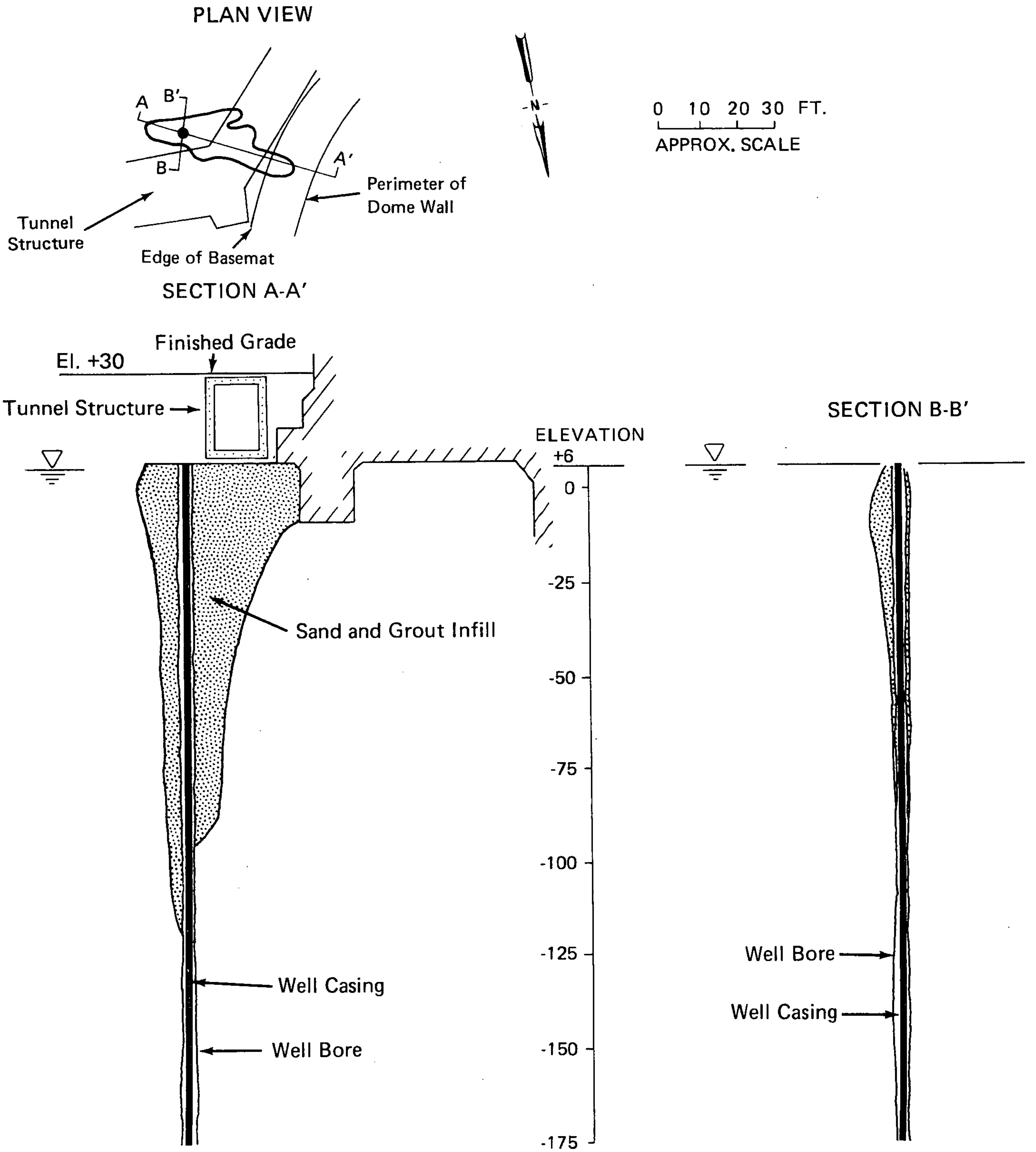
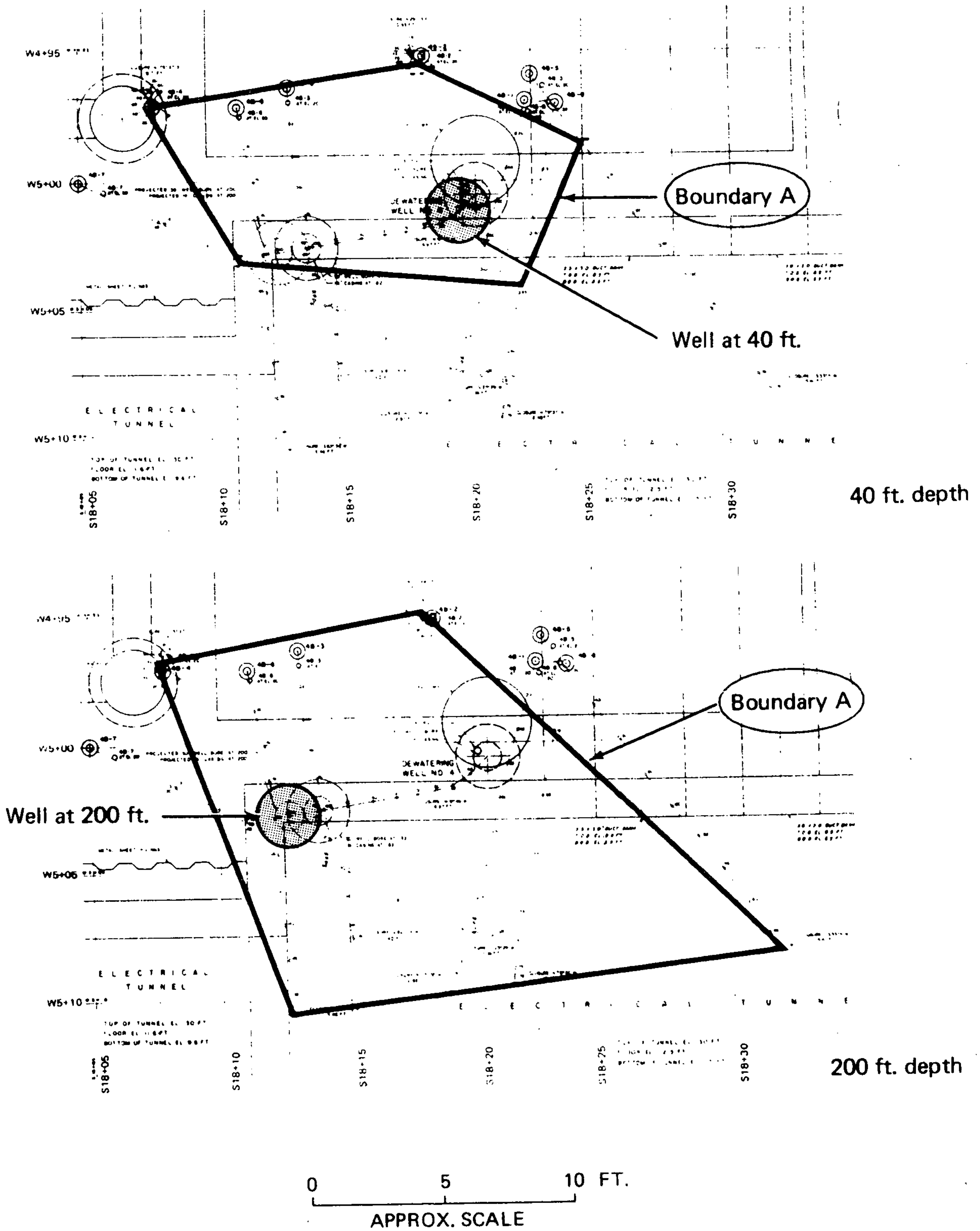


Project:	SONGS 2 & 3	PLAN AND SECTION VIEW OF THE WELL NO. 8 CAVITY	Fig. 7
Project No.	41130I		

WOODWARD – CLYDE CONSULTANTS



Project:	SONGS 2 & 3	DEWATERING WELL NO. 4	Fig.
Project No.	411301	CAVITY BOUNDARY PLAN AT 40 AND 200 FT.	8

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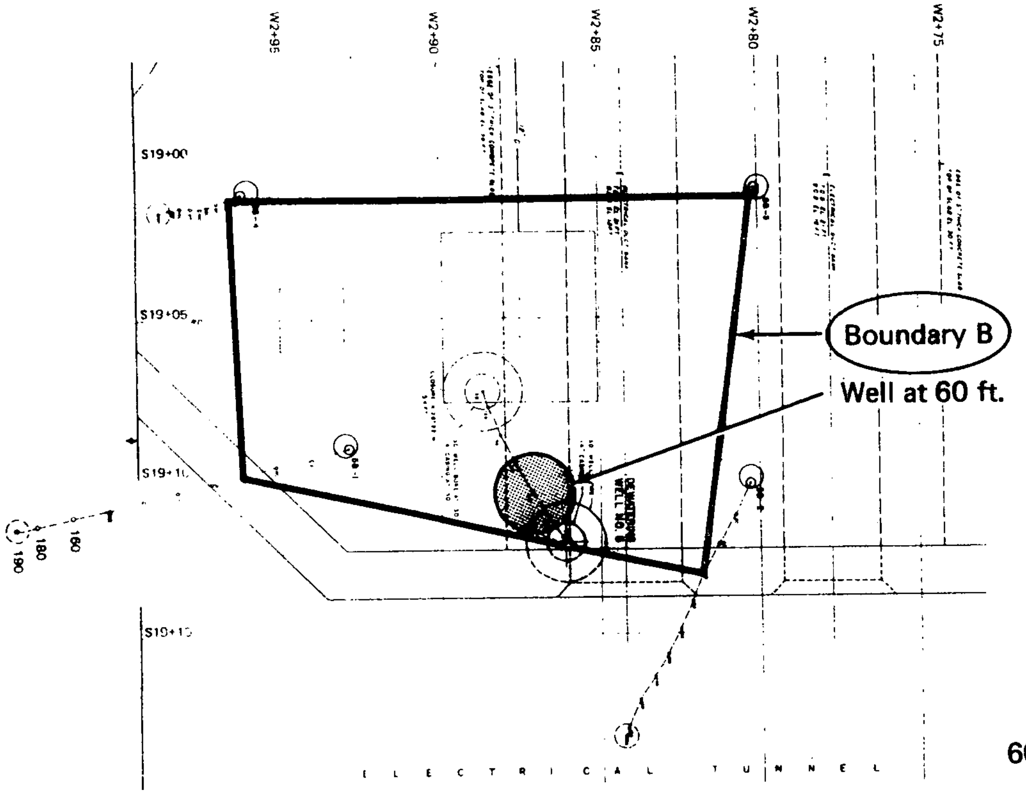
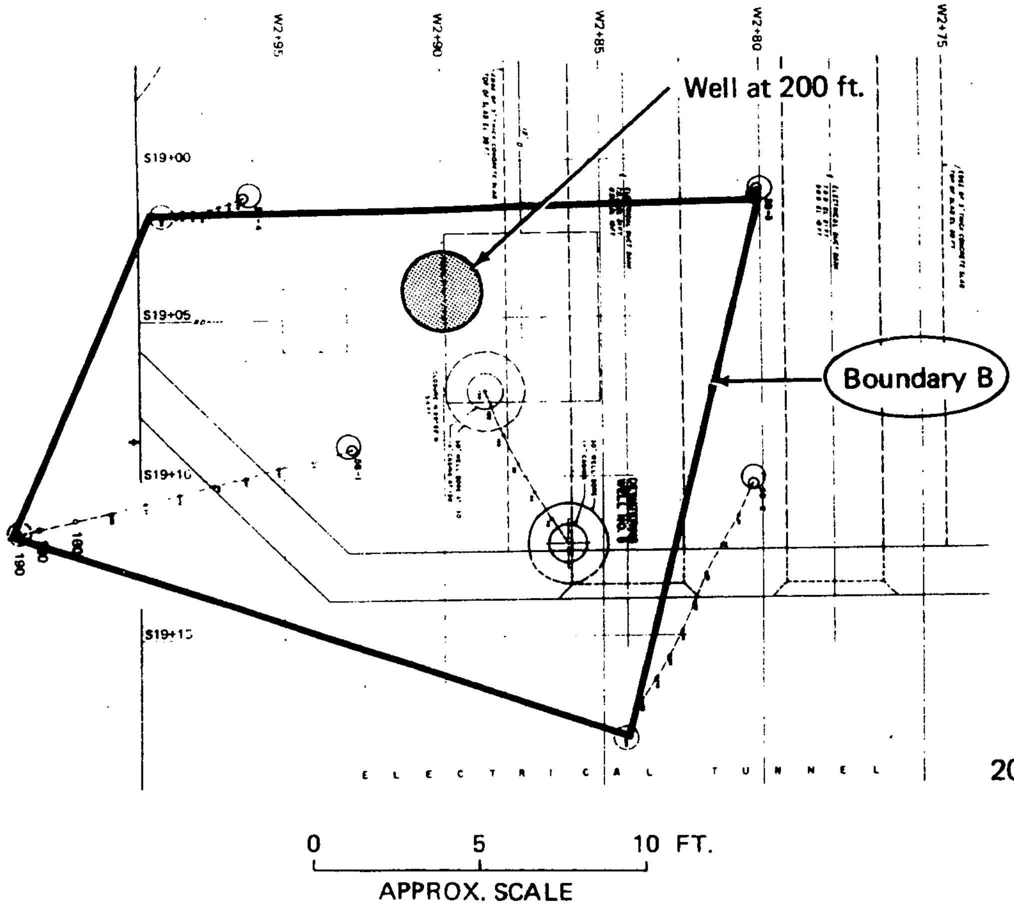


60 ft. depth



200 ft. depth

Project:	SONGS 2 & 3	DEWATERING WELL NO. 5	Fig.
Project No.	411301	CAVITY BOUNDARY PLAN AT 60 AND 200 FT.	9

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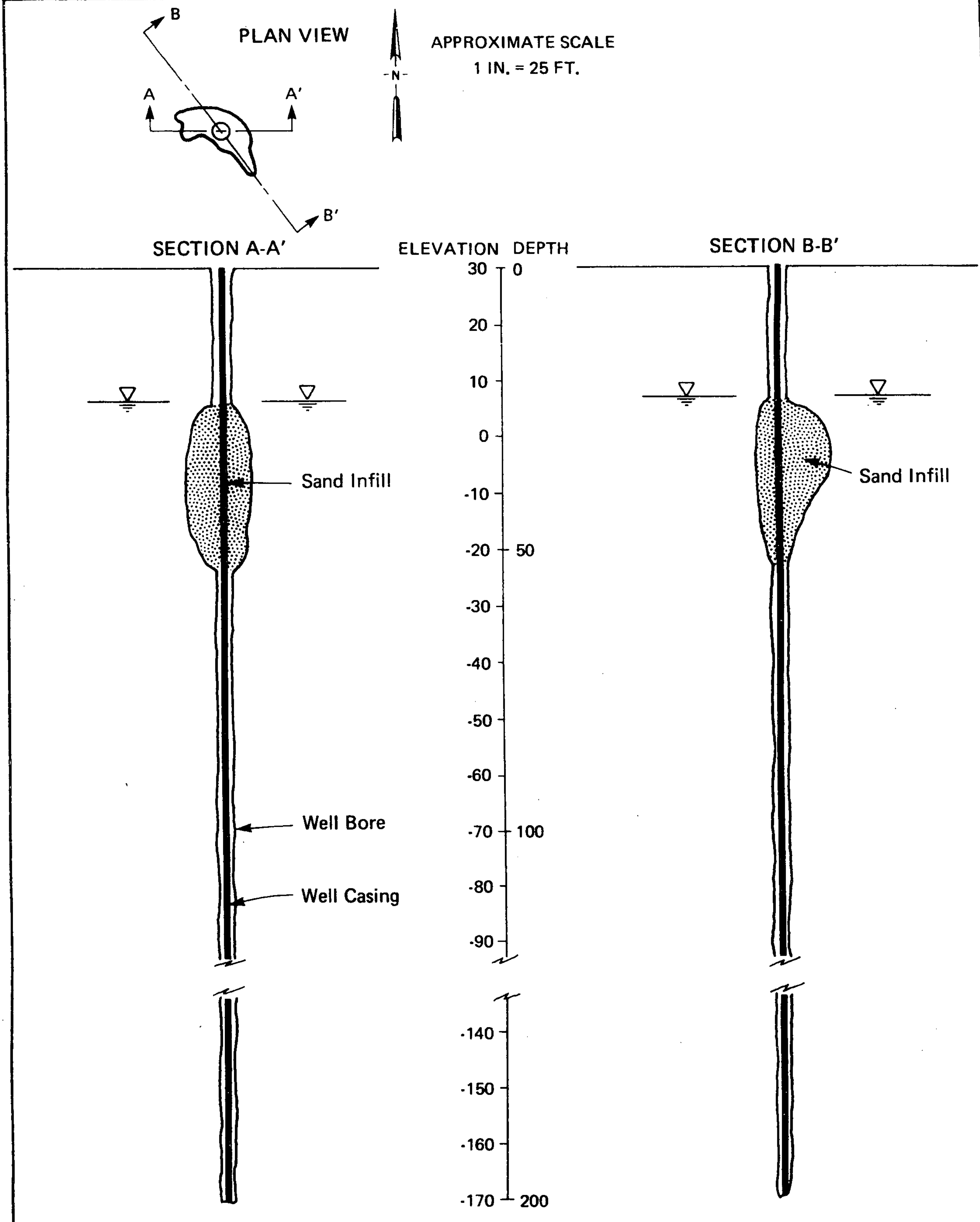

Project: SONGS 2 & 3 Project No. 411301	PLAN AND SECTION VIEWS OF WELL NO. 3	Fig. 10

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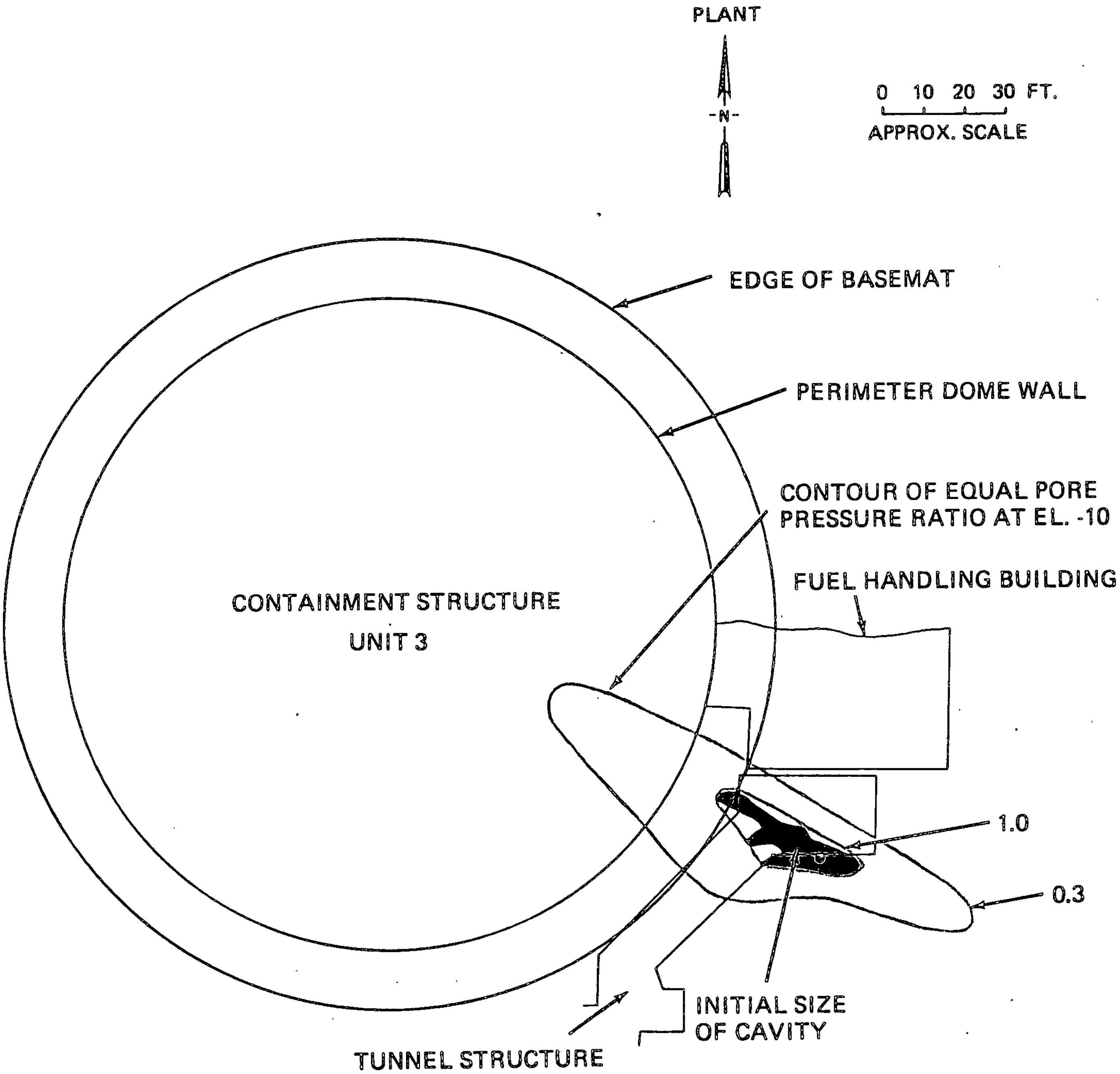

Project:	SONGS 2 & 3	PLAN SECTION OF CAVITY AND PORE PRESSURE RATIOS = 0.3 AND 1.0 AT ELEVATION -10 FEET FOR WELL 8	Fig. 11
Project No.	411301		

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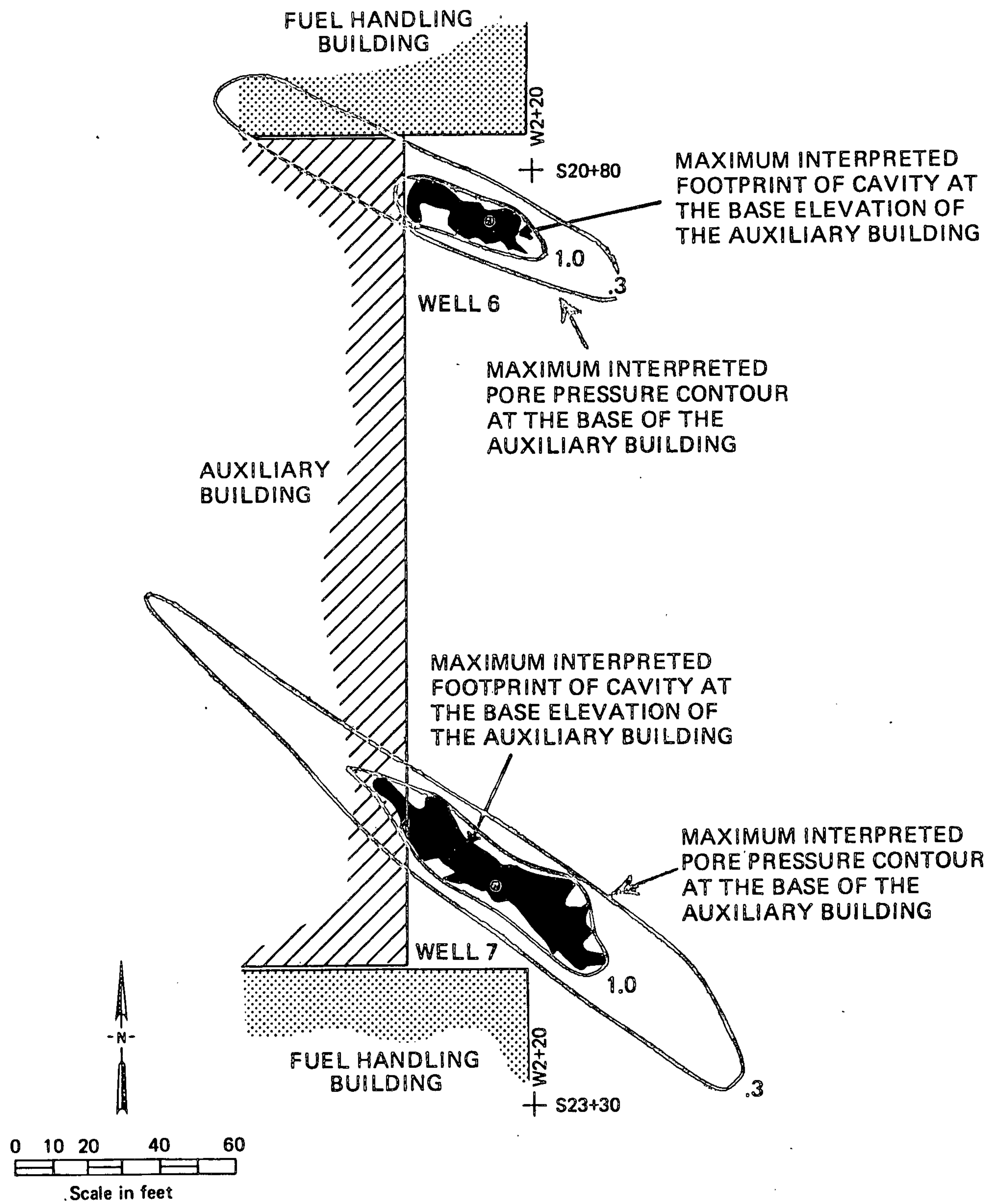

Project:	SONGS 2 & 3	PLAN SECTION OF CAVITY AND PORE PRESSURE RATIOS = 0.3 AND 1.0 AT ELEVATION 0 FEET. FOR WELLS 6 AND 7	Fig. 12
Project No.	411301		

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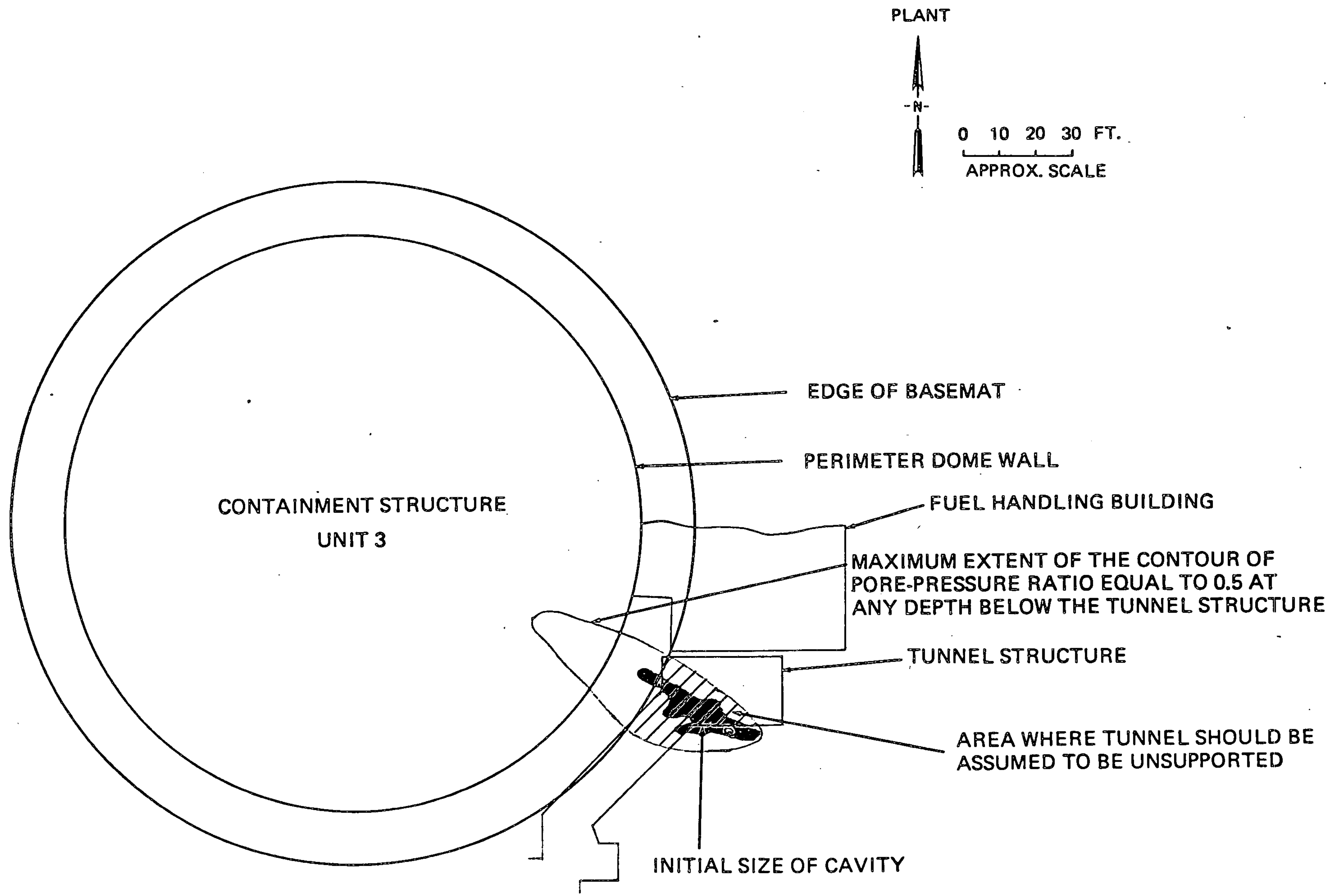

Project:	SONGS 2 & 3	MAXIMUM INTERPRETED EFFECT OF THE CAVITY ON THE TUNNEL STRUCTURE	Fig.
Project No.	411301		13

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APPENDIX A

Mechanisms Of Cavity Formation

APPENDIX A
MECHANISMS OF CAVITY FORMATION

A-1 INTRODUCTION

The extent, size, and configuration of the cavities have been determined, and are presented in the text of this report. This appendix has been prepared to summarize the likely mechanisms of the formation of the cavities. The sections that follow discuss the mechanisms and present the results of piping tests performed in the laboratory.

A-2 DISCUSSION OF THE MECHANISM OF CAVITY FORMATION

The dewatering wells were designed to prevent subsurface erosion, if all components of the well remained intact: the louvers were sized to retain the filter gravel; and, the filter gravel was adequately graded to retain the native sand. It therefore appears likely that, for some of the wells, the components did not remain intact. The key component is the filter gravel: test data presented in Appendix D show that if the gravel were present and intact, erosion of the native sand would not occur. The filter gravel could be missing due to the following three causes: (1) arching in the annulus between the casing and the wellbore during placement of the gravel; (2) compaction and settlement of the gravel under the hydraulic gradient of the pumping; and/or (3) removal of the casing through corrosion. There are no records available to evaluate the likelihood of causes (1) and (2). Some of the casings on the landward side of the site were found to be corroded when inspected by television or when pulled from the ground. It is possible that a seawater/freshwater interface could have caused corrosion of some of the casings, or that galvanic current could have been generated by the dissimilar casing and weld metals (the welds on the recovered casing on the landward side were seriously corroded). Though the largest cavities were encountered at well locations where casing corrosion was significant (Wells 6, 7 and 8), a small cavity was also found at Well 3 where the well casing was found to be relatively unaffected by corrosion, indicating that causes (1) and/or (2) may have been contributory to the forming of a cavity at this well. Thus it is not possible to state definitively which of causes (1), (2) or (3), or what combination of them, may be responsible for the absence of the gravel. The discussion that follows describes a mechanism consistent with site conditions and the laboratory piping tests discussed in Section A-3.

The flow field around a well is sketched in Figure A-1, along with some approximate dimensions for these wells. The flow net shown depicts the intensity of the hydraulic gradient: where the mesh is closely spaced, the hydraulic gradient is expected to be high. The gradient could also be locally high in the uniform flow zone if there is a perturbation in the smooth wall of the well, as shown in Figure A-2: the flow line can concentrate at the peturbation, to cause a locally high gradient. If that local gradient is sufficiently high, and if the filter gravel is absent, then erosion can start at the perturbation, and propagate from that point, as shown on Figure A-3.

It is expected that the erosion feature of Figure A-3 will propagate until the gradient at the end, point a, diminishes to less than the value which will erode the soil in question. For the native sands, which have cohesion due to their gradation and efficient packing, the gradient which will erode them is probably much greater than for truly cohesionless sands. This is supported by the observation that the native sands stand in near-vertical cliffs 100 ft high and vertical cuts have been noted to stand vertically underwater. Thus, subsurface erosion features in the native sand are expected to have a limiting stable size. The erosion feature is not, however, expected to propagate as a cylinder. Instead, because the gradient in the roof of the hole (e.g., point b), can also exceed the critical gradient, the roof is expected also to erode. The infill sand will probably be partially removed by erosion in the absence of a gravel filter, leaving a sloping wedge of infill sand within the erosion feature, as shown in the upper left sketch of Figure A-4. Because the permeabilities of the native and the infill sands are not grossly dissimilar (permeability of infill sand is about 0.1 cm/sec compared to 0.015 cm/sec for the native sand; see Appendix D), the flow for this condition can be estimated from the rough sketch presented in the upper-right of Figure A-4; This flow is expected to lead to further erosion at the end and upper part of the erosion hole until it reaches a size such that the gradient at that eroding end is less than the critical gradient. This then is the hypothesized configuration of the erosion cavities likely to develop adjacent to dewatering wells in sand.

Based on these considerations, it is expected that the cavities formed will be rather lobate, as shown in the lower-right sketch of Figure A-4, and they will have a finite stable size. Similar considerations also lead to the expectation that the cavities would be tabular in the vertical direction. The effect described would be expected to be most severe in the upper drawdown zone, where the gradients are likely to be most severe (see Figure A-5). In addition, in the drawdown zone, the cavity is subjected to wetting and dewatering as the well goes through pumping cycles. The effect of this is to further pull down the roof, accentuating the effects described above. Because the native San Mateo sand is very dense (mean dry density of 123 pcf) and because the infill sand will achieve a lower density (estimated maximum dry density of 105 pcf consistent with a relative density of between 50 and 60%), it is expected that 15 to 20% bulking will be associated with the above described phenomenon. Therefore, it is expected that the stabilized cavity will be full or nearly full of infill sand. This expectation has been corroborated by observations during the field investigations.

Some of the cavity sand is removed during pumping. Because the louvered section starts at about Elev. -60 ft and the most likely location of cavity formation is in the drawdown zone, the cavity should develop a funnel-shape at the base, as shown in Figure A-5. The cavity, therefore, is expected narrow to about the well diameter below the drawdown zone where gradients become small.

A-3 PIPING TEST RESULTS

To simulate the initiation and progression of piping in San Mateo sand, laboratory tests were conducted on a hand-carved block sample of San Mateo sand. Two oblong thumb-like cavities were created in the sample by using a minute air nozzle to blow the sand from the block at the desired locations. One of the cavities was located near the center of the sample and the other at one edge of the sample. The sample, with a layer of glass beads at the inlet and outlet ends, was cast in resin inside a lucite cylinder to provide confinement and to prevent disintegration during saturation. Penetration of the resin was prevented by a cellophane wrap around the sample.

A photograph of the laboratory setup and a sketch describing the apparatus is presented in Figure A-6. Because the resin, the glass beads, and the lucite containers are all transparent, the laboratory apparatus provided a visual observation of the sample throughout the test.

Three tests were run on the sample as follows:

1. The two cavities were plugged with inflated bladders to simulate San Mateo sand without cavities; the inlet water pressure was gradually increased to about 18 psi (about 35 minutes).

2. Same as (1) above, except that the inlet pressure was raised relatively quickly to about 15 psi (5 minutes).

3. The bladders were omitted; the inlet pressure was increased relatively quickly to about 12 psi (5 minutes).

The results of the three tests described above are presented in Figures A-7 and A-8. Two additional tests were run, Nos. 4 and 5, to observe the effect of partial and total removal of glass beads. The observations during these tests provided an estimate of what might happen if there were no gravel packing around the well screens.

During Test No. 1 some of the fines in the San Mateo sand appear to have been washed out: the permeability of the sample increased from 0.13 to 0.24 cm/sec. This is similar to the development stage of well pumping, when some turbidity is expected in the pumped water. The sample remained stable during Test No. 2. The bladders were removed and Test No. 3 was conducted. During this test, sand particles were seen being dislodged and transported from the cavity surface into the cavity. A slight upward progression of the cavity was noted. However, a stable mode was soon reached and the sample remained essentially the same during the remainder of the test when the inlet pressures were increased to as much as 15 psi.

To simulate the condition of pump shutdown and restarting, the laboratory sample was allowed to free-drain by decreasing the gradient and then restarting the flow. Minor but discernable amounts of sand were dislodged from the cavity walls during this hydraulic cycling process.

Next the glass beads were removed from the discharge end of the apparatus to simulate total absence of gravel pack adjacent to the dewatering well screen. Minor scaling and surface degradation was observed, but an equilibrium was reached when no further material was seen being dislodged.

The observations from the above tests lead to the following conclusions:

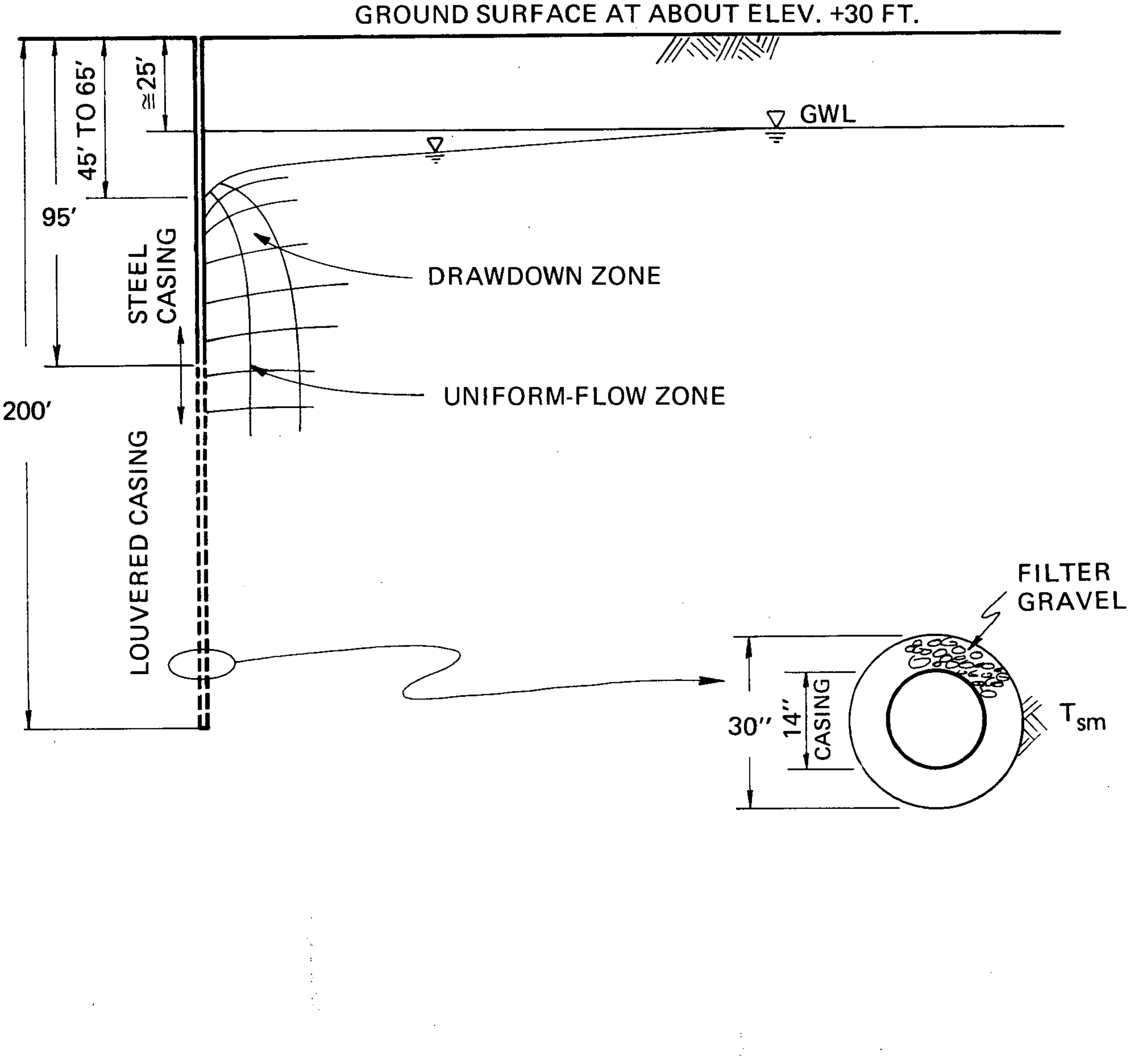
1. Cavity formation is not possible if the gravel pack is in place.

2. A trigger mechanism, such as a missing gravel pack, initiates the loss of sand and starts the cavity formation process.

3. Discernable amounts of sand are dislodged from the cavity walls during each hydraulic cycling event.

4. The simulated cavities in the laboratory always stablized and, for the flow rates and gradients applied, no contiguous pipe developed through the sample.

These results are consistent with and support the hypothesized mechanism of cavity formation described in Section A-2 above.



Project:	SONGS 2 & 3	TYPICAL DEWATERING WELL AND FLOW FIELD DURING OPERATION (SCHEMATIC)	Fig. A-1
Project No.	411301		

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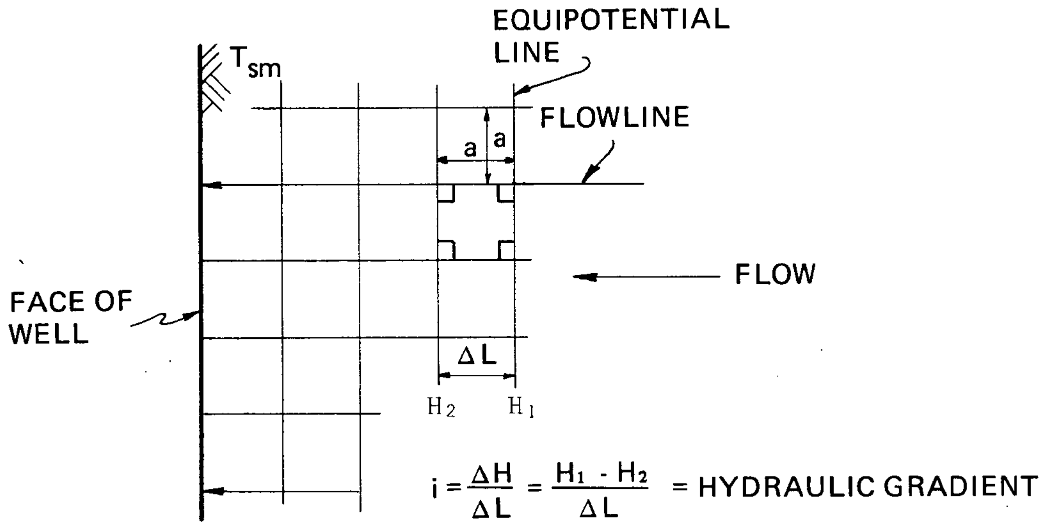
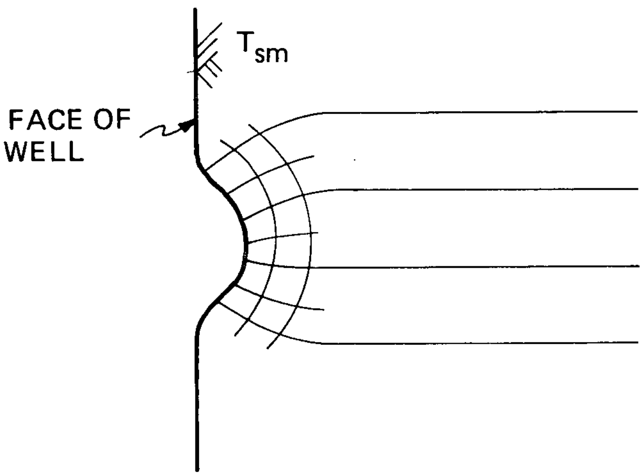


a) UNIFORM WELL FACE



b) INITIAL PERTURBATION AT WELL FACE

Project:	SONGS 2 & 3	SCHEMATIC PRESENTATION OF FLOW FIELDS AT THE WELL FACE	Fig. A-2
Project No.	411301		

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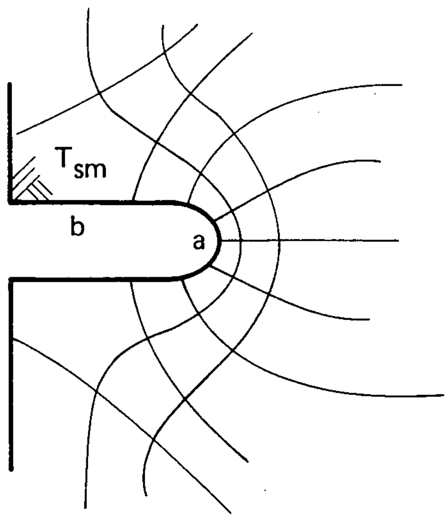
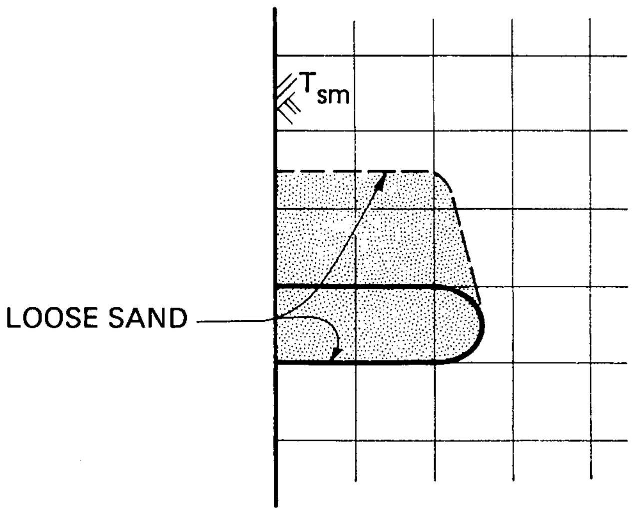


a) IDEALIZED PIPING



b) PROBABLE CAVITY FORMATION

Project:	SONGS 2 & 3	INITIAL PROGRESSION OF EROSION FEATURE	Fig.
Project No.	411301		A-3

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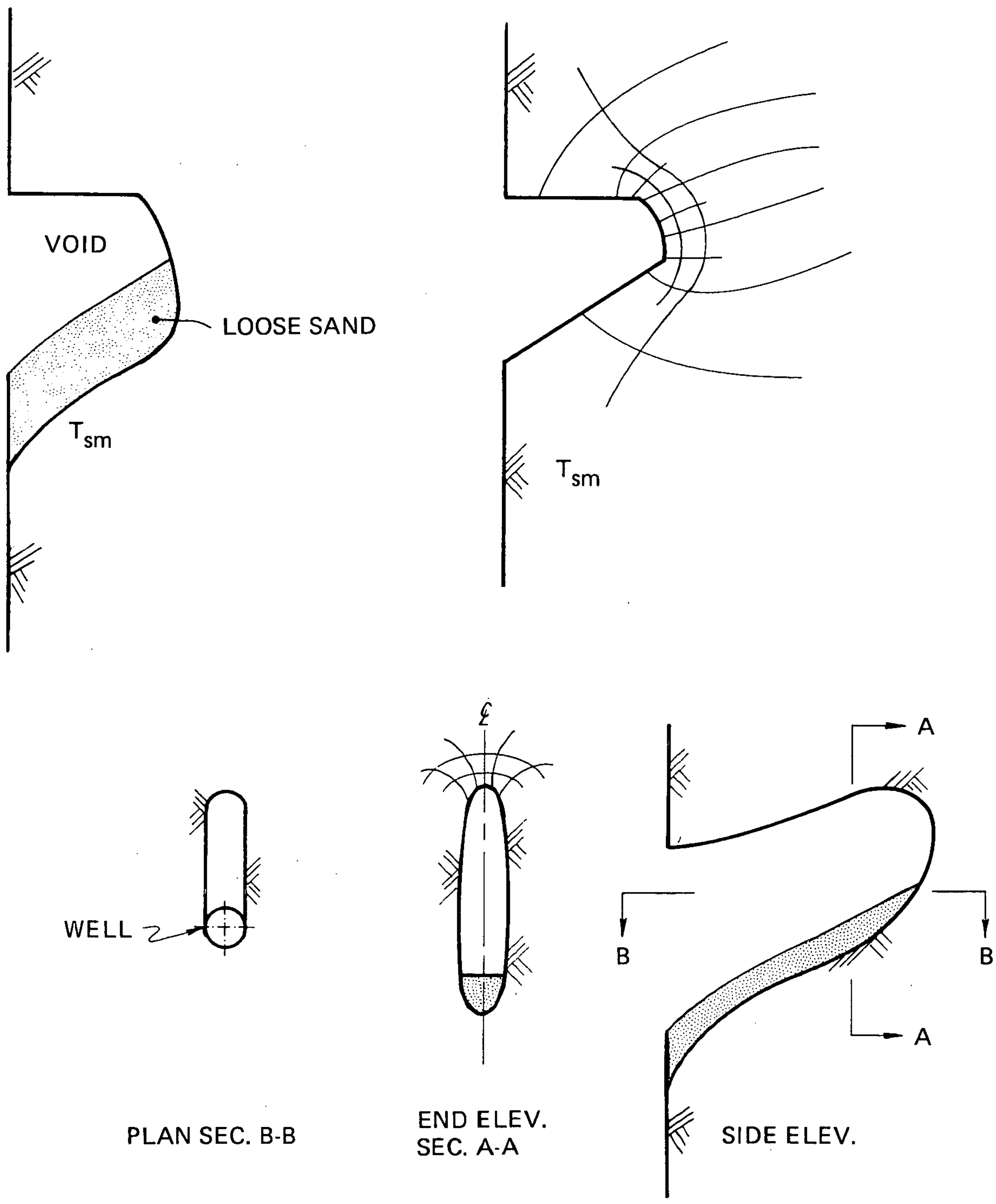

Project:	SONGS 2 & 3	LIKELY FINAL DEVELOPMENT OF EROSION FEATURE	Fig. A-4
Project No.	411301		

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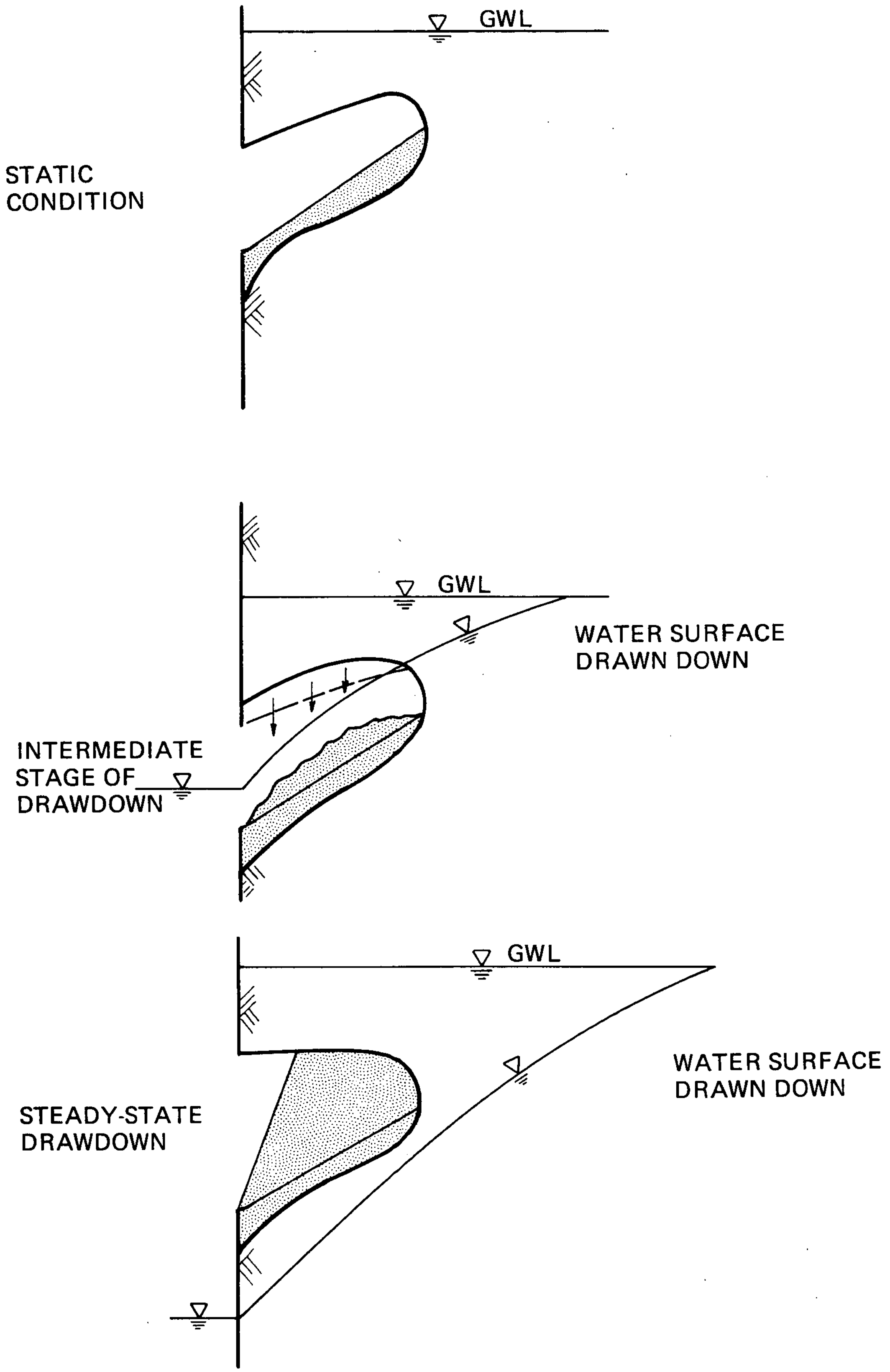

Project:	SONGS 2 & 3	LIKELY CONFIGURATION OF CAVITY	Fig.
Project No.	411301		A-5

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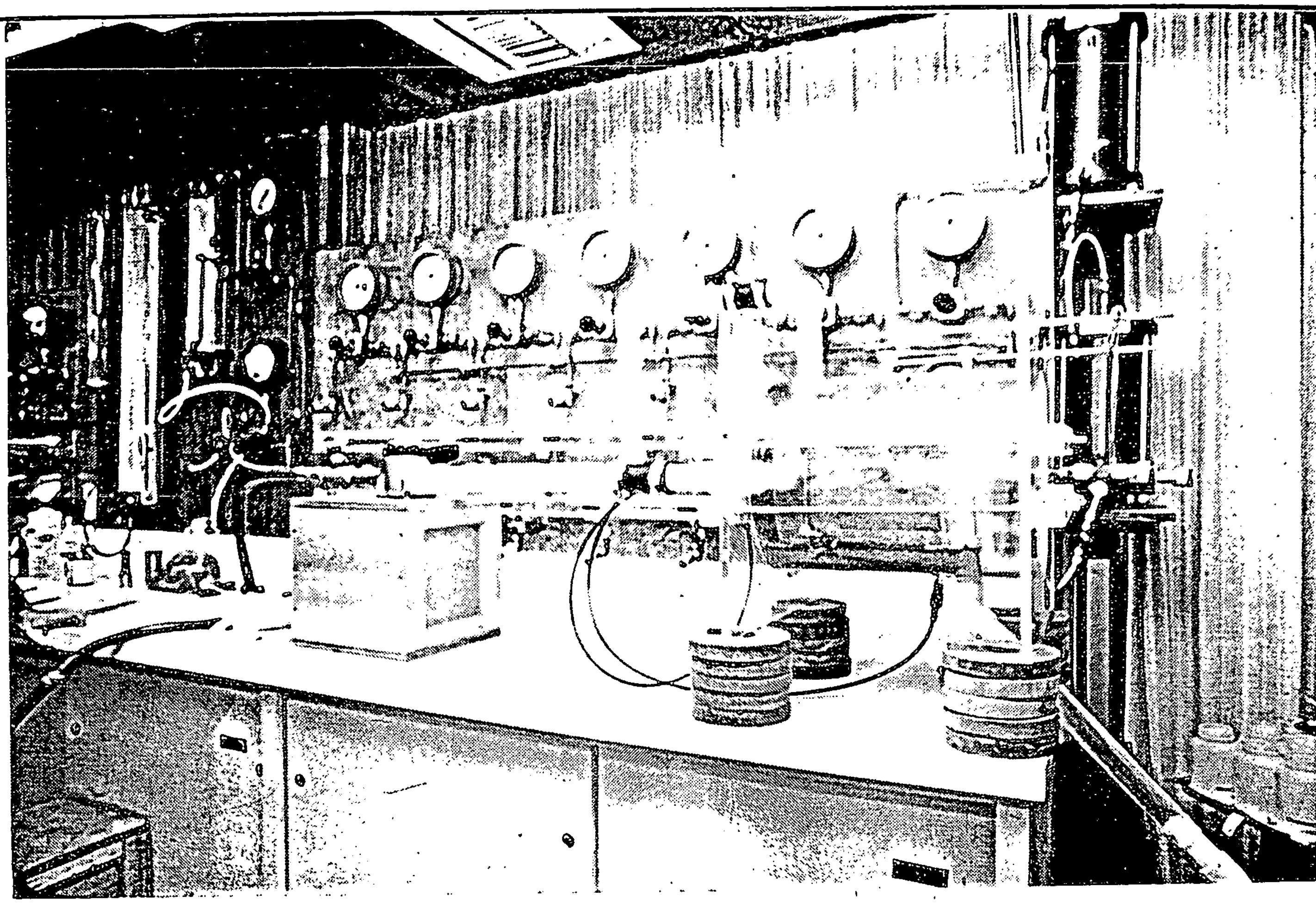
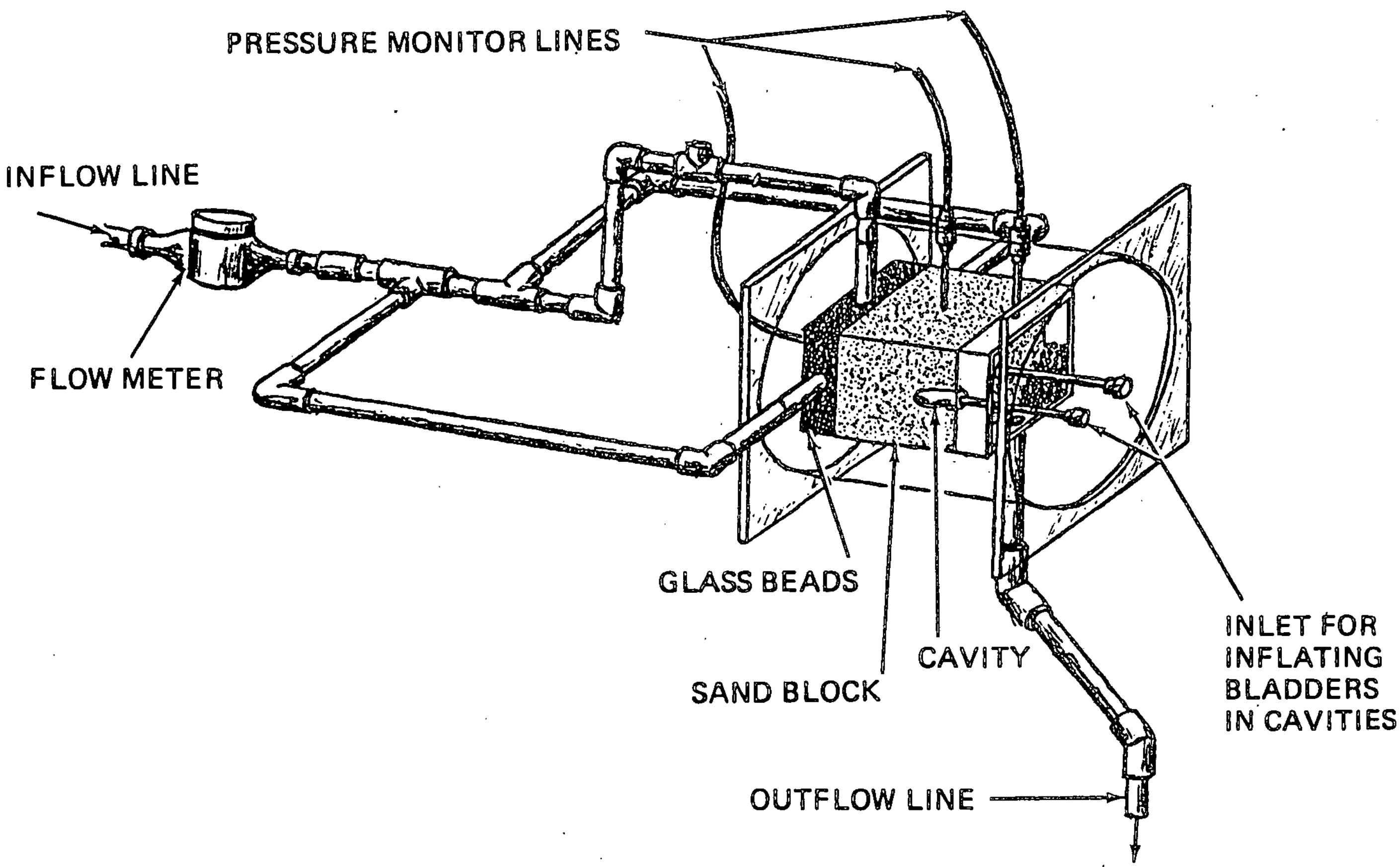
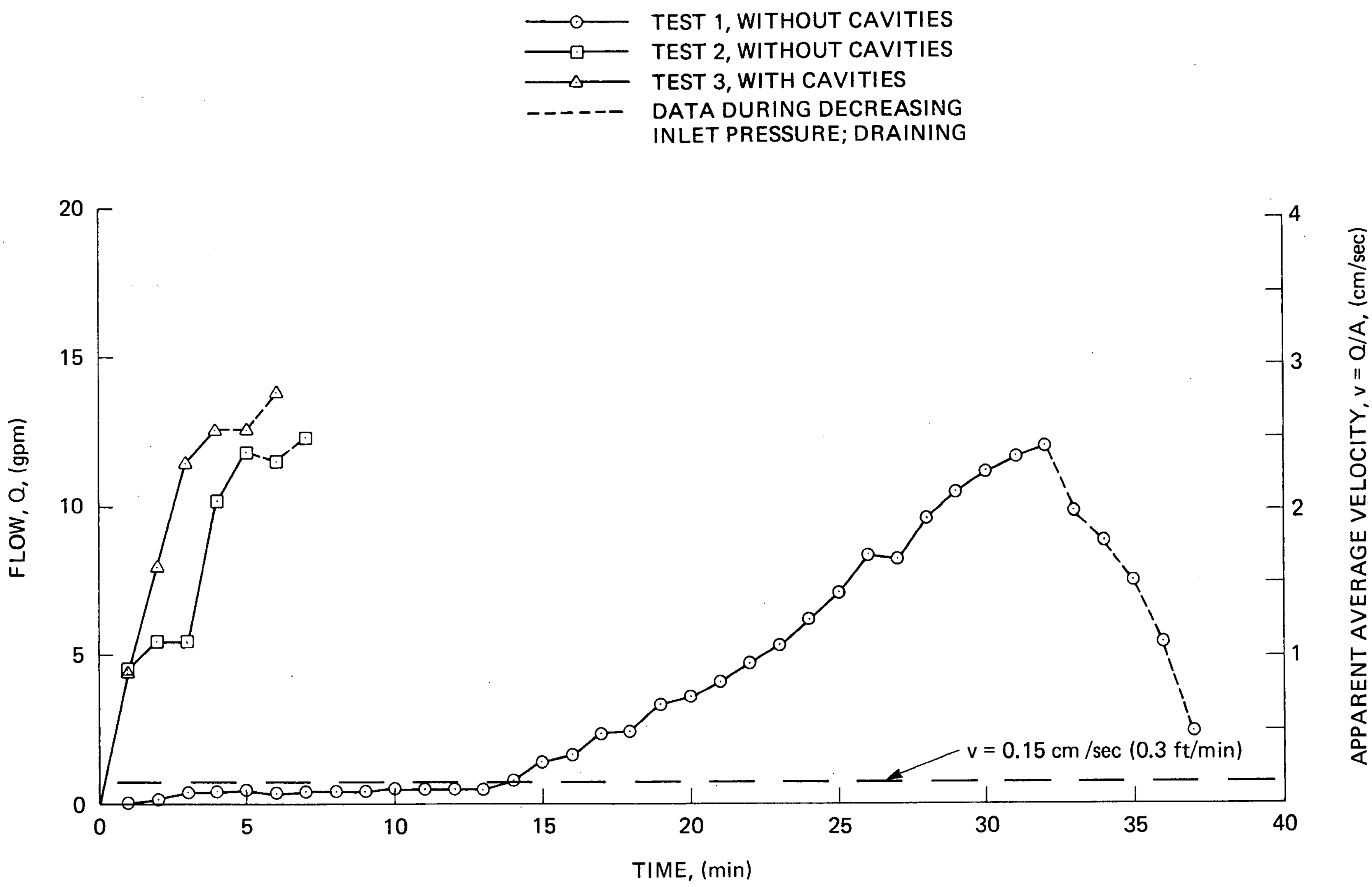




Project:	SONGS 2 & 3	LABORATORY APPARATUS TO STUDY INITIATION AND PROGRESSION OF PIPING	Fig.
Project No.	41130I		A-6

WOODWARD—CLYDE CONSULTANTS



Project: SONGS 2 & 3		TIME VARIATION OF MEASURED FLOWRATE AND AVERAGE VELOCITY	Fig. A-7
Project No. 411301			

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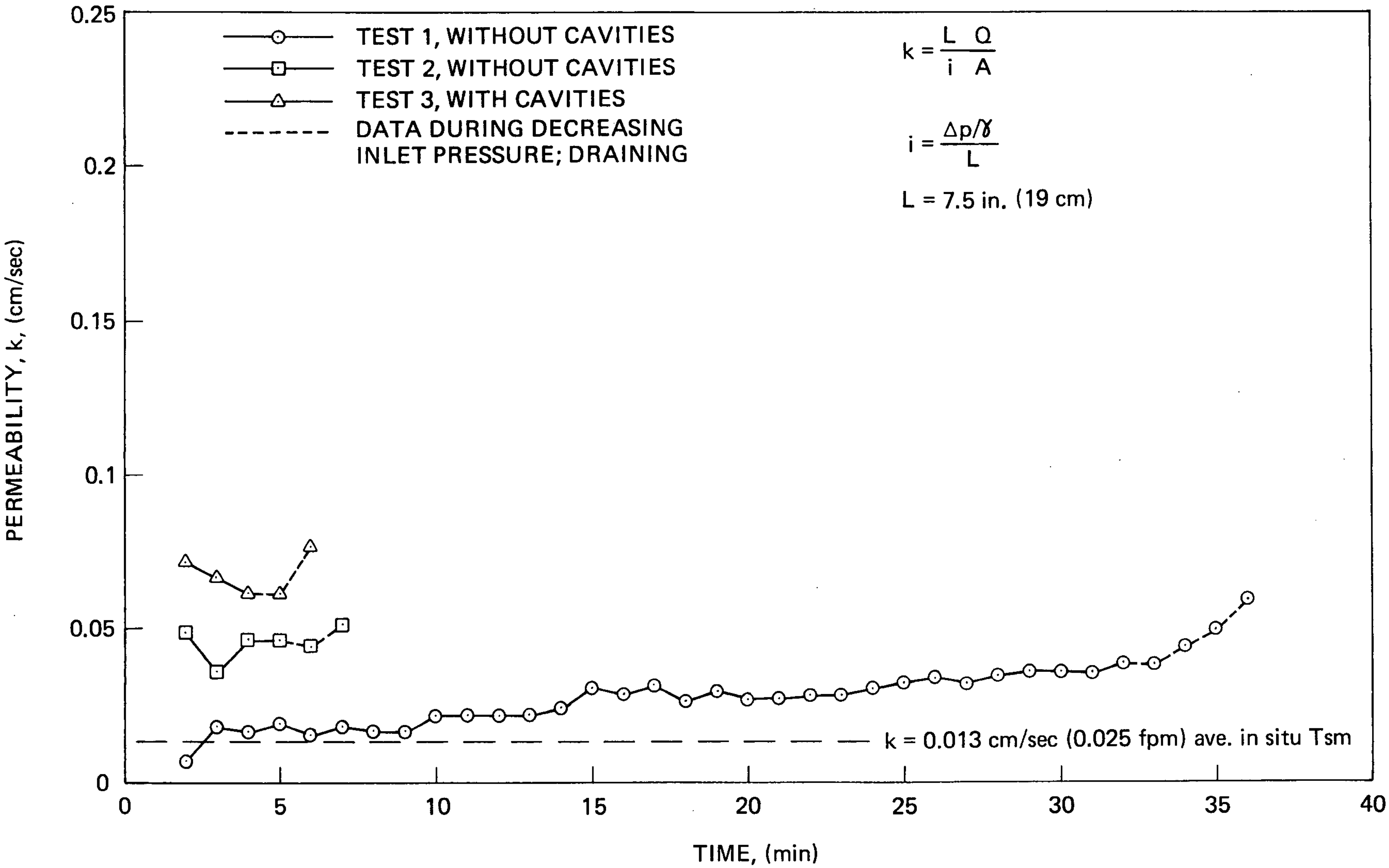

Project:	SONGS 2 & 3	TIME VARIATION OF PERMEABILITY OF SAN MATEO SAND	Fig. A-8
Project No.	41130I		

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APPENDIX B

Well Cleaning, Inspection And Measuring

APPENDIX B
WELL CLEANING, INSPECTION, AND MEASURING

B-1 INTRODUCTION

Various procedures have been utilized to clean and inspect the condition of the casing at the dewatering wells. In some cases the gravel pack was cleaned from the annular space between the well casing and the native San Mateo sand prior to removal of the casing. In these cases, an attempt was made to observe and measure the exposed well walls, if possible. The results of the well cleaning, casing inspection, and wellbore measurements are reported in this appendix.

Prior to the discovery of cavities associated with the dewatering wells at the site, the decommissioning procedure for the deep dewatering wells consisted of the following steps: (1) cut off the 14-in. diameter casing below the level of any anticipated future excavation; (2) place a loose sand backfill inside the casing; (3) weld a steel cap on the remaining 14-in. casing; (4) densify the upper portion of the gravel filter; and, (5) place compacted San Mateo sand backfill over the well. This process had been completed at Wells 4, 5, and 8 and was in progress at Well 6 when the gravel pack collapsed. The collapse occurred after sand had been backfilled in the casing and the surface area was being compacted as the final step in the decommissioning procedure. An investigation was begun following this occurrence to study the possibility of cavities associated with the operation of the deep wells and a new demobilization procedure was set up as follows: (1) using an airlifting technique, clean the sediment from inside the casing and the gravel pack from the annulus, carefully noting the volume of material removed; (2) inspect the inside of the 14-in. diameter casing using a downhole television camera; (3) remove and inspect the 14-in. diameter casing; (4) check the size of the open wellbore with a mechanical caliper and compare the calculated volume with the volume of material removed by airlifting; and, (5) backfill the wellbore with concrete and compare the volume placed with the calculated volume of the well. This procedure was to be followed at all of the deep wells including those which had already been initially decommissioned by sand backfilling. The investigative methods were easily modified to cover special conditions encountered in some wells: including television monitoring in the annular space or open wellbore; wire-brushing to clean the inside surface of the 14-in. diameter casing; and, sonar calipering to investigate beyond the reach of the mechanical caliper.

The following paragraphs describe the various techniques used during the well cleaning, inspection, and measuring phase of the demobilization and summarize the results achieved.

B-2 CLEANING

Well cleaning utilized two types of equipment: a large circular wire brush and an airlifting apparatus. The wire brush was used to remove the encrustations from the inside surface of the 14-in. diameter casing in Wells 3, 4, and 10. This procedure, used only in wells from which the casing was not pulled, made it possible to inspect the casing using the downhole television monitor and verify the interpretations of conditions based on television scans performed earlier.

The airlifting procedure was chosen for well cleaning because it gently vacuums loose sand and gravel from the bottom of the hole; it does not drill or erode the intact sands and it does not cause a pressure gradient adjacent to the well since a uniform water level is maintained in the well by recirculating the pumped water. The airlift procedure is shown schematically in Figure B-1. An airlift pipe (typically 2- or 4-in. diameter) is inserted in the bore hole with an air line introducing air into it a few inches above the tip. The air travels up the pipe, expanding and accelerating as it rises, producing a gentle vacuum-cleaning action at the airlift pipe tip to pick up loose material. The gentleness of the vacuuming action was observed by television while airlifting loose sand and gravel from Well 7 at a depth of 200 ft. The results of airlift cleaning at the various wells are summarized in Table B-1.

B-3 INSPECTION

Extensive use was made of downhole television monitoring during the demobilization process. Television logging was used: (1) inside the well casing to check its condition and to monitor various operations being performed in the wells; (2) after cleaning in the well annulus or wellbore to check for possible cavities initially identified by caliper measurements or the cleaning process; and, (3) in one monitoring bore hole drilled into the cavity at Well 6. A complete summary of the television logs with pertinent observations is presented in Table B-2.

The television logs provided documentation of the conditions in the wells and were an important source of information while establishing demobilization procedures at individual wells.

In addition to television logging of the well casing in-place, all sections of casing removed from the wells were also carefully inspected. Information from these inspections of pulled casings was correlated with data from television scans to aid in the interpretation of the video logs from other wells. A summary of the lengths of casings removed from the wells, with remarks on their condition, is presented in Table B-3. Figure B-2 is a graphical presentation of the casing condition in the various wells based on the information from the television logs and examination of the pulled casing. Figure B-3 contains photographs showing the condition of the casings from Wells 6, 7, and 9 at the time they were removed from the wells.

B-4 WELLBORE AND CAVITY MEASUREMENTS

Two devices were used to measure the size and shape of the wellbore and to aid in the detection of cavities. The first, a mechanical dog-leg caliper is shown on Figure B-4. This device could be fitted with sections of various size for extended reach of the caliper foot. The second measuring device, the sonar caliper, is shown in Figure B-5. A special adaptation, the sonar dog-leg caliper shown in Figure B-6, made it possible to investigate those portions of a cavity which may have remained undetected by the horizontal beam of the regular sonar caliper. A typical sonar readout is shown in Figure B-7. Table B-4 presents the results of the mechanical and sonar caliper investigations.

TABLE B-1

SUMMARY OF AIRLIFT CLEANING OPERATIONS

Well No.	Remarks
1	No airlifting was down inside the 14-in. diameter casing. The annulus was airlift cleaned to a depth of 198 ft; a total of 43 cu yd of material was removed, including approximately 2 cu yds of sand which had washed into the well during heavy rainfall while the cleaning operations were in progress.
2	No airlifting was done inside the 14-in. diameter casing. The annulus was cleaned by airlifting to a depth of 203 ft; the total volume of material removed was 36-1/2 cu yd.
3	No airlift cleaning was done inside the 14 in. diameter casing. The volume of material removed from the annular space between the ground surface and a depth of 54 ft was 17 cu yd. The annulus subsequently refilled to a depth of 44 ft due to caving and all airlifting work at this well was terminated.
3A	No airlifting done at this well.
4	The sand placed inside the 14-in. diameter casing during initial demobilization was removed by airlifting to a depth of 201 ft. The volume of material removed was 5-1/4 cu yd.
5	Airlift cleaning was begun inside the 14-in. diameter casing to remove sand placed during initial demobilization. At a depth of 120 ft, gravel was encountered inside the casing; the well was cleaned to a depth of 150 ft but subsequently refilled to 140 ft with material running in from the annulus. When this happened, airlifting was halted; 4-3/4 cu yd of material had been removed.

Well No.	Remarks
6	A total of 176 cu yd of sand and gravel was removed from this well by airlifting; this followed the removal of approximately 5 cu yd of material by drilling and bailing inside the 14-in. diameter casing. The inside of the 14-in. casing, filled with sand during initial decommissioning, was cleaned to full depth at 200 ft; the annulus was cleaned to a maximum depth of 149 ft but could not be kept open to this depth due to running in of loose sand from the cavity.
7	Approximately 2 cu yd of loose sand and gravel were airlifted from inside the 10-in. and 14-in. diameter casings; the inside of the 10-in. casing was cleaned to 200 ft and the annular space between the two casings was cleaned to a depth of 190 ft. Airlifting in the annulus outside the 14-in. casing produced 320 cu yd of sand and gravel for a total airlift volume of 322 cu yd. Cleaning of the well annulus proceded to a depth of 106 ft; the annulus subsequently filled to a depth of 31 ft with loose sand from the cavity.
8	This well was initially decommissioned by backfilling with sand inside the 14-in. diameter casing. Airlifting was begun to remove this material; gravel from the annulus was encountered at a depth of 115 ft. The inside of the casing was cleaned to 188 ft, producing 105 cu yd of material. Sand, running in from the annulus, kept refilling the casing to a depth of 112 to 114 ft. After 142 ft of the 14-in. diameter casing were pulled and a 20-in. diameter solid casing set to stabilize the well, the remaining 14-in. casing was cleaned to 192 ft. Placement of an inflatible packer in the annulus, to create a bridge and prevent material from falling in, made it possible to clean the annulus to a depth of 198 ft. The total volume of material airlifted from the well was 291 cu yd.
9	Airlift cleaning was done inside the 14-in. diameter casing to remove 46 ft of debris; approximately 2 cu yd of material were removed. The annulus was cleaned to full depth at 202 ft. The total volume of material air lifted was 34-1/2 cu yd.

Well No.	Remarks
10	No airlifting was done at this well.
11	No airlifting was done at this well.
12	No airlifting was done at this well.

TABLE B-2

SUMMARY OF TV TAPES

Cassette No.	Date	Well No.	Remarks
1	05 Jul 77	1	Log run inside 14-in. diameter casing to 141 ft depth. Unsuccessful "fishing" attempt to remove pump shaft.
2	05 Jul 77	1	Log run inside 14-in. diameter casing from approximately 87 to 135 ft depth.
		6	Log run inside 14-in. diameter casing from 91 to 200 ft depth.
3	05 Jul 77	7	Log run inside 14-in. diameter casing to 138 ft depth; camera not centered, so only 1/3 to 1/2 of well face can be seen. Log of inside 10-in. diameter casing from 138 to 198 ft depth.
4	06 Jul 77	9	Log run inside 14-in. diameter casing which starts at approximately 55 ft and ends at 154 ft depth. Hole filled with debris at 154 ft.
		2	Log of inside 14-in. diameter casing depth 32 to 187 ft; bottom of hole filled with debris.
		11	Log of inside 14-in. diameter casing from 22 to 199 ft depth.
5	06 Jul 77	3	Log run inside 14-in. diameter casing from 59 to 196 ft depth.
		3A	Log of inside 14-in. diameter casing from 28 to 186 ft depth. Visibility very poor.
6	22 May 78	10	Log of well after wire-brush cleaning inside of 14-in. diameter casing,

Cassette No.	Date	Well No.	Remarks
			beginning of well down to 197 ft depth; lost visibility.
7	06 Jul 77	10	Log run inside 14-in. diameter casing from 94 to 196 ft; poor visibility below 160 ft obscuring well face.
		7 (re-run)	Log of inside 14-in. diameter casing from 118 to 134 ft. Log of inside 10-in. diameter casing from 134 to 196 ft depth; 10-in. casing appears to end at 196 ft.
8	26 Jul 77	6	Log of well after airlift operation and casing pulled; log runs from 28 to 75 ft depth.
9	27 Jul 77	6	Log run after airlift operation and casing pulled 27 to 73 ft - not clear 27 to 66 ft - not clear 27 to 70 ft very clear, shows void 62 to 72 ft to 22 ft - poor visibility trying to look to side 52 ft - very clear, shows void entrance clearly
10	01 Aug 77	9	Log run after the airlift operation and the casing removed. Poor visibility but hole appears to be standing without any caving down to 160 ft.
11	24 Aug 77	3	Out of focus; murky; no data.
12	31 Aug 77	3A	Log run inside 14-in. diameter casing from 25 to 194 ft depth.
13	10 Oct 77	6	Log run after the airlift operation and casing pulled. A special device, a side-looking lens, was used to look into the void.
14	02 Feb 78	8	Log starts at 30 ft depth inside 20-in. diameter casing used to hold open the hole during cleaning of broken off 14-in. diameter casing below 150 ft. Log ends at 182 ft due to poor visibility

Cassette No.	Date	Well No.	Remarks
			caused by material knocked off the well sides.
		6	Log starts at 35 ft in large diameter casing, shows horizontal break in casing at 62 ft depth. Log ends at 66 ft.
15	06 Feb 78	8	Log starts inside 20-in. diameter casing from 146 to 183 ft but due to poor visibility, no pertinent information was obtained. Second run also no good.
16	14 Mar 78	4	Log run inside 14-in. diameter casing but poor visibility prevented any information from being gained.
17	17 Mar 78	4	Log run inside 14-in. diameter casing from 23 to 199 ft depth.
18	28 Mar 78	3	Brushing the casing was very effective. Log of inside 14-in. diameter casing starts at top of well and ends at 177 ft depth, water level at 21 ft. Very poor visibility from 170 to 177 ft.
19	07 Apr 78	4	Log run inside 14-in. diameter casing after brush cleaning, 2 louvers connected along spiral weld, log ends at 188 ft depth.
		6	Log was made to inspect the placement of the crescent tool in the casing at 60 ft depth.
20	13 Apr 78	6	Log was made to inspect the crescent tool placed at approximately 60 ft; tool placed in proper location and no entry of formation material at the slipped joint indicated. Log run inside 36-in. diameter casing to 122 ft but visibility poor.
21	29 Jun 77	1	Log run inside 14-in. diameter casing from 26 to 196 ft depth.
		7	Log run inside 14-in. diameter casing from 34 to 121 ft depth.

Cassette No.	Date	Well No.	Remarks
22	13 Jun 77	6	Log of inside 14-in. diameter casing begins at 53 ft and ends at 125 ft depth.
23	22 Jul 77	7	Attempt to retrieve fishing tool lost in hole while being used to pull the inner 10-in. diameter casing.
		9	Log run inside 14-in. diameter casing, depth from 27 to 195 ft, lost visibility below 195 ft.
		10	Log of inside 14-in. diameter casing starting at 77 ft depth.
24	Edited Nov 77		Edited tape prepared by R.L. McNeill for presentation to the NRC
		6	0 to 10 min - 5 Jul 77 - cleaned inside of casing
		2	10 to 16 min - 6 Jul 77 - inside casing
		7	16 to 18 min - 5 Jul 77 - airlift operation
		3A	18 to 28 min - inside 14-in. diameter casing
25 Reel-AMPEX	20 Apr 78	6	The camera was used to set in place the sealing device between pipes. The tape shows the hole bottom at 124 ft. The walls of the casing appear sheared and rolled up. It is difficult to orient the camera and consequently the shape of the casing or hole is difficult to delineate.
26 Reel SONY V32	20 Apr 78	Boring 6A-8	The log shows the roof of the cavity is 4 ft below the water table. The camera is pulled from the water for short intervals to show the vertical walls. Hole diameter 3-7/8".
27 Reel SONY V32	20 Apr 78	Boring 6A-8	Log to 200 ft shows size and shape of cavity; plastic casing from Boring 6A-9 seen.

Cassette No.	Date	Well No.	Remarks
28 Reel SONY K60	31 May 78	5	Log run inside 14-in. diameter casing to a depth of 141 ft; casing deterioration noted at 115, 125, and 126 ft.

TABLE B-3

REMOVAL OF WELL CASING

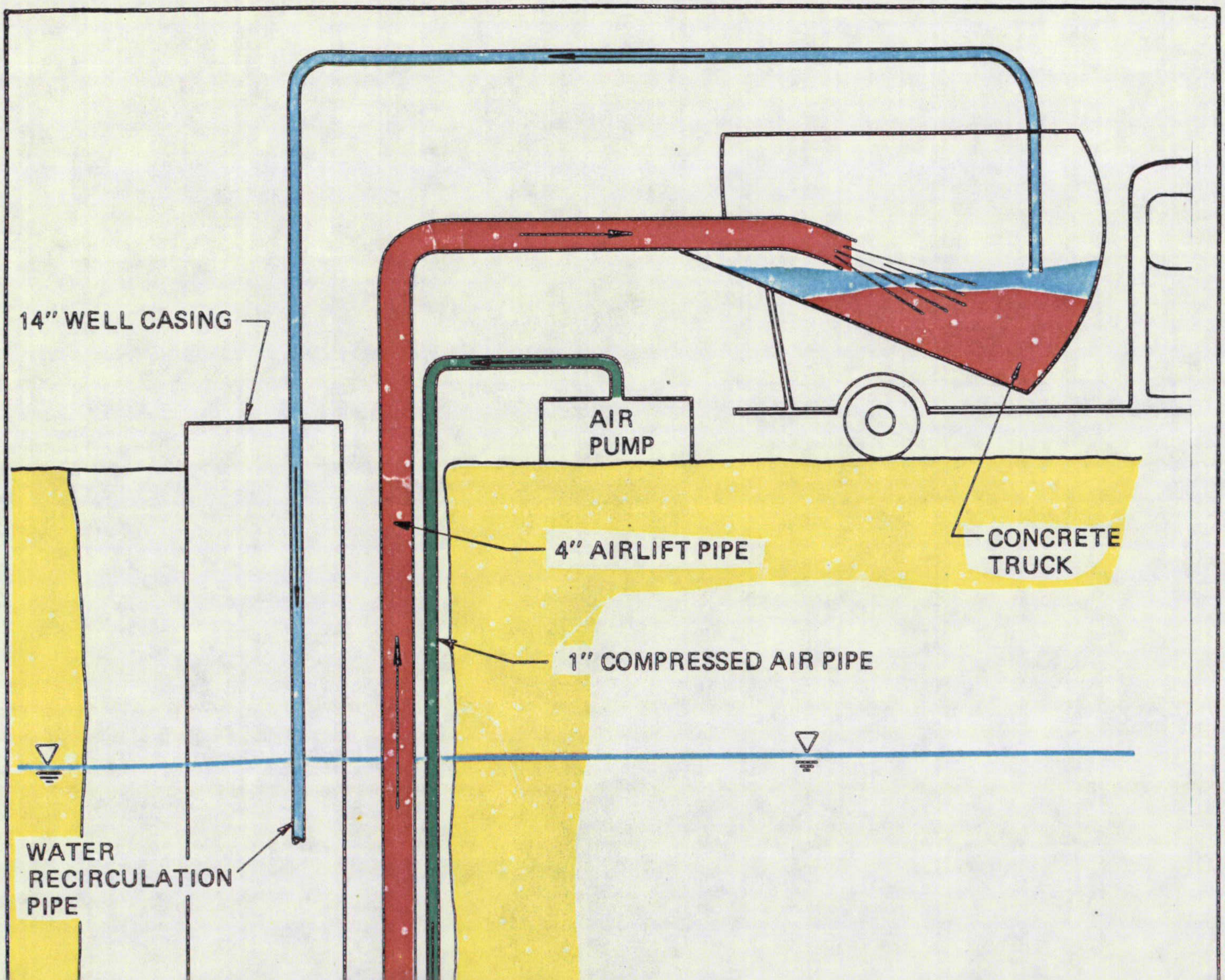
Well No.	Casing Diameter (inches)	Length Removed (feet)	Remarks
1	14	201	Moderately to very heavily encrusted. No corrosion holes.
2	14	202	Very heavily encrusted throughout. One corrosion hole; approximately 1 in. x 2 in., at 115 ft.
6	14	150	Moderately to very heavily encrusted. Numerous corrosion holes from 130 to 150 ft depth; holes range in size from 1 to 2-in. diameter to approximately 3 in. x 12 in.
7	10	136	Slightly to moderately encrusted. Louvers enlarged. Two corrosion holes noted in slotted section; approximately 3 to 5 in. in diameter.
8	14	142	Slightly to heavily encrusted. Numerous small (approximately 1-in. diameter) holes at the following depths: 118 to 120 ft; 130 to 134 ft; and, 137 to 140 ft.
9	14	196	Heavily encrusted throughout. No significant corrosion or enlargement at louvers.

TABLE B-4

RESULTS OF MECHANICAL AND SONAR CALIPER MEASUREMENTS

Well No.	Type of Measurement	Remarks
1	Mechanical	Measured full depth of open wellbore. Maximum diameter was 43-in. at 35 and 55 ft depths; 30 to 33-in. diameter below 60 ft depth. No indication of cavity formation.
2	Mechanical	Measured full depth of open wellbore. Maximum diameter was 47-in. at 140 ft depth; enlargement at 25 ft depth to 42-in. diameter; generally 31 to 34-in. in diameter. No indication of cavity formation.
3	Limited Mechanical and Sonar	An attempt was made to operate the mechanical caliper in the well annulus with the 14-in. diameter casing still in place; this did not produce useful results. The sonar caliper was successfully operated in the annulur space to a depth of 44 ft; the results of this investigation indicated an enlargement of the well bore in the northwesterly direction between the depths of 37 and 44 ft.
6	Mechanical and Sonar	Mechanical caliper measurements were made in the following depth ranges: 30 to 70 ft; and 100 to 125 ft. These measurements indicated a cavity between the 54 and 70 ft depth with a dimension in the north-south direction greater than 14 ft and in the westerly direction extending approximately 8 ft from the center of the well. The well diameter in the 100 to 125 ft depth range was approximtely 38 to 42-in. Sonar caliper investigation was conducted from depths of 35 to 74 ft and later from 26 to 38 ft. Both of these runs indicated enlargements of the wellbore with a maximum dimension exceeding 20 ft; the largest part of the cavity measured extended approximately 40 ft in the east-west direction at a depth of 62 ft.

Well No.	Type of Measurement	Remarks
7	Limited Sonar	Limited sonar caliper measurements were made from the annular space with the casing still in the well. An enlargement of the well bore extending approximately 17 ft from the center of the well toward the east was found at a depth of about 30 ft.
8	Mechanical	An attempt was made to make measurements from the annular space with the 14-in. diameter casing still in place. No significant results were obtained.
9	Mechanical	Measured the full depth of the open well bore. Slight enlargement (3±in.) of the well-bore detected. No indication of cavity formation.



Project:	SONGS 2 & 3	AIRLIFT OPERATION	Fig.
Project No.	41130I		B-1

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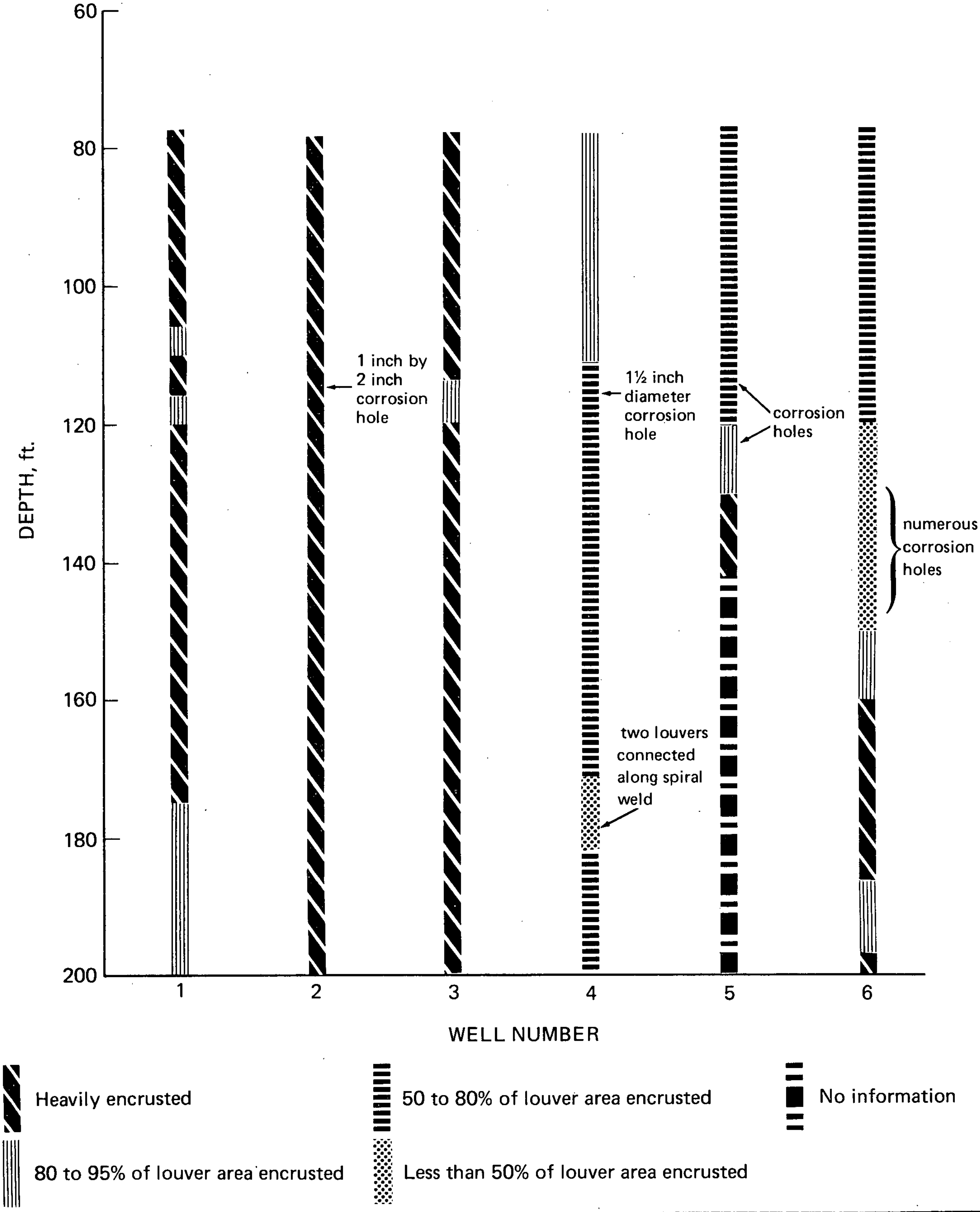

Project: SONGS 2 & 3 Project No. 41130I	DEWATERING WELLS – CONDITION OF CASING	Fig. B-2a

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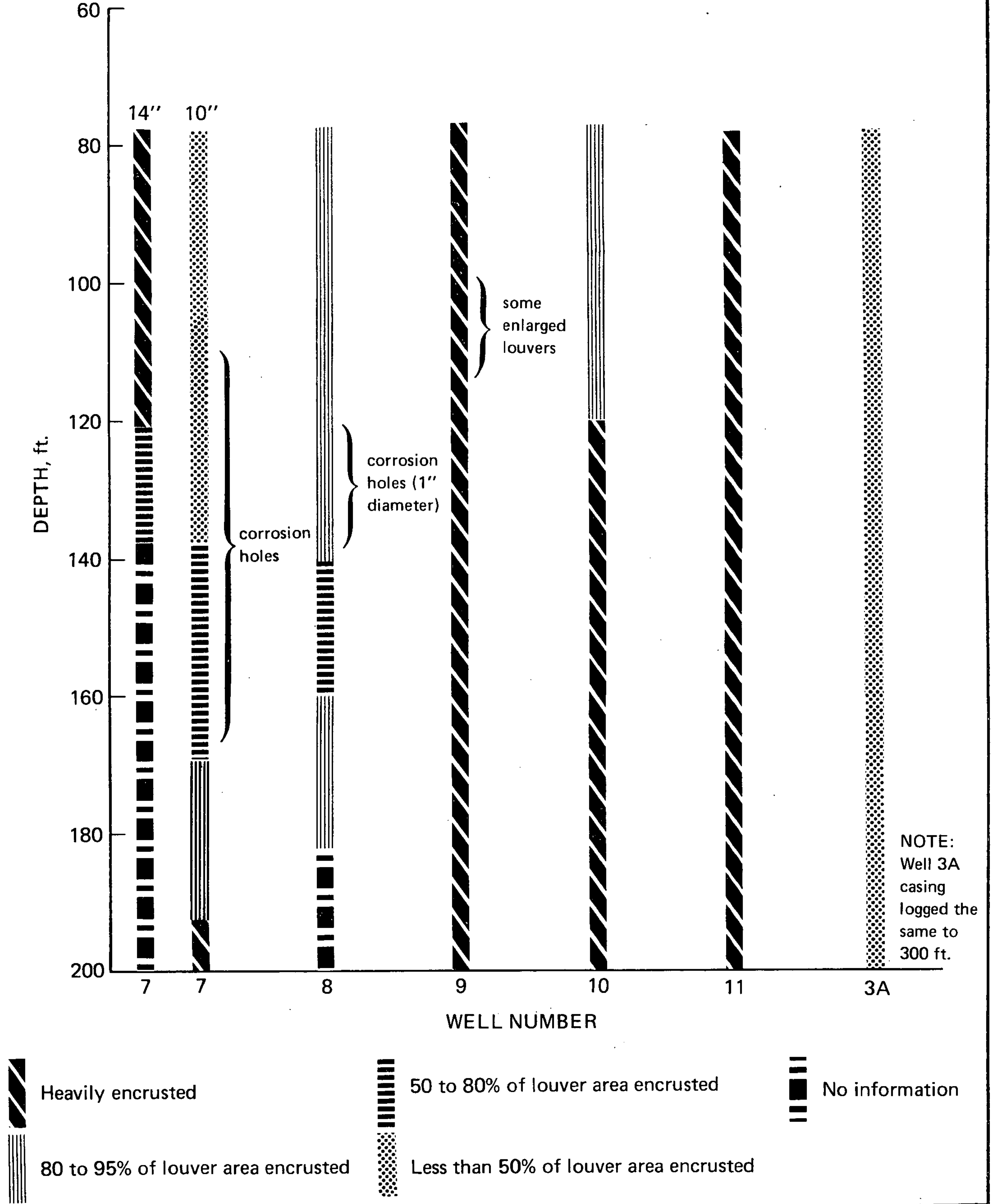

Project: SONGS 2 & 3 Project No. 41130I	DEWATERING WELLS – CONDITION OF CASING	Fig. B-2b

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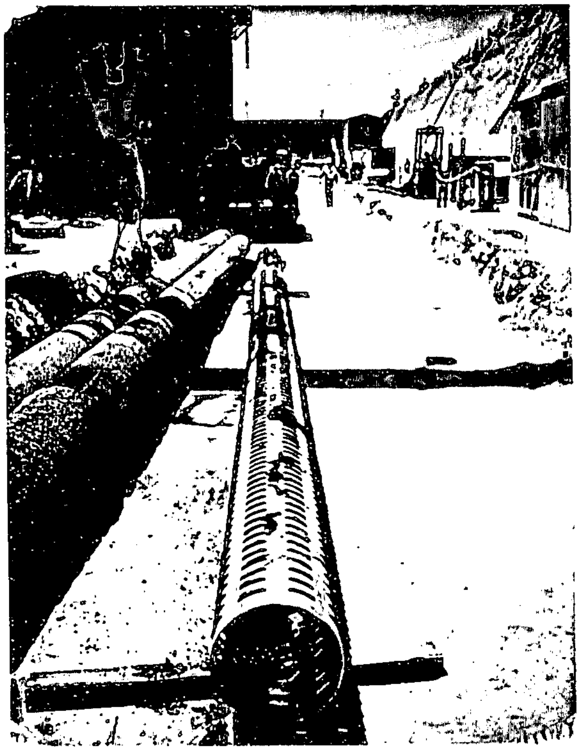

14" CASING WELL #6

10" CASING WELL #7

14" CASING WELL #9

Project:	SONGS 2 & 3	TYPICAL WELL CASING CONDITIONS	Fig. B-3
Project No.	411301		

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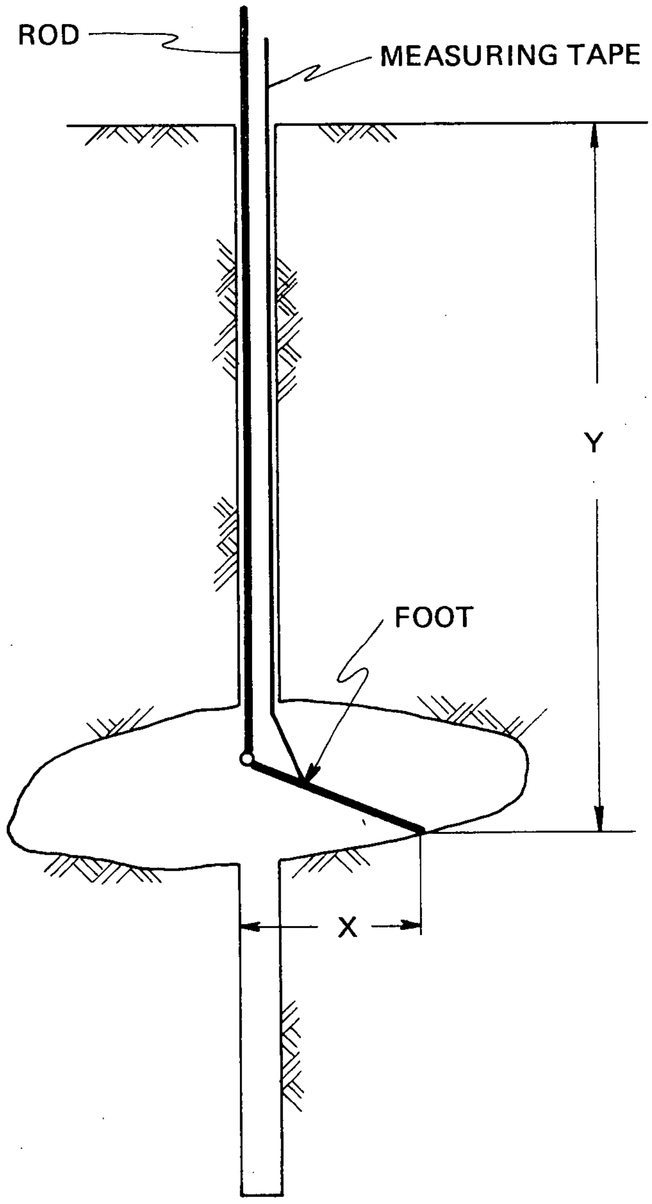

Project:	SONGS 2 & 3	MECHANICAL DOG-LEG CALIPER	Fig.
Project No.	411301		B-4

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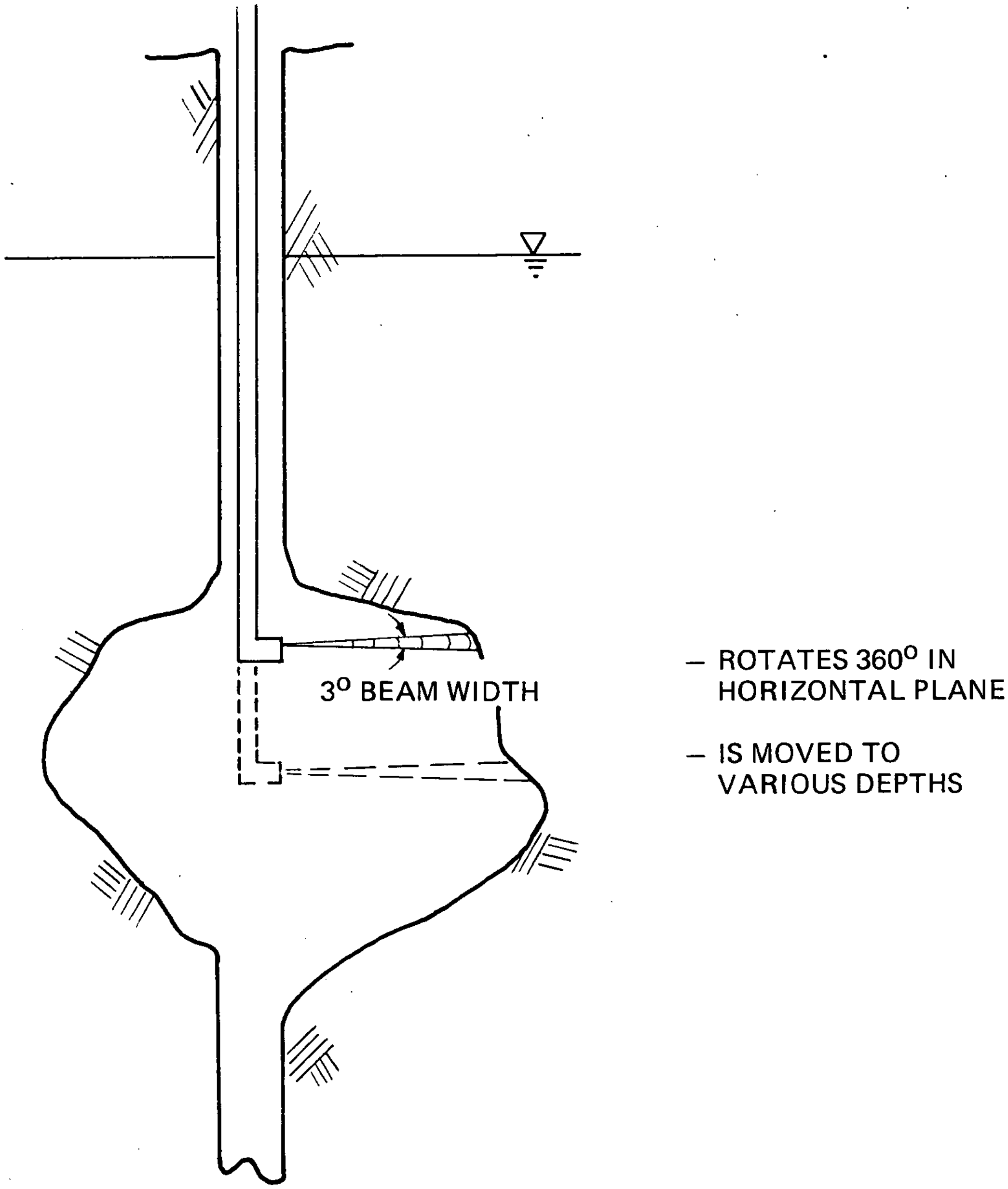
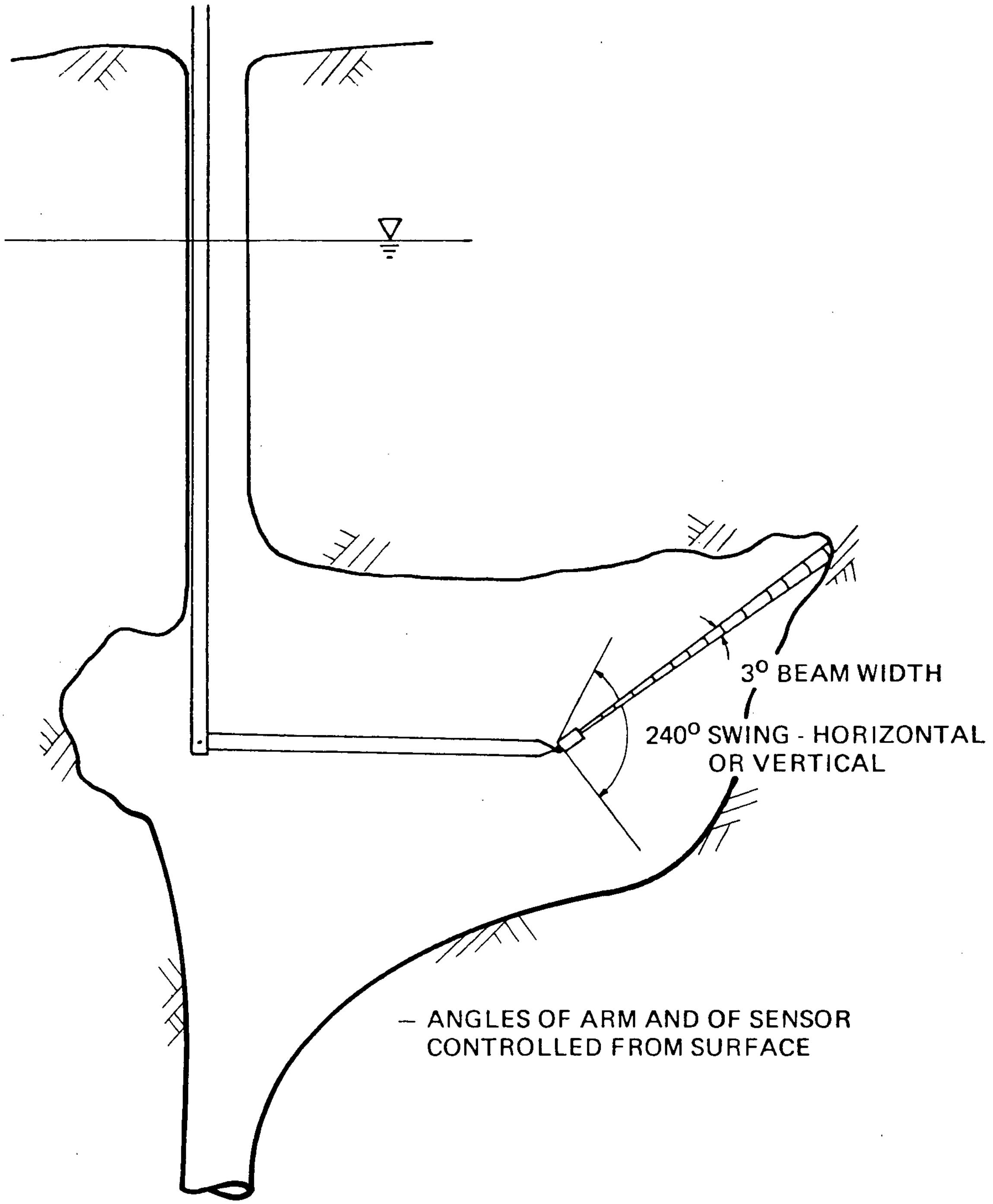
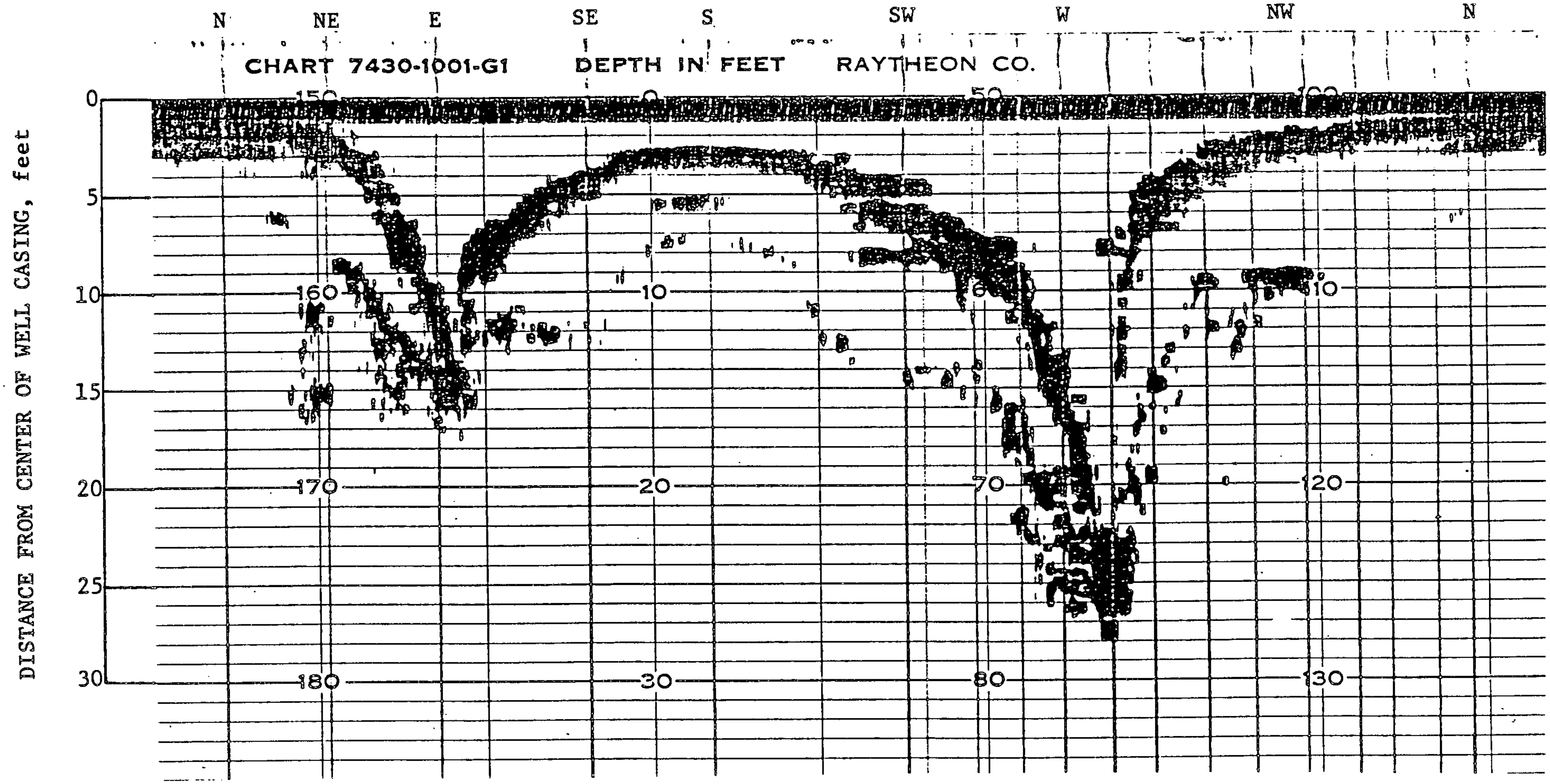


Project:	SONGS 2 & 3	SONAR CALIPER	Fig. B-5
Project No.	411301		

WOODWARD–CLYDE CONSULTANTS



Project:	SONGS 2 & 3	SONAR DOG-LEG CALIPER	Fig.
Project No.	411301		B-6



Project: SONGS 2 & 3 Project No. 411301	TYPICAL SONAR TRACE FOR WELL NO. 6 ELEVATION 66' BELOW SURFACE

Fig. B-7

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APPENDIX C

Exploration Drilling And Grouting

APPENDIX C

EXPLORATION DRILLING AND GROUTING

C-1 INTRODUCTION

The details of the drilling and grouting programs are summarized in this appendix. These programs were implemented to identify the boundaries of disturbed material near the dewatering wells and to fill any open voids in these disturbed zones with grout. This appendix includes a general description of the exploration drilling and grouting programs; a brief well-by-well description of the investigative drilling and grouting (including tabulated data on drilling and grouting, plots of drilling locations, and stick logs for all bore holes); a description of analyses used to evaluate the progress and effectiveness of the program; and, a general summary of the observations.

Drilling investigations were begun at certain wells after possible cavities and wellbore enlargements were disclosed during initial investigations which included airlifting, TV logging, mechanical caliper and sonar logging (see Appendix B). The purposes of the drilling were: (1) to identify any existing cavities or disturbed zones and locate their horizontal and vertical boundaries; (2) to estimate the properties of the loose materials filling the cavities; (3) to place limits on the size of possible wellbore enlargements at depth; and (4) to provide access to these areas for grouting.

The demobilization investigations at each well were planned to explore the relevant conditions specific to the location of the well. Preliminary boring layout was based on the results of the initial investigations within the wellbore. New data were continuously analyzed and the results used to modify the investigation to assure complete areal coverage for exploration and grouting.

C-2 EXPLORATION DRILLING

Exploration drilling was done using a truck-mounted drill rig and the borings were advanced using the rotary drilling method. Revert was used as the circulating fluid. Soil samples were taken at 10-ft intervals, at changes in material types, and after significant changes in drilling characteristics. A Standard Penetration Test (SPT) sampler or a 2-in. diameter disc penetrometer were used to obtain blow count data with depth. They were generally driven by a 140-lb hammer dropping 30 in. except in the case of angle holes where a slightly larger driving energy was utilized. Any blow count with a value greater than 50 blows for 12 in. of penetration was considered to be native material and refusal was defined as 50 blows for 3 in. of penetration. When penetration tests were not run, information on the nature of the material being drilled was interpreted from visual inspections of the cuttings, drilling rates, pulldown pressures, and fluid circulation.

Exploration drilling consisted of bore holes terminating in two depth ranges. The deep holes extend to the full depth of the dewatering wells (about 200 feet); and the shallow holes were drilled to between 50 and 120 ft deep. The objectives of the deep drilling were: (1) to ensure, by closely-spaced holes, that all cavities larger than 3 ft immediately adjacent to the wellbore would be located; (2) to locate the maximum depth of a known cavity; (3) to provide additional subsurface information for the design of the grouting program; and, (4) to provide holes outside of the disturbed zone for the crosshole seismic investigation. The objectives of the shallow drilling program were: (1) to locate any cavities or zones of disturbed material and delineate their extent and shape; (2) to investigate the properties of the cavity-infill materials; (3) to provide access for grouting; and, (4) to provide a check on the effectiveness of the grouting program while it was still in progress. Both vertical and angle holes were employed in this investigation. A summary of the drilling activities at each well is presented in Table C-1.

Gyroscopic and slope indicator surveys were run in many of the investigation bore holes in order to check their direction and drift as a function of depth. These surveys provided information necessary to accurately locate the boundaries of the disturbed zones and to evaluate the need for additional drilling between existing bore holes. The number of these surveys performed at each well site is included in Table C-1.

C-3 GROUTING

Grout was placed in the cavities and drill holes using both gravity and pressure injection methods. Gravity grouting was used primarily to fill any large void spaces evacuated by airlifting to help stabilize the upper portions of the cavities, to backfill wells where the well casing had been removed and the wellbore measured. Grout was also placed around the casing in holes being prepared for the crosshole seismic surveys.

The pressure grouting program followed gravity grouting of the void spaces at the top of the cavities (created by the emptying of the cavity-infill sand with the airlift); its objectives were to fill any remaining voids and to provide nominal densification of the cavity-infill materials. Grouting was done in stages on a grid pattern around the known or suspected cavity locations to assure that the cavities would be completely filled. A grout test program was performed between 9 and 15 May 1978 to develop guidelines for pressure grouting cavities detected near dewatering wells. Specific objectives of this program included improving the definition of:

1. The methods of advancing the holes that would provide a tight seal between the casing and loose material.
2. The water:cement ratios that would be accepted by the loose sand and native San Mateo Formation.

3. The pressures required to inject the grout and hydrofracture the soil.
4. The quantities of grout that would be accepted.
5. The direction and configuration of grout travel.

The area selected for the grout testing program was located adjacent to the west side and near the south end of the Unit 3 Turbine Building. The ground surface elevation of this area was at Elev. +15 ft at the time of the testing. A portion of area was excavated below the water table and backfilled with loose sand to simulate cavity-infill material. During the test, six grout injection pipes were driven and jetted below the water table. Grout was pumped through the injection pipes at grout mixes ranging from 1:1 to 3:1 (water cement ratio by volume). Also, four borings were drilled with the variation of SPT-value with depth obtained when samples were taken during the drilling.

The details of this test program are documented in the report prepared by Bechtel Power Corporation dated June 1978 and transmitted on 12 June 1978 with the 26 May 1978 progress report. The results of the test program indicated that grout could penetrate cavity-infill material at relatively low pressure and were used to provide initial guidelines for the exploration/grouting program at Well 8. These guidelines were subsequently modified as the exploration/grouting progressed from Well 8 to Wells 6 and 7.

Several types of grout were used during the grouting process as dictated by investigation/demobilization procedures. Grout volumes placed at each well site are summarized in Table C-2.

During the grouting operations, the structures adjacent to the wells were surveyed to monitor movements. These surveys indicate that no significant movement occurred.

C-4 WELL-BY-WELL: DESCRIPTION OF EXPLORATION/GROUTING WORK

C-4.1 Well 1

The gravel pack was removed by airlifting from the annulus of Well 1; the 14-in. diameter casing was pulled, and no corrosion holes were found. A mechanical caliper survey did not reveal any significant enlargements of the wellbore. The well was demobilized by gravity grouting. No exploration or grout holes were drilled.

C-4.2 Well 2

The procedures followed at Well 2 were the same as those at Well 1. There was no indication of any cavity during the initial investigation; the well was demobilized by gravity grouting. No exploration or grout holes were drilled.

C-4.3 Well 3

Attempts to airlift the gravel pack from the annulus around Well 3 revealed evidence of a shallow cavity. Mechanical caliper and sonar investigations indicated that the wellbore enlargement was both shallow and of limited lateral extent.

A total of 31 borings were drilled at Well 3 to identify the boundaries of the disturbed zone and the characteristics of cavity-infill materials. Of these borings, six were used in the crosshole seismic investigation; four of the six extended to the full depth of the wellbore (approximately 200 ft). Details of the drilling program are summarized in Table C-1 and C-3; the boring locations are shown on Figure C-1a. Graphic logs of all bore holes are presented on Figure C-1b.

The zone of disturbed material delineated by the drilling program extends in a northeasterly-southwesterly direction. It is approximately 15 ft by 6 ft in plan dimension. The portion of the cavity cleaned by airlifting extends from a depth of about 31 to 39 ft and locally near the wellbore to a maximum depth of 54 ft. This portion of the cavity was subsequently refilled prior to the crosshole surveys.

No grouting has been done at Well 3, except to backfill around the PVC casing set in those borings prepared for use in the crosshole seismic survey. Well was demobilized by backfilling the wellbore with sand, gravel, and concrete.

C-4.4 <u>Well 3A</u>

Well 3A was operated for just two weeks as a test well. TV logging of the inside of the well casing showed minor encrustation and louver corrosion. The bottom of the well had only 6 ft of fill. It was concluded that the existence of any cavity at this well was extremely unlikely. The 14-in. diameter casing and gravel pack were left in place; the well was demobilized by gravity grouting inside the casing.

C-4.5 <u>Well 4</u>

Well 4 was initially decommissioned by cutting off the top of the 14-in. diameter casing at Elev. -7 ft, backfilling the casing with sand, and welding on a steel cap. The well was subsequently reopened and the sand backfill removed by airlifting. Wire-brush cleaning and TV logging of the inside of the casing did not reveal any significant deterioration or structural problems in the well. As a follow up to this information, exploration drilling was undertaken specifically to locate and delineate possible cavities.

Eight deep investigation borings were drilled; PVC casing was grouted in place for the crosshole seismic investigation; six of these holes were drilled to the full depth of the wellbore. SPT samples were taken at 10-ft intervals. There was no evidence of open voids; small zones of disturbed materials and lean concrete were encountered in the bore holes within 40 ft of the ground surface. These zones were the result of the operations involved in reopening the well. Details of the deep drilling are summarized in Table C-1 and C-4; the bore hole locations are shown on Figure C-2a. Graphic logs of all borings are presented on Figure C-2b. Below these zones no disturbed material was encountered by the borings nor was evidence of cavity indicated by crosshole seismic surveys between these borings. Based on these observations, no further drilling was felt necessary.

No grouting has been done at Well 4 except to backfill around the PVC casing in the eight borings use for the crosshole seismic investigation. Well was demobilized by backfilling the wellbore with sand, gravel, and concrete.

C-4.6 Well 5

Well 5 was initially decommissioned by cutting the top of the 14-in. diameter casing, backfilling with sand, and welding on a steel cap. A shallow drilling program (holes 20 to 57 ft deep) was begun to check for the presence of near-surface cavities. Shallow cavities were of particular concern because the area around the well had been excavated to Elev. +6 ft for construction access. During the drilling of the shallow investigation holes, the ground surface immediately surrounding the well began to cave. Subsequently, a total of 19 shallow holes were drilled as located on Figure C-3a. Of these borings all encountered native soil throughout their depths except Boring 5-F which was interpreted to have drifted toward the well into the cavity. Because no SPT samples were taken during this program, the distinction between cavity-infill and native material was made by checking the static penetration of the drill stem while it supported the full weight of the drilling rig. Subsequently, a 2-in. diameter disc connected to A-rod was driven into the annular space between the well casing and the wellbore using a 140-lb hammer falling 30 in. The continuous driving record from this operation showed 1 to 2 blows per foot to a depth of about 24 ft at which point a driving resistance of 50 blows for 6-in. of penetration was encountered and the operation was terminated. It was interpreted that the annular space contained sand infill to a depth of 24 ft (about Elev. -18 ft) with gravel pack below this depth.

To facilitate the delineation of the local cavity suggested by the caving adjacent to the wellbore during drilling and the later exploration of the deeper portions of the well, a 30-in. diameter steel casing was vibrated into place around the well to Elev. -30 ft. During this operation a depression of the ground surface up to about 1 ft deep developed around the well. This depression was elliptical in plan shape with its long axis in an east-west direction with a maximum plan dimension of 8 to 10 ft. Locally toward Boring 5-F, it extended as far as 8 ft from the center of the wellbore.

A shallow pressure grouting program was set up to stabilize the cavity area around Well 5 with the following specific objectives: (1) define the extent of the cavity from grout pipe driving records; (2) seal the upper zone around the casing to minimize or eliminate fall-in from this area during cleaning of the well below Elev. -30 ft; (3) fill all open cavity areas in the vicinity of the well above Elev. -30 ft; and (4) grout loose materials in the vicinity of the well above Elev. -30 ft. Grout pipes were driven or jetted into place at 32 locations around Well 5. Based on the observed depression caused by driving the 30-in. diameter casing, the initial boring data, and the grout pipe installation data, the configuration of the cavity at Well 5 was interpreted as shown on Figure C-3b.

Cement grout was pumped under pressure at 29 locations; a total take of about 0.8 cu yd resulted, see Table C-2. The small volumes of grout take confirm the small size of the cavity. Subsequent to these operations, a 4-ft diameter section of CMP was placed around the well casing and extended to the level of the present ground surface. The excavation was then backfilled to the present ground surface with compacted soil fill.

In addition to the shallow exploration drilling, four closely-spaced holes were drilled to the full depth of the well to investigate the area around the well below the depth of pressure grouting, and to facilitate crosshole seismic measurements. These borings were samples at 10-ft intervals using the SPT.

PVC casing was grouted into place in each hole. Below these zones no disturbed material was encountered by the borings nor was evidence of cavity indicated by crosshole seismic surveys between these borings. Based on these observations, no further drilling was felt necessary.

A plot plan showing the locations of the four deep drill holes is presented in Figure C-3c. Figures C-3d through C-3f contain the graphic logs for all bore holes.

Well was demobilized by backfilling the wellbore with sand, gravel, and concrete.

C-4.7 <u>Wells 6, 7 and 8</u>

Due to the size of the cavities which developed at Wells 6, 7, and 8, and the proximity of these wells to Seismic Category I structures, the exploration and grouting programs were more extensive and complex than those at the other wells. The exploration drilling consisted of three distinct programs: (1) initial exploration; (2) deep drilling; and (3) shallow exploration/grouting. Locations for the initial drilling program were based on the results of mechanical caliper and sonar investigations within the wellbore. The objectives of this first series of borings were to accumulate preliminary information on the extent of the cavity and to provide access for grouting of the void spaces evacuated by airlifting the material at the top of the cavity. The grouting which accompanied this initial drilling program was performed using both pressure injection and gravity methods with the purpose of filling the open voids in the cavity to stabilize it for further investigation.

The objectives of the deep drilling program were: (1) to ensure, by closely-spaced holes, that all cavities larger than 3 ft would be located; (2) to discover the maximum depth of the known cavity; and, (3) to provide additional subsurface information for the design of the grouting program. SPT samples were taken at 10-ft intervals or in adjacent holes at every 5 ft in loose materials. Gyroscopic and/or slope indicator surveys were run to evaluate the direction and drift of the deep holes in order to more accurately locate the boundaries of the disturbed zones.

The exploration/grouting program was the final drilling and grouting performed. This program was carried out in stages with grouting for one stage in a particular area completed prior to drilling in subsequent stages. The objectives of the program were: (1) to define the vertical and lateral extent of the cavity away from the well; (2) to fill any voids within the cavity with grout; and (3) to provide a self-checking program which would assure completeness. During this phase of the investigations, SPT samples were generally taken at 5-ft intervals in adjacent holes. The holes were pressure grouted.

C-4.7.1 Well 6

During the early exploratory work at Well 6, the sand placed inside the casing during initial decommissioning was removed by airlifting; the gravel filter, to a depth of 149 ft, was also airlifted; 150 ft of the 14-in. diameter casing was then removed. Mechanical caliper and sonar surveys located an elongated cavity with its main axis trending in a northwesterly-southeasterly direction (see Appendix B). The first drilling investigation, designed only to locate the open voids evacuated by airlifting at the top of the cavity, consisted of 35 auger holes. These bore holes also provided access for gravity grouting of the void space. Data on this and all subsequent drilling at Well 6 are summarized in Table C-1 and C-6. Locations of the borings are shown on Figure C-4a; graphic logs of all bore holes are presented on Figures C-4b through C-4p.

Deep drilling at Well 6 consisted of 22 borings. Of these, 19 extended to the full depth of the well (Elev. -170 ft); the remaining three drifted into the wellbore between Elev. -124 ft and Elev. -160 ft. Eighteen of the deep holes (6B-1 through 6B-18) were gravity grouted. Borings 6B-19 through 6B-22 were pressure grouted during the exploration/grouting program.

The deep drilling program produced the following results: (1) no open voids or disturbed materials were encountered below a depth of 140 ft (Elev. -110 ft); (2) no open voids were encountered in the known cavity region; and (3) the cavity-infill material consists of loose to dense sand, well gravel, and grout. For a more detailed discussion of the deep drilling, refer to the February 1979 "Report on Deep Exploration Drilling Program, Dewatering Well No. 6" by Bechtel Power Corporation.

The exploration/grouting program followed the deep drilling investigation. A total of 74 holes were drilled and pressure grouted in three stages: Stage 1, 51 holes; Stage 2, 14 holes; and, Stage 3, 9 holes. Drilling consisted of both vertical and angle holes. Nine angle holes were drilled adjacent to and beneath the Auxiliary Building. In holes which encountered disturbed material, drilling was continued 15 ft into native material.

Communication between grout holes was common during early pressure grouting with grout traveling as much as 15 ft between holes. Communication and grout volumes injected decreased appreciably as grouting progressed.

Following are the results of the exploration/grouting program: (1) the angle holes beneath the Auxiliary Building did not encounter any disturbed zones; (2) no open voids were encountered in the region of the known cavity; and (3) the cavity is filled with loose to dense sand and grout. For a more detailed discussion of this phase of exploration and grouting, and for cross sectional drawings of the disturbed zones, refer to the February 1979 "Report on Exploration/Grouting Program, Dewatering Well No. 6" by Bechtel Power Corporation.

Based on the results of the several phases of drilling, it was concluded that the cavity extends a maximum of 22 ft northwest and 12 ft southeast of the wellbore; its maximum width is 8.5 ft. Material was disturbed from the ground surface to a maximum depth of 140 ft (Elev. -110 ft). The information from the borings supports the conclusion that the cavity does not extend beneath the Auxiliary Building. The grouting program at Well 6 has assured that the void spaces are filled and has resulted in nominal densification of the loose cavity-infill materials.

Demobilization of Well 6 was completed by backfilling the wellbore with sand.

C-4.7.2 Well 7

Airlift cleaning of the annulus of Well 7 proved unsuccessful (see Appendix B), so the 14-in. diameter casing was left in place and only a limited sonar investigation could be performed from within the wellbore. This preliminary work led to an initial drilling investigation which consisted of 54 shallow borings to identify open voids in the top of the cavity and enable them to be filled by gravity grouting. Several of these holes were drilled after the large open void evacuated by airlifting was gravity grouted. Tables C-1 and C-7 contains a summary of drilling data for the initial drilling investigation; it also summarizes work done during the deep drilling and exploration/grouting programs. Figures C-5a and C-5b through

C-5x present a plot plan of the borings and graphic logs of all of the bore holes, respectively.

A total of 37 borings were attempted for the deep investigative program at Well 7; 24 were completed to the design depth of 200 ft. One hole was terminated at 195 ft due to drilling difficulties; one was terminated at 122 ft after it drifted into the wellbore. The remaining 11 borings were terminated for various reasons, at depths less than 20 ft. All of these holes were backfilled by gravity grouting.

The results of the deep drilling program are: (1) no open voids or significant zones of disturbed material were encountered below a depth of 120 ft (Elev. -90 ft); (2) no open voids were encountered in the region of the known cavity; and (3) the cavity is filled with grout and loose to dense sand. A more detailed discussion of this program can be found in the June 1979 Bechtel Power Corporation "Report on Deep Drilling Program, Dewatering Well No. 7."

Following the deep drilling, 142 investigation holes were drilled and pressure grouted for the shallow exploration/grouting program. This work was done in two stages: Stage 1, 118 holes; and, Stage 2, 24 holes. To assure that these holes extended to the bottom of the disturbed zone, they were drilled at least 15 ft into native material beyond the last contact with grout or disturbed sand. Both vertical and angle holes were drilled. Seven angle holes were drilled to extend beneath the Auxiliary Building and three vertical holes were drilled through its basement to locate the maximum extent of the cavity beneath the building.

No open voids were found during the exploration/grouting program and the maximum depth at which loose material was encountered was 125 ft (Elev. -95 ft). Communication between holes during pressure grouting decreased significantly as grouting proceeded;

maximum travel between holes during grouting was approximately 40 ft.

It can be concluded from the information obtained during investigative drilling that the cavity is a long, narrow feature with its main axis tending in a northwesterly-southeasterly direction. The maximum dimension of the cavity in the long direction is 76 ft; its maximum width is 18 ft. The cavity extends a maximum of 10 ft beneath the Auxiliary Building. The disturbed zone does not extend below a depth of 120 ft (Elev. -90 ft). The grouting programs have filled the void spaces in the cavity and resulted in nominal densification of the loose cavity fill materials. For a more detailed discussion of this phase of exploration and grouting, and for cross-sectional drawings of the disturbed zones, refer to the June 1979 "Report on Exploration/Grouting Program, Dewatering Well No. 7," by Bechtel Power Corporation.

A metal cap has been placed over the 14-in. diameter casing in Well 7. The well is demobilized.

C-4.7.3 Well 8

Well 8 had initially been decommissioned by backfilling the well casing with sand. Following the discovery of a cavity at Well 6, the casing and annulus of Well 8 were cleaned by airlifting; 142 ft of the 14-in. diameter casing were removed. A mechanical caliper survey confirmed the existence of a cavity at Well 8.

Sixty-six holes were drilled during the initial investigation with grout placed in three stages. The first stage was a gravity grouting program intended to fill the large void space evacuated by airlifting at the top of the cavity. The second stage used pressure injection of the grout into the disturbed materials below the grout cap to help stabilize this large grout mass for subsequent investigations. Continued airlifting of material from the well annulus resulted in the removal of loose sand from below the previously placed grout cap. A third stage of grouting, using gravity placement, was initiated to fill this new void space.

A summary of pertinent information on the drilling for the initial and deep investigations and the exploration/grouting program is presented in Table C-1 and C-8. Figure C-6a is a plot of all the drilling locations. Graphic logs of each bore hole are presented in Figures C-6b through C-6s.

Nineteen holes were drilled for the deep exploration program at Well 8. Seventeen of these borings extended to the full depth of 180 ft (Elev. -172.5 ft). One drifted into the well bore and was terminated at Elev. -142.5 ft; mechanical problems caused excessive drift in the remaining hole causing it to be terminated at Elev. -13.5 ft. All of these holes were backfilled by gravity grouting.

The results of the deep drilling program are: (1) adjacent to the well, the maximum depth of disturbed material is 115 ft (Elev. -107.5 ft); (2) no open voids were encountered in the region of the known cavity; and (3) the cavity fill consists of grout and loose to very dense sand. For a more detailed discussion of the deep drilling program, refer to the August 1978, "Report on Deep Drilling Exploration Program, Dewatering Well No. 8," by Bechtel Power Corporation.

The exploration/grouting program which followed the deep drilling consisted of 108 borings: Stage 1, 54 holes; Stage 2, 7 holes; Stage 3, 29 holes; and check holes, 18. These included both vertical and angle holes; 9 angle holes were drilled to extend beneath the Unit 3 Containment structure. No disturbed material was encountered beneath the Containment building Tendon Gallery; the disturbed zone stopped at the Tendon Gallery wall. During the exploration grouting program, no open voids were encountered in the region of the known cavity; the maximum depth of disturbed material was 115 ft (Elev. -107.5 ft). A more detailed description of this phase of the demobilization with cross-sections of the cavity as interpreted from the drilling information can be found in the August 1978 "Report on Shallow Exploration/Grouting Program, Dewatering Well No. 8" by Bechtel Power Corporation.

Data obtained from the various drilling investigations at Well No. 8 support the conclusion that the cavity is a relatively narrow, steep-sided linear feature extending 27 ft northwest of the well and 10 ft east. The maximum width of the cavity is 6 ft; the maximum depth of the disturbed zone is 115 ft (Elev. -107.5 ft). The primary cavity has several extensions to the west of the well which are, at most, 4 ft wide, 80 ft deep, and extend up to 19 ft from the axis of the primary cavity. The grouting programs have filled the void spaces of the cavity and resulted in nominal densification of the loose sands.

Well 8 was demobilized by backfilling the wellbore with sand.

C-4.8 Well 9

The gravel pack in the well annulus and 49 ft of fill from inside the casing were removed by airlifting. The casing was removed in good condition with only minor corrosion holes below 90 ft. A mechanical caliper survey did not reveal any enlargements of the wellbore. Well 9 was demobilized by gravity grouting. No exploration or grout holes were drilled.

C-4.9 Well 10

After the 14-in. diameter casing had been cleaned by wire brushing, a TV survey showed that the casing was in good condition and did not have any corrosion holes. No further work was done inside the wellbore.

A total of seven borings were drilled at Well 10. Four holes, drilled to the full depth of the well (200 ft), were prepared for the crosshole seismic investigation. In these holes (10B-1 through 10B-4), SPT samples were taken at 10-ft intervals; no evidence of disturbed material was found. These four borings were cased with PVC and gravity grouted around the casing.

Borings 10B-5 through 10B-7, intermediate depth holes to 130, 125 and 70 ft, respectively, were sampled using SPT at intervals from 1-1/2 to 10 ft. No evidence of disturbance was found. These borings were backfilled by gravity grouting. Well was demobilized by backfilling the wellbore with sand, gravel, and concrete.

Tables C-1 and C-9 presents a summary of drilling activities at Well 10. Figure C-7a is a plot of the boring locations; graphic logs of all of the bore holes are presented on Figure C-7b.

C-4.10 Wells 11 and 12

Wells 11 and 12 lie outside of the permanent seawall. Both wells have not yet been demobilized: only the pumping assemblies have been removed. They have not been operated since March 77 and February 78 respectively. No drilling investigations have been done and none are planned at these two wells.

C-5 SUMMARY

The analyses of the data obtained during the exploration and grouting programs were performed while work was still in progress. They provided the control necessary to make program adjustments to assure that any existing cavities would be located, their maximum extent in any direction known, and that all voids would be filled with grout.

The drilling and sampling programs have placed limits on the maximum vertical and lateral extent of the zones of disturbed material.

Gyroscopic and slope indicator surveys in many of the borings provide accurate information on their direction and drift so that the cavity boundaries can be accurately located.

The phased grouting programs have assured that all open voids are filled with grout. Pressure grouting has resulted in nominal densification of loose cavity-infill materials.

The deep drilling investigations at Wells 6, 7, and 8 support the conclusion that there are no significant enlargements of the wellbore at depth and that the maximum depth of the disturbed zone near the wellbore is 140 ft (Elev. -110 ft) at Wells 6 and 7, and 115 ft (Elev. -107.5 ft) at Well 8.

TABLE C-1

SUMMARY OF DRILLING ACTIVITY AT EACH WELL

Well No.	Program	No. of Borings (no. of gyroscopic or slope indicator surveys)	Elevation Range at Depth (ft)	Period
3	Exploration Borings	31 borings (27 slope indicator and 1 gyroscopic surveys)	-8 to -181	Apr-Oct 78
4	Exploration Borings	8 borings (8 gyroscopic surveys)	-65 to -175	Oct-Dec 78
5	Exploratory Borings	19 borings	+10 to -27	Sep 77
	Exploration Borings	4 borings (1 slope indicator and 4 gyroscopic surveys)	-170 to -175	Sep-Oct 78
6	Exploration Borings	7 borings (2 slope indicator surveys)	-53 to -183	May-Jun 77
	Exploratory Borings	28 borings (11 slope indicator surveys)	+25 to -72	Dec 77 - May 78
	Deep Exploration Borings	22 deep borings (plus 4 less than 10 ft) (21 gyroscopic surveys)	-124 to -171	May-Oct 78
	Exploration/ Grouting Borings	74 borings (14 gyroscopic surveys)	+13 to -140	Jul-Oct 78
7	Exploratory Borings	54 borings (15 slope indicator surveys)	+5 to -170	Jan-Jul 78

Well No.	Program	No. of Borings (no. of gyroscopic or slope indicator surveys)	Elevation Range at Depth (ft)	Period
	Deep Exploration Borings	37 deep borings (11 incomplete) (26 gyroscopic surveys)	-92 to -170	Jul-Sep 78
	Exploration/ Grouting Borings	142 borings (37 gyroscopic surveys	+20 to -110	Oct 78 - Feb 79
8	Exploration Borings	39 borings (2 slope indicator surveys and 3 borings for grout monitoring)	+15 to -33	Sep 77
	Exploration Borings	27 borings (14 slope indicator surveys)	-6 to -80	Dec 77 - Mar 78
	Deep Exploration Borings	19 borings (2 incom- plete) (17 gyroscopic multi-shot surveys, 2 single-shot data only)	-172.5	Mar-Jul 78
	Shallow Exploration/ Grouting Borings	108 borings (24 gyroscopic multi- shot surveys)	+5 to -66	May-Jul 78
10	Exploration Borings	7 borings (7 gyro- scopic multi-shot surveys)	-40 to -170	Nov-Dec 78

TABLE C-2

SUMMARY OF GROUT VOLUMES AT EACH WELL

Well No.	Date	Program Grout Volume*	Remarks
1	24 Jan 78	46.5 cu yds	Gravity - backfill well bore; Elev. 20 to 168'
2	12 Aug 77	42 cu yds	Gravity - backfill well bore; Elev. +14 to -168'
3	24 Jun 78 & 27 Jul 78 to 2 Aug 78	232 bags	Gravity - backfill around 4" PVC for crosshole seismic
3A	7 Sep 77 to 8 Sep 77	15 cu yds	Gravity backfill 14" casing.
4	20 Oct 77	102 cu yds	Gravity backfill of excavation (below Elev. +5') in area between well and electrical and piping gallery.
	18 Oct 78 to 8 Dec 78	273 bags	Gravity, grouting 4" PVC cross hole pipe, Holes B-1 - B-8.
	29 Nov 78	8 cu yds	Gravity, Grout cap inside well bore 42" CMP, elev. interval -4 to -19'.
5	4 Oct 77 to 21 Oct 77	0.8 cu yds	Pressure - total of 29 holes, grouting around well.
	27 Sept 78 to 6 Oct 78	181 bags	Gravity - crosshole survey pipe closure holes B-1 - B-4.
	14 Dec 78	1.5 cu yds	Gravity - grout cap in well casing 42" CMP, elev. interval + 13 to 0'.
6	23 Jun 77 to 29 Jun 77	8.3 cu yds	Gravity - stabilizer plate for 42" CMP casing.

* Grout slurry volumes as measured at ground surface. (Note: volumes are given in terms of cubic yards and bags of cement as a function of how they were recorded in the field at the time of mixing).

Well No.	Date	Program Grout Volume*	Remarks
	25 Apr 78	112 cu yds	Gravity - fill voids, 7 holes of A series.
	1 Jun 78 to 17 Oct 78	406 bags Deep Exploration Drilling Program	Gravity - 18 holes of B series.
	17 Aug 78 to 17 Oct 78	122 bags Deep Exploration Drilling Program	Pressure - 4 holes of B series
	17 Aug 78 to 17 Oct 78	500 bags Exploration/ Grouting Program	Pressure - Total of 74 holes stages 1, 2, and 3
7	4 Apr 78	48.5 cu yds	Gravity - cavity backfill.
	1 Aug 78 to 21 Sept 78	828 bags Deep Exploration Drilling Program	Gravity - Total of 26 holes 7B-1 thru 7B-27
	18 Oct 78 to 7 Feb 79	1421 bags Exploration/ Grouting Program	Pressure - Total of 115 holes in stage I, 24 holes in Stage II.
	18 Oct 78 to 7 Feb 79	12 bags Exploration/ Grouting Program	Pressure - Total of 3 holes inside Radwaste Building
	1 Mar 79	192 cu yds	Gravity - slurry backfill of excavation after removal of loose material, elev. -5' to +30'.
8	23 Sept 77	104 cu yds	Gravity - cavity backfilled.
	26 Oct 77 to 1 Nov 77	10 cu yds	Pressure - cavity.
	3 Mar 78	76 cu yds	Gravity - cavity filled through 3 holes of A series.

* Grout slurry volumes as measured at ground surface. (Note: volumes are given in terms of cubic yards and bags of cement as a function of how they were recorded in the field at the time of mixing).

Well No.	Date	Program Grout Volume*	Remarks
8	31 Mar 78 to 11 Jul 78	22 cu yd Deep Drilling Exploration Program	Gravity - Total of 19 holes 8B-1 thru 8B-19
	7 Jun 78 to 15 Jul 78	251 bags Shallow Exploration/Grouting Program	Pressure - Total of 107 holes
	1 Aug 77	40 cu yds	Gravity - backfill well bore, elev. +25 to -170'.

* Grout slurry volumes as measured at ground surface. (Note: volumes are given in terms of cubic yards and bags of cement as a function of how they were recorded in the field at the time of mixing).

TABLE C-3

SUMMARY OF EXPLORATION BORINGS AT WELL 3

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
3A-1	60		Yes	17+50.4	6+51.9
3A-2	67		Yes	17+50.3	6+50.1
3A-3	60		Yes	17+59.5	6+47.6
3A-4	87		Yes	17+49.5	6+47.7
3A-5	90		Yes	17+49.6	6+56.7
3A-6	80		Yes	17+61.7	6+51.5
3A-7	80		Yes	17+58.7	6+57.5
3A-8	80		Yes	17+47.0	6+48.1
3A-9	80		Yes	17+57.7	6+43.9
3A-10	80		Yes	17+52.6	6+41.3
3A-11	70		Yes	17+49.9	6+43.8
3A-12	80		Yes	17+59.3	6+41.2
3A-13	80		Yes	17+53.8	6+57.2
3A-14	80		Yes	17+47.6	6+58.6
3A-15A	120	Yes		17+63.0	6+56.1
3-A	100		Yes	17+55.7	6+45.9
3-B	60		Yes	17+61.8	6+40.8
3-C	60		Yes	17+46.1	6+51.6
3-D	60		Yes	17+55.8	6+57.0
3-E	60		Yes	17+62.2	6+46.1
3-F	60		Yes	17+62.0	6+43.5
3-Q	210		Yes	17+42.0	6+50.4
3-R	211			17+42.5	6+47.5
3-S	200			17+42.5	6+42.5
3-T	200		Yes	17+61.6	6+34.9
3-U	210		Yes	17+66.2	6+52.0
3-V	200		Yes	17+55.5	6+64.9
3-W	38		Yes	17+63.4	6+51.2
3-X	59		Yes	17+61.6	6+37.4
3-Y	40		Yes	17+44.7	6+45.4
3-Z	59			17+52.9	6+58.4

TABLE C-4

SUMMARY OF EXPLORATION BORINGS AT WELL 4

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level	
				S	W
4B-1	200	Yes		18+22.6	4+96.8
4B-2	200	Yes		18+18.5	4+95.0
4B-3	200	Yes		18+13.2	4+96.4
4B-4	200	Yes		18+08.0	4+97.0
4B-5	200	Yes		18+22.7	4+95.9
4B-6	200	Yes		18+11.0	4+97.0
4B-7	122	Yes		18+05.0	5+00.0
4B-8	90	Yes		18+23.5	4+97.0

* From Elev. +30 ft.

TABLE C-5

SUMMARY OF EXPLORATORY AND EXPLORATION BORINGS AT WELL 5

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
A	Not recorded			19+17	2+87
B	57			19+11	2+91
C	57			19+15	2+90
D	57			19+08	2+84
E	57			19+14	2+83
F	20			19+12	2+80
G	20			19+12	2+77
H	22			19+13	2+93
I	25			19+19	2+92
J	27			19+21	2+86
K	43			19+18	2+80
L	22			19+14	2+75
M	27			19+08	3+09
N	27			19+12	3+07
O	27			19+18	3+05
P	27			19+23	3+02
Q	27			19+30	3+00
R	27			19+18	2+97
S	27			19+11	2+99
5B-1	200	Yes		19+09.1	2+92.9
5B-2	205	Yes		19+10.3	2+80.3
5B-3	200	Yes		19+01.0	2+80.1
5B-4	200	Yes	Yes	19+01.1	2+96.2

* From Elev. +30 ft.

TABLE C-6

SUMMARY OF EXPLORATION, EXPLORATORY, DEEP EXPLORATION AND EXPLORATION/GROUTING BORINGS AT WELL 6

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
1	83			20+85.5	2+32.5
2	213			20+90.4	2+23.5
3	96			20+96.1	2+27.8
4	214			20+98.5	2+30.9
5	177			20+98.5	2+24.5
6	203		Yes	20+91.8	2+36.1
7	204		Yes	20+89.4	2+28.5
6A-1	83			20+86.7	2+48.5
6A-2	83		Yes	20+88.8	2+48.3
6A-3	83		Yes	20+92.5	2+47.7
6A-4	5			20+90.6	2+47.0
6A-5	81		Yes	20+95.4	2+47.5
6A-6	100			20+92.7	2+41.1
6A-7	41			20+94.6	2+25.0
6A-8	48			20+92.9	2+38.8
6A-9	20.5			20+93.6	2+35.2
6A-10	26			20+90.6	2+31.9
6A-11	23			20+93.1	2+27.2
6A-12	73			20+90.4	2+44.8
6A-13	100			20+87.3	2+44.9
6A-14	100			20+84.4	2+45.0
6A-15	13			20+81.5	2+44.9
6A-16	100			20+93.9	2+44.5
6A-17	4			20+90.8	2+25.2
6A-18	50			20+87.2	2+24.7
6A-19	74			20+97.2	2+25.5
6A-20	74		Yes	20+87.8	2+40.0
6A-21	42			20+93.5	2+24.9
6A-22	80		Yes	20+97.6	2+41.6
6A-23	80		Yes	20+90.6	2+49.0
6A-24	102		Yes	20+83.2	2+47.9
6A-25	80		Yes	20+82.9	2+40.7
6A-26	80		Yes	20+85.6	2+36.2

* From Elev. +30 ft.

Table C-6
Page 2

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
6A-27	80		Yes	20+97.7	2+35.3
6A-28	90		Yes	20+98.9	2+27.0
6B-1	201	Yes		20+88.8	2+31.6
6B-2	200	Yes		20+91.3	2+35.9
6B-3	200	Yes		20+96.3	2+35.9
6B-4	200	Yes		20+98.8	2+31.6
6B-5	8			-- Abandoned --	
6B-5A	200	Yes		20+94.9	2+26.9
6B-6	200	Yes		20+91.3	2+27.2
6B-7	200	Yes		20+89.5	2+33.5
6B-8	1			20+93.8	2+37.6
6B-8A	200	Yes		20+93.6	2+36.5
6B-9	200	Yes		20+97.5	2+34.5
6B-10	6.5			20+97.0	2+28.5
6B-10A	200	Yes		20+97.5	2+27.5
6B-11	200	Yes		20+92.5	2+26.5
6B-12	200	Yes		20+88.6	2+28.6
6B-13	6.5			-- Abandoned --	
6B-13A	154	Yes		20+97.5	2+30.5
6B-14	200	Yes		20+98.7	2+27.9
6B-15	200	Yes		20+92.5	2+35.0
6B-16	200	Yes		20+99.5	2+29.5
6B-17	200	Yes		21+00.0	2+32.0
6B-18	200	Yes		21+00.5	2+30.5
6B-19	190			21+00.0	2+26.0
6B-20	172	Yes		20+98.0	2+26.0
6B-21	200	Yes		20+96.0	2+28.5
6B-22	200	Yes		20+96.3	2+27.2
E9	17			20+83	2+45
Em4A	80			20+84	2+50
Em13	70			20+84	2+41
F4	80			20+85	2+50
F6	125	Yes		20+85	2+48
F7	100			20+85	2+47
F30	80			20+85	2+24
G9.5	40			20+87	2+44.5
G11A	150			20+87	2+43
Gm11	21			20+88	2+43
Gm19	90			20+88	2+35
H4	45			20+89	2+50
H7	75			20+89	2+47
H9	90			20+89	2+45
H14A	90			20+89	2+40
H15	60			20+89	2+39

* From Elev. +30 ft.

Table C-6
Page 3

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
H30	60			20+89	2+24
Hm10	70			20+90	2+44
Hm13A	85			20+90	2+41
Hm18	150			20+90	2+36
J5.6	100	Yes		20+91	2+48
J8	55			20+91	2+46
J12	31.5			20+91	2+42
J17	50			20+91	2+37
J21	150			20+91	2+33
J25	70			20+91	2+29
Jm5	70			20+92	2+49
Jm29	75			20+92	2+25
K17	145			20+93	2+37
K31	60			20+93	2+23
K34	60			20+93	2+20
Km4	40			20+94	2+50
Kr13	70			20+94.5	2+41
L8	100	Yes		20+95	2+46
L10	100	Yes		20+95	2+44
L17	100			20+95	2+37
L25	25			20+95	2+29
Lm4A	40			20+96	2+50
Lm24	135			20+96	2+30
M14	40			20+97	2+40
M21A	150			20+97	2+33
M22	30			20+97	2+32
M28	170			20+97	2+26
M30	100			20+97	2+24
Mm17.3	80			20+98	2+36.9
Mn27	32			20+98	2+27
N25	120			20+99	2+29
N30	160			20+99	2+24
Nm19	40			21+00	2+35
Nm21	150			21+00	2+33
O34	75			21+01	2+20
Dm16	90			20+82	2+38
Dm22	130	Yes		20+82	2+32
F18	80	Yes		20+85	2+36
G26.5	80			20+87	2+28
G32	160			20+87	2+22
Hm14	120	Yes		20+90	2+40
K9	110	Yes		20+93	2+45
K11	90			20+93	2+43
L9	130	Yes		20+95	2+45
Mm18.5	90			20+98	2+36
Nm14	160			21+00	2+40

* From Elev. +30 ft.

Table C-6
Page 4

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
Pm25	120	Yes		21+04	2+29
Pm29	120	Yes		21+04	2+25
Q34	80	Yes		21+05	2+20
Em6	60	Yes		20+84	2+48
G5	100	Yes		20+87	2+49
G8	80			20+87	2+46
Hm8	90			20+90	2+46
Jm15	75			20+92	2+39
K14	69			20+93	2+40
K19	150			20+93	2+35
L31.5	100			20+95	2+23
Lm15	90			20+96	2+39

* From Elev. +30 ft.

TABLE C-7

SUMMARY OF EXPLORATORY, DEEP EXPLORATION AND EXPLORATION/GROUTING BORINGS AT WELL 7

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
7A-1	50			22+85.4	2+28.7
7A-2	60			22+80.4	2+36.5
7A-3	100			22+73.0	2+40.0
7A-4	60			22+70.0	2+43.0
7A-5	100		Yes	22+63.0	2+41.5
7A-6	80		Yes	22+55.7	2+40.2
7A-7	60			22+62.4	2+30.0
7A-8	50			22+59.5	2+47.5
7A-9	80		Yes	22+52.7	2+48.7
7A-10	25			22+47.1	2+44.7
7A-11	190		Yes	22+71.2	2+21.8
7A-12	200		Yes	22+64.3	2+20.6
7A-13	200		Yes	22+79.6	2+20.5
7A-14	80			22+76.2	2+07.1
7A-15	45			22+85.2	2+07.0
7A-16	63		Yes	22+92.2	2+06.8
7A-17	58		Yes	23+01.0	2+07.7
7A-18	60		Yes	23+10.1	2+08.5
7A-19	80		Yes	22+88.3	2+43.8
7A-20	80		Yes	22+98.5	2+13.2
7A-21	80		Yes	22+69.2	2+06.7
7A-22	80		Yes	22+66.6	2+13.4
7A-23	80		Yes	22+38.4	2+45.4
7A-24	80			22+87.9	2+20.5
7A-25	80		Yes	22+77.7	2+38.6
7A-26	200			22+82.5	2+23.9
7A-27	100			22+85.3	1+95.3
7A-28	100			22+90.3	1+95.3
7A-29	80			22+61.4	1+95.3
7A-30	120			22+79.9	2+18.6
7A-31				22+65.0	2+37.0
7A-32				22+72.5	2+22.0
7A-33				22+81.6	2+14.8
7A-34				22+90.0	2+07.1

* From Elev. +30 ft.

Table C-7
Page 2

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
7A-35				22+92.2	2+06.8
7A-36	39			22+83.7	2+07.0
7A-37	64			22+97.3	2+07.5
7A-38	70			23+01.9	2+05.7
7A-39	62			22+94.5	2+06.9
7A-40	52			22+86.6	2+07.1
7A-41	42			22+72.0	2+07.5
7A-42	60			22+69.7	2+07.6
7A-43	41			22+77.0	2+11.4
7A-44	69			22+86.8	2+16.6
7A-45	70			22+67.5	2+48.0
7A-46	65			22+63.5	2+48.0
7A-47	65			22+59.5	2+48.0
7A-48	75			22+55.5	2+48.0
7A-49	69			22+51.5	2+48.0
7A-50	60			22+47.5	2+48.0
7A-51	73			22+56.9	2+35.0
7A-52	33			22+53.6	2+39.0
7A-53	32			22+61.2	2+41.9
7A-54	70			22+63.3	2+39.7
7B-1	200	Yes		22+68.5	2+30.0
7B-2	200	Yes		22+71.2	2+36.0
7B-3	200	Yes		22+75.5	2+34.5
7B-4	195	Yes		22+78.6	2+31.2
7B-5	200	Yes		22+75.5	2+27.3
7B-6	11			22+70.5	2+23.1
7B-6A	200	Yes		22+70.0	2+22.0
7B-7	11			22+67.9	2+32.0
7B-7A	10			22+68.9	2+31.5
7B-7B	10			22+66.8	2+31.5
7B-8	200	Yes		22+73.1	2+36.0
7B-9	200	Yes		22+78.3	2+33.1
7B-10	10			22+78.3	2+27.1
7B-10A	9			22+78.3	2+26.0
7B-10B	200	Yes		22+77.8	2+27.0
7B-11	200	Yes		22+73.2	2+32.0
7B-12	122	Yes		22+67.9	2+27.2
7B-13	2			22+68.0	2+35.9
7B-13A	10.6			22+67.9	2+35.4
7B-13B	200	Yes		22+69.6	2+36.9
7B-14	200	Yes		22+65.8	2+31.0
7B-15	200	Yes		22+65.8	2+35.6
7B-16	200	Yes		22+66.8	2+36.7
7B-17	200	Yes		22+68.0	2+28.6
7B-18	200	Yes		22+63.8	2+35.7

* From Elev. +30 ft.

Table C-7
Page 3

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
7B-19	20			22+81.1	2+29.6
7B-19A	200	Yes		22+82.0	2+29.2
7B-20	200	Yes		22+76.0	2+23.1
7B-21	200	Yes		22+69.0	2+23.3
7B-22	10			22+79.6	2+26.0
7B-22A	200	Yes		22+80.8	2+25.3
7B-23	20			22+74.5	2+23.2
7B-23A	200	Yes		22+75.5	2+23.2
7B-24	200	Yes		22+80.0	2+30.5
7B-25	200	Yes		22+66.9	2+27.4
7B-26	200	Yes		22+67.0	2+23.3
7B-27	200	Yes		22+74.5	2+27.4
A7	110	Yes		22+45	2+47
A13	70	Yes		22+45	2+41
Am13.5	70	Yes		22+46	2+41
B5	100	Yes		22+47	2+49
B9	60			22+47	2+45
B13	70	Yes		22+47	2+41
B19	63	Yes		22+47	2+35
Bm19	65	Yes		22+48	2+35
C9	10			22+49	2+45
Cm5	7			22+50	2+49
D5	100	Yes		22+51	2+49
D9	70			22+51	2+45
D13	60			22+51	2+41
D15	70	Yes		22+51	2+39
D19	65	Yes		22+51	2+35
Dm15	70	Yes		22+52	2+39
E6	85	Yes		22+53	2+48
E9	100			22+53	2+45
E13	70	Yes		22+53	2+41
E19	70	Yes		22+53	2+35
Em5	100			22+54	2+49
F16	50			22+55	2+38
Ff5.7	100	Yes		22+56	2+48
Fg13.4	75			22+56	2+41
Fj15	32			22+56	2+39
G5	100	Yes		22+57	2+49
Gb15	38			22+57	2+39
Gm5	80			22+58	2+49
Gm7	100			22+58	2+47
H5	95	Yes		22+59	2+49
H9	85			22+59	2+45
H13	120			22+59	2+41
H19	70	Yes		22+59	2+35

* From Elev. +30 ft.

Table C-7
Page 4

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
Hm18	120			22+60	2+36
I15	70	Yes		22+61	2+39
Ib14	140			22+61	2+40
J5	100	Yes		22+63	2+49
J9	115			22+63	2+45
Jb23	80			22+63	2+31
Jm10	75	Yes		22+64	2+44
Jm17	120			22+64	2+37
K11	120			22+65	2+43
K15	120			22+65	2+39
Ka26.6	85			22+65	2+27
Km15	80	Yes		22+66	2+38
L9	80			22+67	2+45
L15	120			22+67	2+39
L16	90	Yes		22+67	2+39
L36	70			22+67	2+18
L43	60			22+67	2+11
Lb23	120			22+67	2+31
M5	80	Yes		22+69	2+49
M13	80			22+69	2+41
M23	120			22+69	2+31
M26	120			22+69	2+28
Ms23.1	135			22+71	2+31
N7	60			22+71	2+47
N13	80			22+71	2+41
N15	70			22+71	2+39
N45	80			22+71	2+09
N48	60			22+71	2+06
O11	100	Yes		22+73	2+43
O15	70			22+73	2+39
Od27.3	120			22+73	2+27
P11	9.5			22+75	2+43
P19	60			22+75	2+35
P43	60			22+75	2+11
P45	80			22+75	2+09
P48	60			22+75	2+06
Pm21.9	75			22+76	2+32
Q47	65	Yes		22+77	2+07
Qd27.3	80			22+77	2+27
Qe30.7	85			22+78	2+23
Qp35.3	100			22+78	2+19
R45	80			22+79	2+09
R48	60			22+79	2+06
Ra39.2	100			22+79	2+15
Rd24.1	80			22+79	2+30
Rm22	80			22+80	2+32

* From Elev. +30 ft.

Table C-7
Page 5

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
Rm41	95	Yes		22+80	2+13
S42	80			22+81	2+12
Sc29.5	80			22+81	2+25
Sd33	80			22+81	2+21
Sh36.9	100			22+82	2+17
St26	80			22+83	2+28
T43	70			22+83	2+11
T47	80			22+83	2+07
Tr31.3	60			22+85	2+23
Tt35.2	80			22+85	2+19
U27	65			22+85	2+27
U38.3	80			22+85	2+16
U42	80			22+85	2+12
U45	80			22+85	2+09
U48	60			22+85	2+06
Un28.3	60			22+86	2+26
V45	35			22+87	2+09
Vo37.6	80			22+88	2+16
W47	70			22+89	2+07
Wd30.5	60			22+89	2+24
X48	80			22+91	2+06
Xb35.7	60			22+91	2+18
Xe39.6	80			22+92	2+14
Y45	85			22+93	2+09
Y47	75	Yes		22+93	2+07
Ys35.5	60			22+95	2+19
Yt37.2	80			22+95	2+17
Zf40.6	60			22+96	2+13
AA47	85	Yes		22+97	2+07
AA48	80			22+97	2+06
AAt37.3	60			22+99	2+17
BB45	60			22+99	2+09
BBg40.6	60			23+00	2+13
BBm48	80	Yes		23+00	2+06
CC48	80			23+01	2+06
DD48	12			23+03	2+06
F9	80			22+55	2+45
GM11	80			22+58	2+43
Hm13	100			22+60	2+41
I5	59			22+61	2+49
I9	20			22+61	2+45
I13	10			22+61	2+41
I17	90			22+61	2+37
Im5	28			22+62	2+49
Im7	75			22+62	2+47

* From Elev. +30 ft.

Table C-7
Page 6

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
J17	120			22+63	2+37
K13	120			22+65	2+41
K37	70	Yes		22+65	2+17
L5	60			22+67	2+49
L11	80			22+67	2+43
M17	100			22+69	2+37
M24	120			22+69	2+30
N44	60	Yes		22+71	2+10
O17	110	Yes		22+73	2+37
Pm31.5	90			22+76	2+23
Q19	27			22+77	2+35
Q21	80	Yes		22+77	2+33
V27	70	Yes		22+87	2+27
W45	80	Yes		22+89	2+09
Z48	80			22+95	2+06
RW1	45	Yes		22+46	2+60
RW2	41			22+49	2+62
RW3	41			22+46	2+65

* From Elev. +30 ft.

TABLE C-8

SUMMARY OF EXPLORATION, DEEP EXPLORATION, AND SHALLOW EXPLORATION/GROUTING BORINGS AT WELL 8

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
8A	57			24+52.7	2+98.8
8B	38			24+50.2	3+07.5
8C	58			24+54.2	2+93.6
8D	39			24+45.6	3+02.6
8E	61		Yes	24+55.2	2+77.1
8F	47			24+55.2	2+73.1
8G	47			24+47.3	2+79.7
8H	47			24+63.2	2+83.1
8I	57			24+62.7	2+86.6
8J	57			24+58.7	2+98.6
8K	57			24+43.7	2+96.3
8L	57			24+45.3	2+86.6
8M	33			24+58.0	3+10.2
8N	57			24+66.0	3+13.0
8O	65			24+55.2	2+81.1
8P	15			24+41.2	3+06.6
8Q	63		Yes	24+51.5	3+03.3
8R	57			24+40.7	3+01.5
8S	15			24+50.2	3+12.5
8T	31			24+51.2	3+06.1
8U	30			24+52.2	3+01.0
8V	29			24+53.3	2+96.3
8W-1	16			24+46.2	3+05.5
8W-2	25				
8X	57			24+57.1	3+06.5
8Y	29			24+55.0	3+09.3
8AA	28			24+55.2	2+84.6
8RR	63			24+48.0	2+94.8
8SS	37			24+57.6	3+03.4
8TT	60			24+55.2	2+93.6
8UU	32			24+57.0	2+92.4
8VV	70			24+51.6	3+01.8
8WW	16			24+46.5	3+09.0
8XX	22			24+56.0	3+03.5

* From Elev. +30 ft.

Table C-8
Page 2

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
8YY	32			24+54.1	3+01.3
8ZZ	19			24+56.2	3+09.1
8BB				24+55.1	2+90.6
8CC				24+57.9	2+88.8
8DD				24+49.2	2+86.6
8A-1	64			24+38.9	3+02.8
8A-2	88		Yes	24+43.9	3+05.2
8A-3	64			24+47.4	3+09.5
8A-4	36			24+52.6	3+12.1
8A-5	45		Yes	24+54.8	3+12.2
8A-6	55		Yes	24+58.5	3+15.9
8A-7	55		Yes	24+62.3	3+18.6
8A-8	40			24+52.4	2+96.4
8A-9	56			24+35.9	2+95.7
8A-10	55			24+36.2	2+87.9
8A-11	79		Yes	24+53.8	2+93.7
8A-12	110		Yes	24+51.3	2+92.3
8A-13	52		Yes	24+54.7	2+80.1
8A-14	62		Yes	24+58.1	2+78.2
8A-15	42		Yes	24+45.6	3+06.3
8A-16	36		Yes	24+49.9	3+10.2
8A-17	36			24+57.4	3+13.5
8A-18	55			24+52.4	3+02.4
8A-19	90		Yes	24+51.4	2+94.1
8A-20	70		Yes	24+48.0	3+00.2
8A-21	92		Yes	24+56.5	2+82.0
8A-22	60			24+55.7	3+06.1
8A-23	57			24+61.3	2+81.5
8A-24	60			24+57.5	2+97.0
8A-25	59			24+44.3	2+97.8
8A-26	57			24+47.5	2+91.2
8A-27	68		Yes	24+45.3	3+03.1
8B-1	180	Yes		24+50.2	2+86.4
8B-2	150			24+52.7	2+90.9
8B-3	180	Yes		24+57.7	2.90+9
8B-4	180	Yes		24+60.2	2+86.6
8B-5	180	Yes		24+57.7	2+82.2
8B-6	180	Yes		24+52.7	2+82.2
8B-7	180	Yes		24+51.2	2+93.5
8B-8	180	Yes		24+50.0	2+89.6
8B-9	180	Yes		24+55.2	2+92.6
8B-10	180	Yes		24+60.4	2+89.6
8B-11	180	Yes		24+60.4	2+83.6

* From Elev. +30 ft.

Table C-8
Page 3

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	Site Coordinates at Ground Level W
8B-12	180	Yes		24+55.2	2+80.6
8B-13	180	Yes		24+50.0	2+83.6
8B-14	180	Yes		24+51.4	2+89.3
8B-15	21			24+52.7	2+92.2
8B-16	180	Yes		24+54.0	2+92.1
8B-17	180	Yes		24+52.4	2+91.5
8B-18	180	Yes		24+51.0	2+91.0
8B-19	180	Yes		24+50.0	2+94.0
A22	30			24+34.5	2+97.4
Bo21.9	30			24+35.3	2+99.3
Ch20.8	26	Yes		24+36.1	2+00.7
Do20.2	35	Yes		24+38.7	3+02.2
Dv21.1	21	Yes		24+39.6	3+01.5
E26	25			24+41.3	2+96.8
E30	25			24+42.5	2+93.0
En19.6	35	Yes		24+40.4	3+03.2
Eq25.5	40.5	Yes		24+42.4	2+97.8
Eu20.1	24.5	Yes		24+41.1	3+03.1
F34	40			24+45.7	2+89.8
F38	40			24+46.9	2+86.0
Fg19.5	35	Yes		24+41.9	3+03.9
Fu19.7	35	Yes		24+42.9	3+04.1
G20.1	55.8	Yes		24+43.3	3+03.7
G22	20			24+44.8	3+02.2
G26	40			24+45.1	2+98.0
G28	45			24+45.7	2+96.1
G30	30			24+46.3	2+94.2
G34	45			24+47.6	2+90.4
G38	25			24+48.8	2+86.6
G42	25			24+50.1	2+82.8
G46	32			24+51.3	2+79.0
G50	30			24+52.6	2+75.2
G54	27			24+53.8	2+71.4
Ge33.6	45			24+47.9	2+90.9
Gm19.4	35	Yes		24+44.0	3+04.7
Gm22	20			24+44.8	3+02.2
Gv29.3	50	Yes		24+47.9	2+95.5
H24	45			24+46.4	3+05.5
H28	45			24+47.7	2+96.8
H40	40			24+51.3	2+85.3
He20.5	30.7	Yes		24+45.8	3+04.1
Hm42	40			24+52.8	2+83.7
Ho37.2	50			24+51.6	2+88.4
J22	40			24+46.4	3+07.2
J23	30			24+47.7	3+03.1

* From Elev. +30 ft.

Table C-8
Page 4

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
J26	40			24+48.9	2+99.3
J30	65			24+50.1	2+95.5
J34	30			24+51.4	2+91.7
J46	35			24+55.2	2+80.2
J50	52.5			24+56.4	2+76.4
J54	27			24+57.6	2+72.6
J58	48			24+58.9	2+68.9
Jc19.8	24.5	Yes		24+47.2	3+05.3
Je43	50			24+54.6	2+83.3
Jt18.2	35	Yes		24+48.1	3+07.2
K28	35			24+51.4	2+98.0
K36	45			24+54.0	2+90.4
K42	96			24+55.8	2+84.7
K44	65			24+56.4	2+82.8
K46	28.5			24+57.1	2+80.9
K56	35			24+60.2	2+71.4
Kb19.5	28	Yes		24+48.9	3+06.1
Kq17.6	30	Yes		24+49.5	3+08.4
L22	30			24+51.5	3+04.4
L26	25			24+52.7	3+00.5
L30	30			24+54.0	2+96.7
L34	25			24+55.2	2+92.9
L44	27			24+58.4	2+83.4
L46	53			24+59.0	2+81.5
L50	50			24+60.2	2+77.7
L54	27			24+61.4	2+73.9
L58	50			24+62.7	2+70.1
Le18.4	21.5	Yes		24+50.9	3+08.0
Lm38	60			24+57.4	2+89.4
Lm42	59			24+58.7	2+85.6
Lt21.8	40	Yes		24+53.1	3+05.7
Lv16.7	30	Yes		24+51.7	3+09.9
M56	41			24+64.0	2+72.5
Ma18.1	21.5	Yes		24+52.2	3+08.7
Mn35.2	10			24+58.5	2+92.8
Mo23.1	15			24+54.9	3+04.4
N26	30			24+56.5	3+01.8
N30	41			24+57.7	2+98.0
N33.5	48			24+58.8	2+94.7
N38	40			24+60.3	2+90.3
N42	63			24+61.5	2+86.5
N46	42			24+62.8	2+82.8
N50	50			24+64.0	2+78.9
N54	37			24+65.2	2+75.1
Na16.6	18	Yes		24+53.7	3+10.6
Nd16.2	30	Yes		24+54.1	3+11.4

* From Elev. +30 ft.

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level S	W
Nd18.1	25			24+54.0	3+09.4
Oo16	20	Yes		24+56.5	3+12.2
Ou22.2	30			24+58.9	3+06.7
P18	25			24+57.8	3+10.6
P26	40			24+60.3	3+03.0
Pm15.5	15	Yes		24+58.1	3+13.3
Qm17.7	13.5			24+60.6	3+11.9
F22c	31			24+41.8	3+10.2
G24c	40			24+44.5	2+99.9
Gm29c	40			24+47.0	2+95.5
H26c	39			24+47.0	2+98.7
H32c	25			24+48.9	2+93.0
Hr21c	40			24+46.8	3+03.9
J22.5c	35			24+47.8	3+02.6
J28c	47.5			24+49.6	2+97.4
Jm44c	58			24+55.6	2+82.5
K24c	40			24+50.2	3+01.8
K52c	50			24+58.9	2+75.1
Km21.8c	30			24+50.5	3+04.2
L48c	55			24+59.6	2+79.6
Lm18c	30			24+51.1	3+08.5
Lm31c	35			24+55.2	2+96.1
Ln45c	77			24+59.7	2+82.8
M40c	40			24+59.0	2+87.8
M50c	50			24+62.1	2+78.3

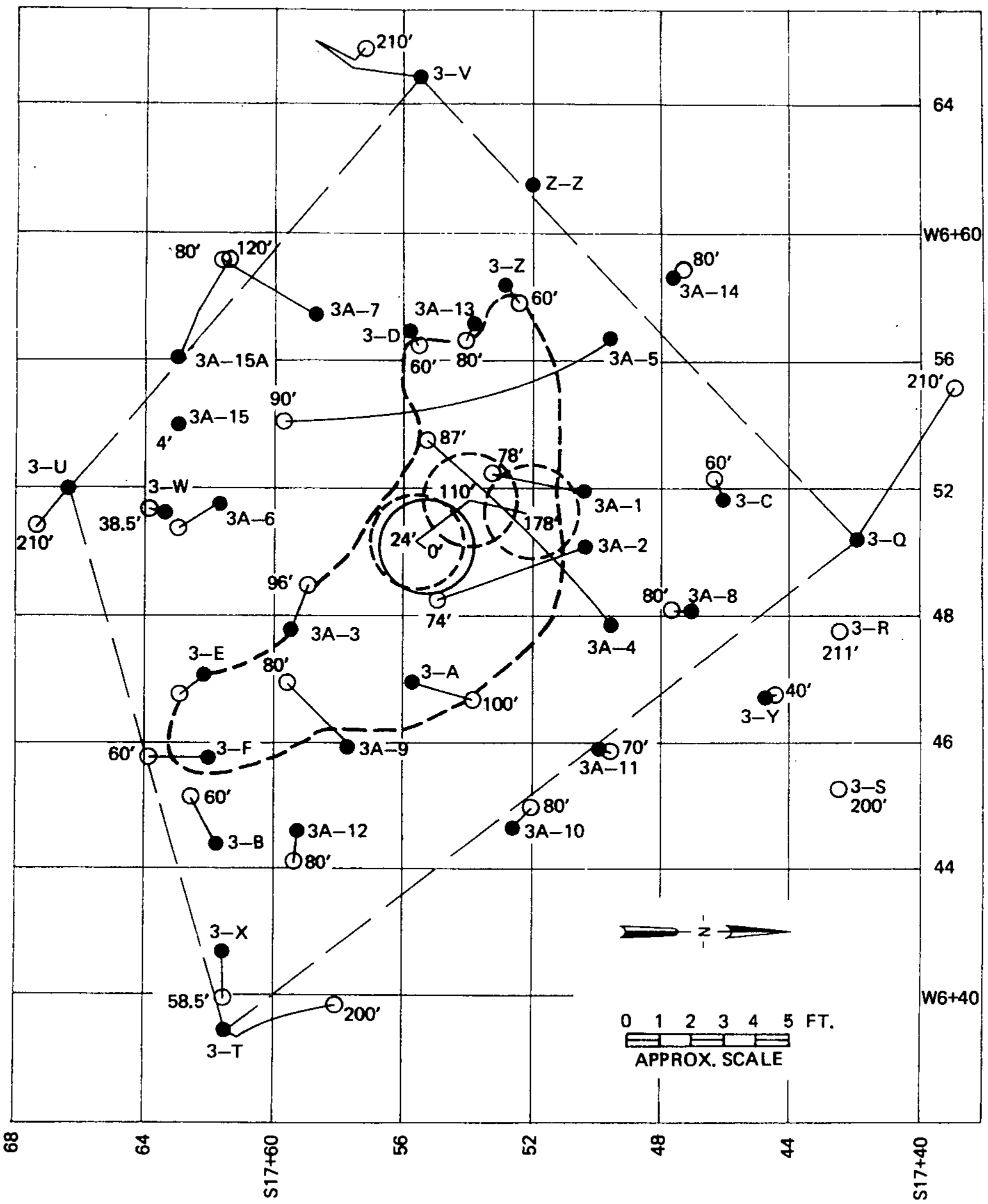
* From Elev. +30 ft.

TABLE C-9

SUMMARY OF EXPLORATION BORINGS AT WELL 10

Boring No.	Total Depth (feet)*	Gyroscopic Multi-Shot Survey	Slope Indicator Survey	Site Coordinates at Ground Level	
				S	W
10B-1	200	Yes		26+10.4	6+28.7
10B-2	200	Yes		26+16.1	6+34.2
10B-3	200	Yes		26+14.2	6+48.0
10B-4	200	Yes		26+05.2	6+24.8
10B-5	130	Yes		26+11.2	6+39.4
10B-6	125	Yes		26+04.6	6+35.0
10B-7	70	Yes		26+15.0	6+38.0

* From Elev. +30 ft.

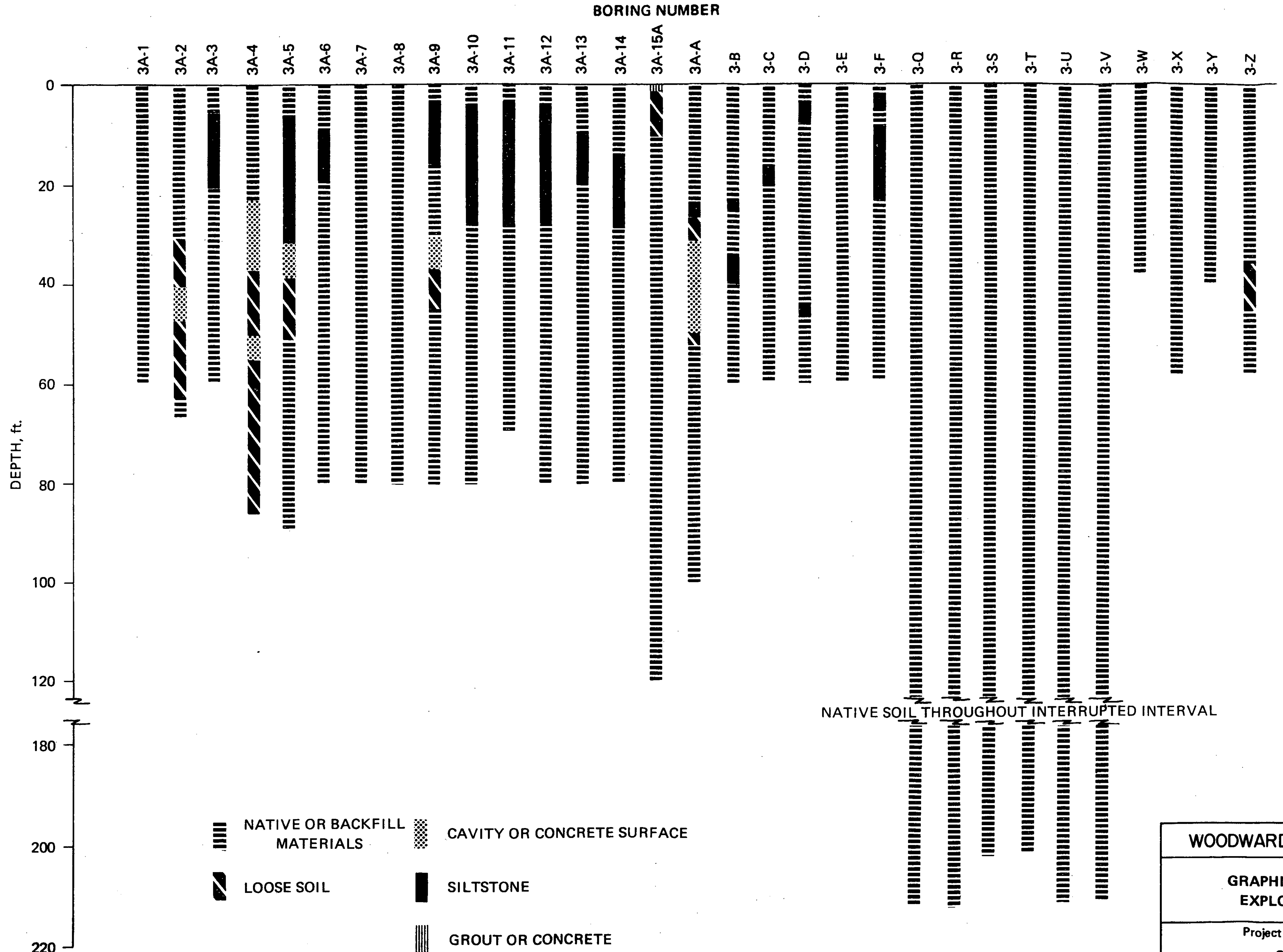


DEWATERING WELL NO. 3 LOCATION OF DRILL HOLES

3-1

Project: SONGS 2 & 3 Project No. 411301	DEWATERING WELL NO. 3 LOCATION OF DRILL HOLES	Fig. C-1a

WOODWARD–CLYDE CONSULTANTS

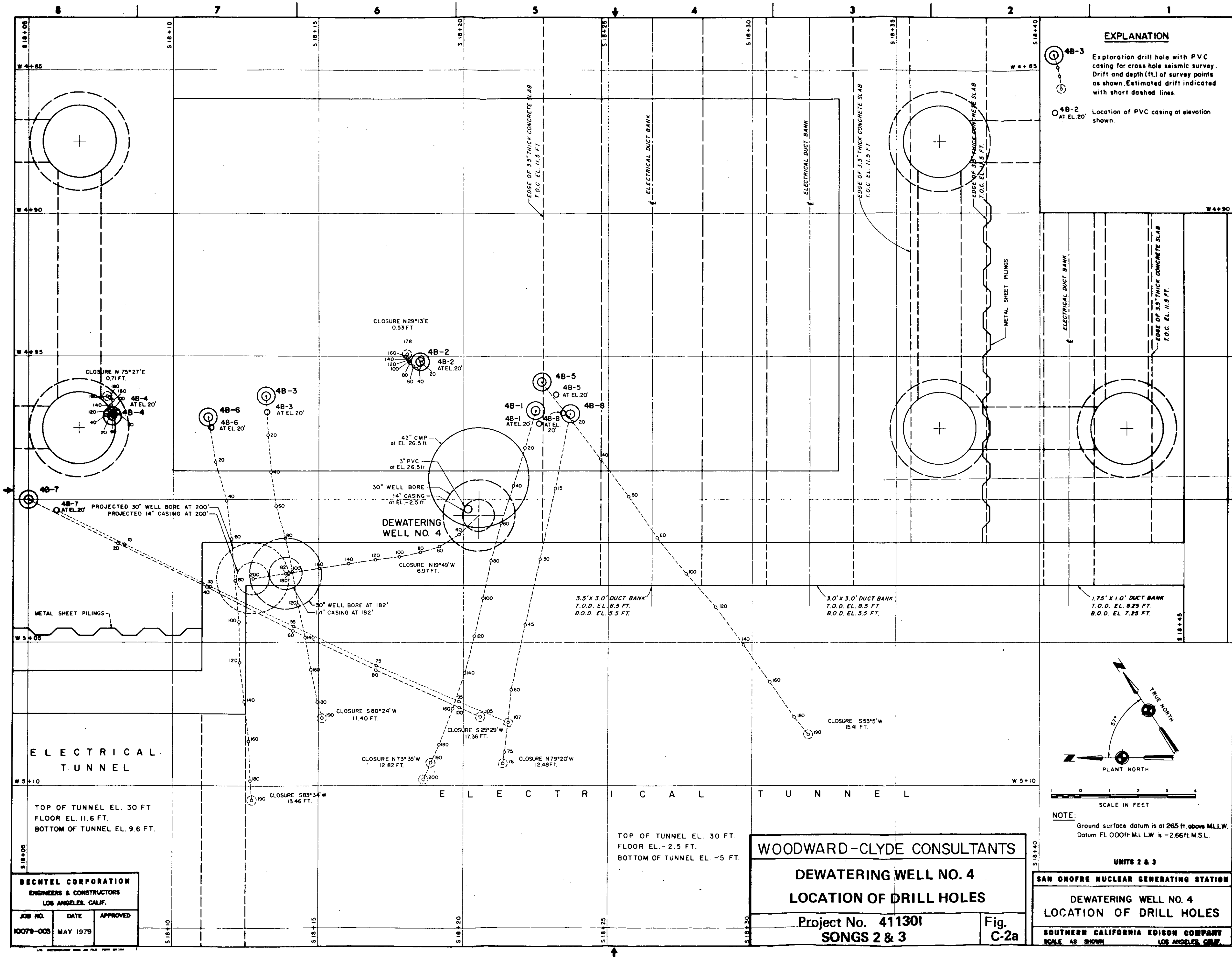


WOODWARD-CLYDE CONSULTANTS

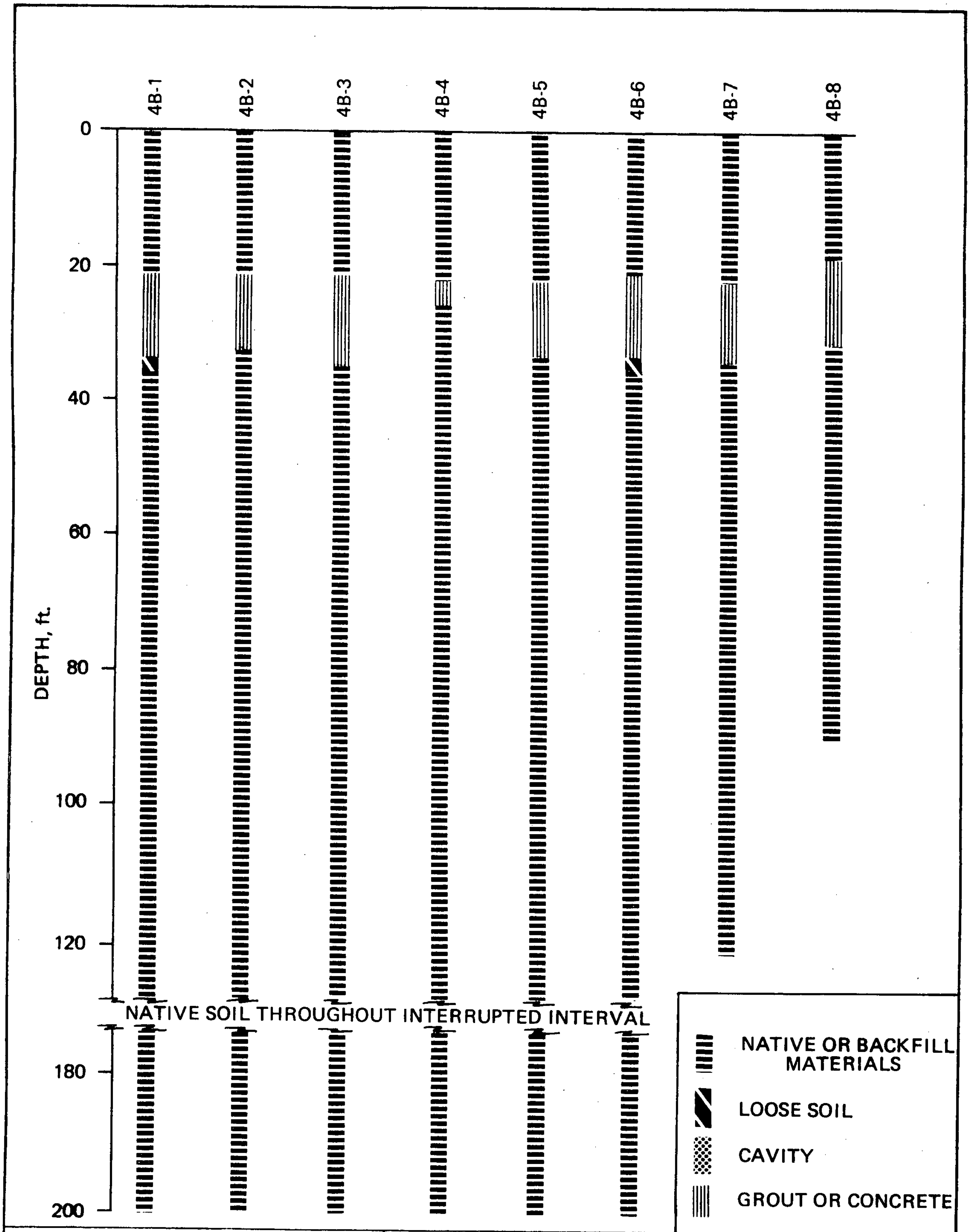
GRAPHIC LOGS, WELL NO. 3
EXPLORATION BORINGS

Project No. 411301
SONGS 2 & 3

Fig. C-1b

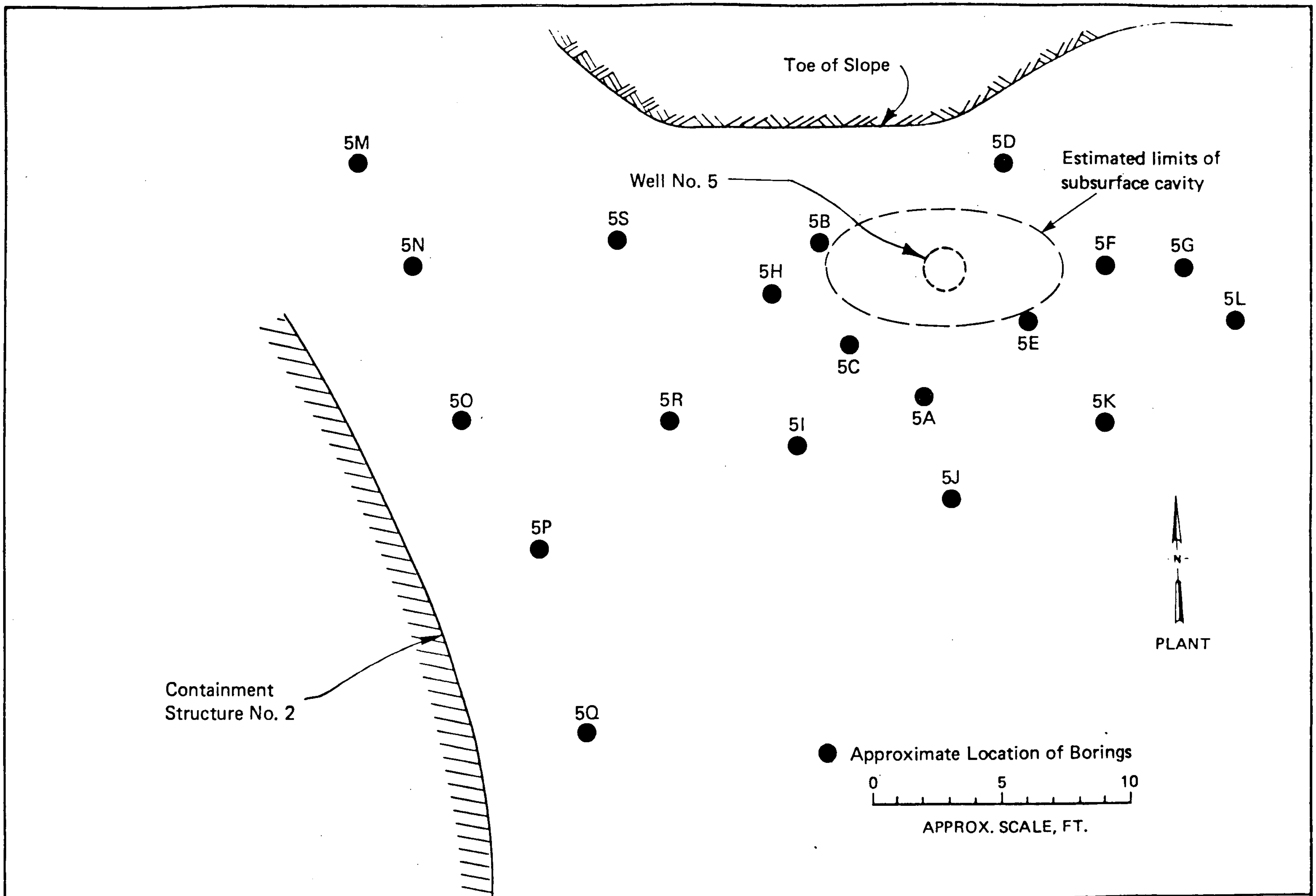


EXPLANATION
4B-3 Exploration drill hole with PVC casing for cross hole seismic survey. Drift and depth (ft.) of survey points as shown. Estimated drift indicated with short dashed lines.
4B-2 AT EL.20' Location of PVC casing at elevation shown.
EDGE OF 3.5' THICK CONCRETE SLAB T.O.C. EL. 11.5 FT.
ELECTRICAL DUCT BANK
METAL SHEET PILINGS
CLOSURE N29°13'E 0.53 FT
CLOSURE N 75°27'E 0.71 FT.
42" CMP at EL. 26.5 ft
3" PVC at EL. 26.5 ft
30" WELL BORE
14" CASING at EL. -2.5 ft
DEWATERING WELL NO. 4
PROJECTED 30" WELL BORE AT 200'
PROJECTED 14" CASING AT 200'
CLOSURE N19°49'W 6.97 FT.
30" WELL BORE AT 182'
14" CASING AT 182'
3.5' X 3.0' DUCT BANK T.O.D. EL. 8.5 FT. B.O.D. EL. 5.5 FT.
3.0' X 3.0' DUCT BANK T.O.D. EL. 8.5 FT. B.O.D. EL. 5.5 FT.
1.75' X 1.0' DUCT BANK T.O.D. EL. 8.25 FT. B.O.D. EL. 7.25 FT.
CLOSURE S80°24'W 11.40 FT.
CLOSURE S25°29'W 17.36 FT.
CLOSURE N73°35'W 12.82 FT.
CLOSURE N79°20'W 12.48 FT.
CLOSURE S53°5'W 15.41 FT.
CLOSURE S83°34'W 13.46 FT.
ELECTRICAL TUNNEL
TOP OF TUNNEL EL. 30 FT. FLOOR EL. 11.6 FT. BOTTOM OF TUNNEL EL. 9.6 FT.
TOP OF TUNNEL EL. 30 FT. FLOOR EL. -2.5 FT. BOTTOM OF TUNNEL EL. -5 FT.
TRUE NORTH
PLANT NORTH
SCALE IN FEET
NOTE: Ground surface datum is at 26.5 ft. above M.L.L.W. Datum EL. 0.00 ft. M.L.L.W. is -2.66 ft. M.S.L.
BECHTEL CORPORATION ENGINEERS & CONSTRUCTORS LOS ANGELES, CALIF.
JOB NO. 10079-003 DATE MAY 1979 APPROVED
WOODWARD-CLYDE CONSULTANTS
DEWATERING WELL NO. 4
LOCATION OF DRILL HOLES
Project No. 411301 SONGS 2 & 3
Fig. C-2a
UNITS 2 & 3
SAN ONOFRE NUCLEAR GENERATING STATION
DEWATERING WELL NO. 4 LOCATION OF DRILL HOLES
SOUTHERN CALIFORNIA EDISON COMPANY
SCALE AS SHOWN LOS ANGELES, CALIF.



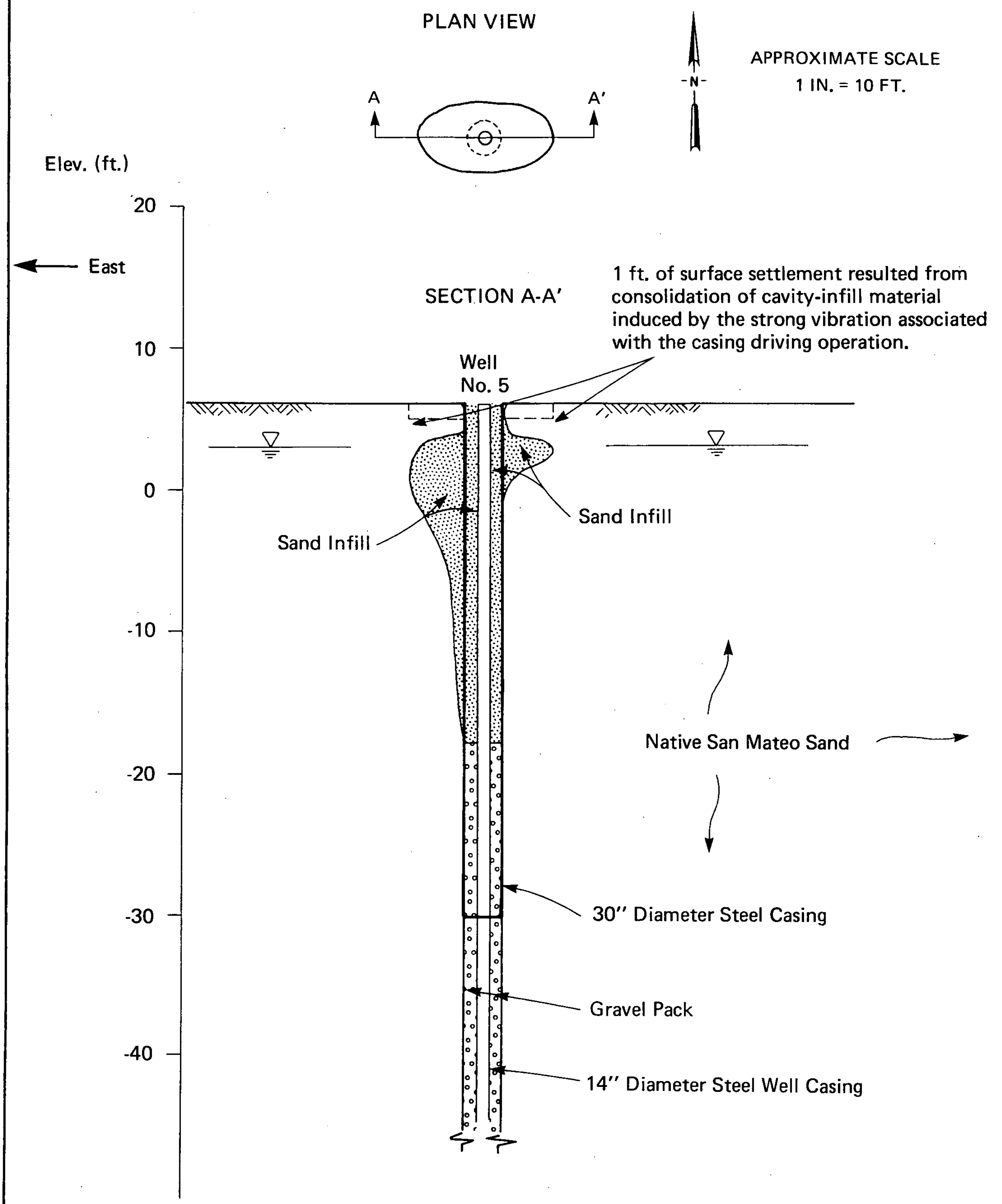
Project: SONGS 2 & 3 Project No. 411301	GRAPHIC LOGS, WELL NO. 4 EXPLORATION BORINGS	Fig. C-2b

WOODWARD—CLYDE CONSULTANTS



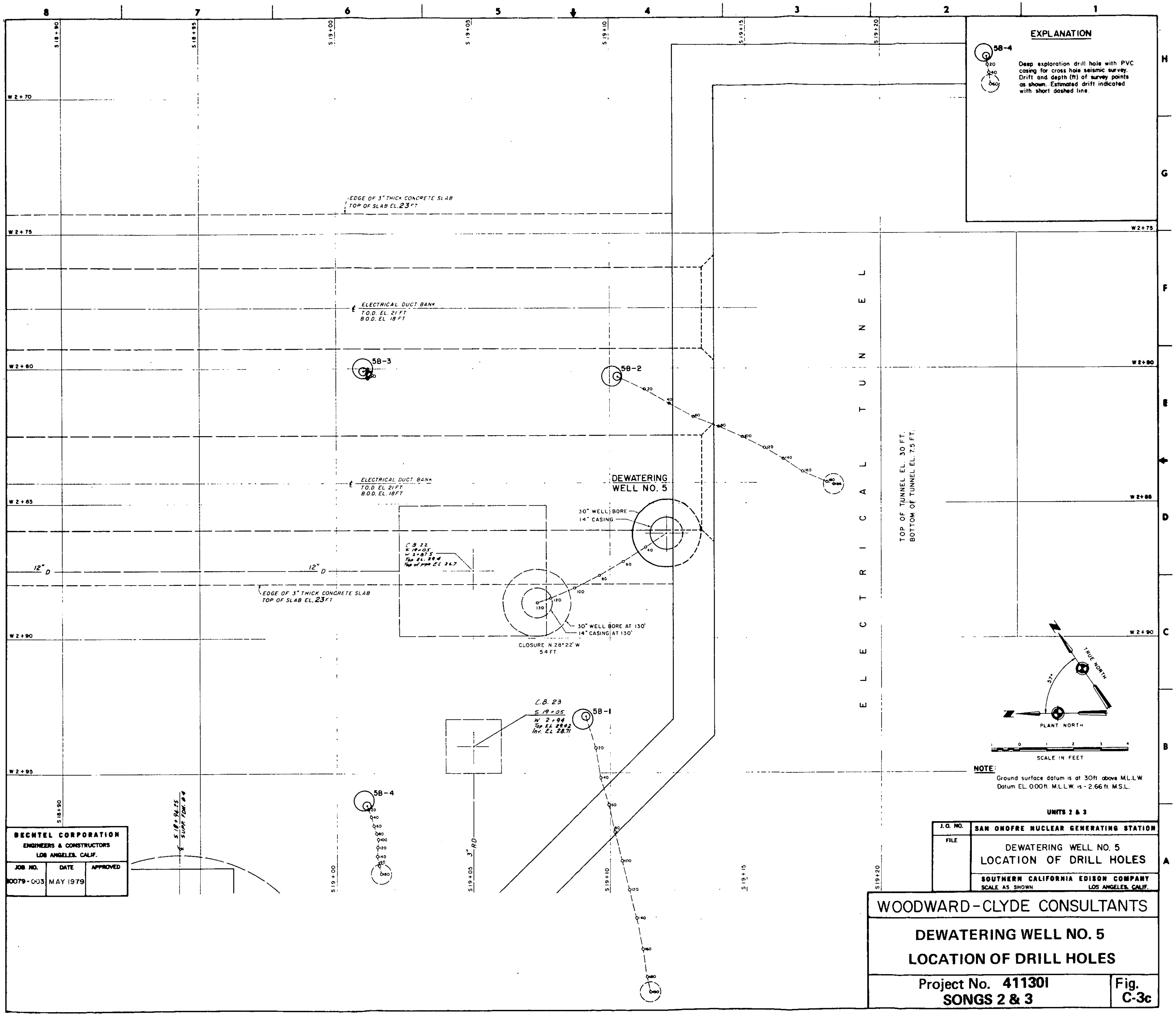
Project: SONGS 2 & 3	PLAN VIEW OF CAVITY AND EXPLORATION BORINGS AT WELL NO. 5	Fig. C-3a
Project No. 411301		

WOODWARD-CLYDE CONSULTANTS



Project:	SONGS 2 & 3	PLAN AND EAST-WEST CROSS SECTION THROUGH CAVITY AT WELL NO. 5	Fig.
Project No.	41130I		C-3b

WOODWARD—CLYDE CONSULTANTS

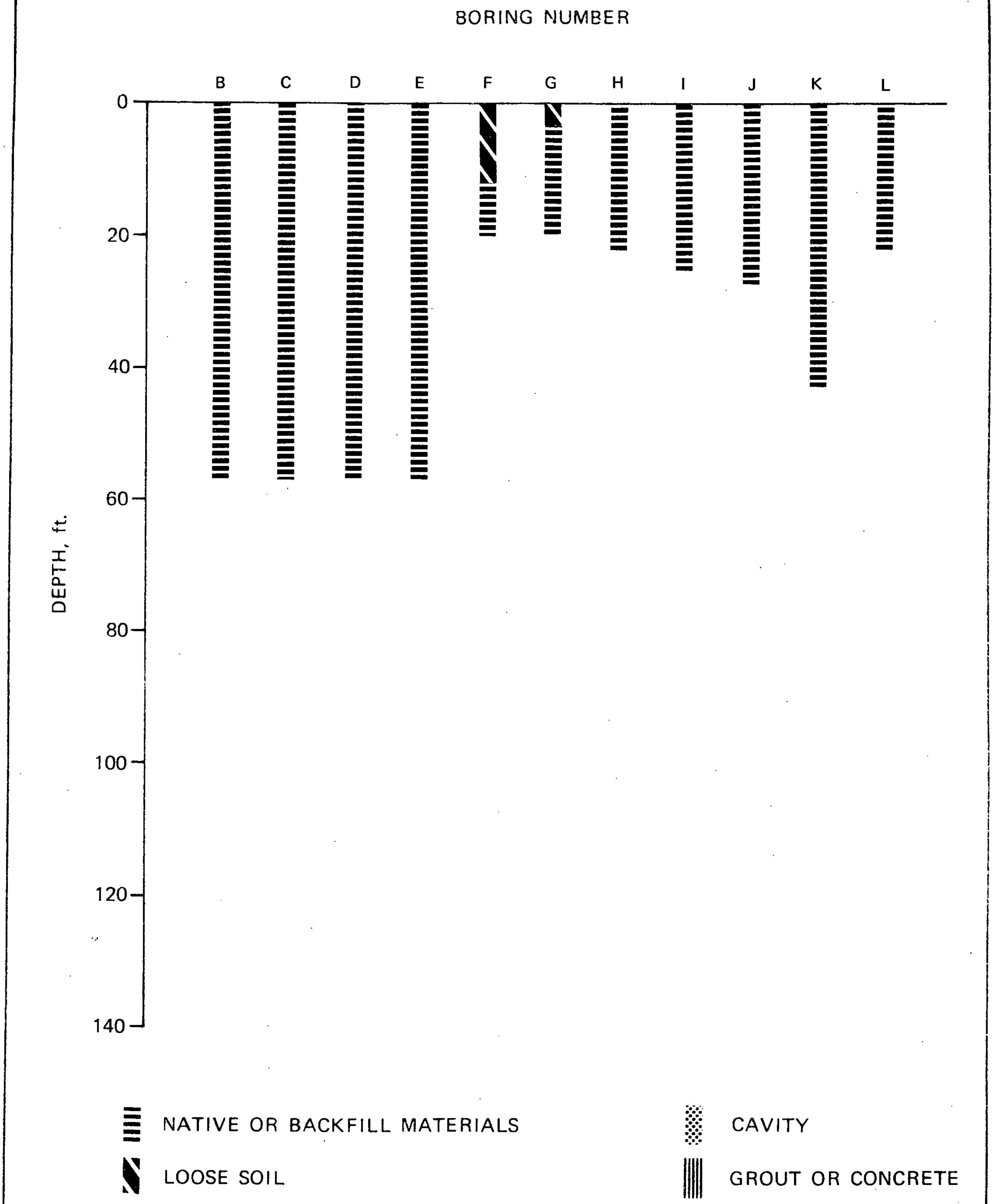


WOODWARD-CLYDE CONSULTANTS

DEWATERING WELL NO. 5
LOCATION OF DRILL HOLES

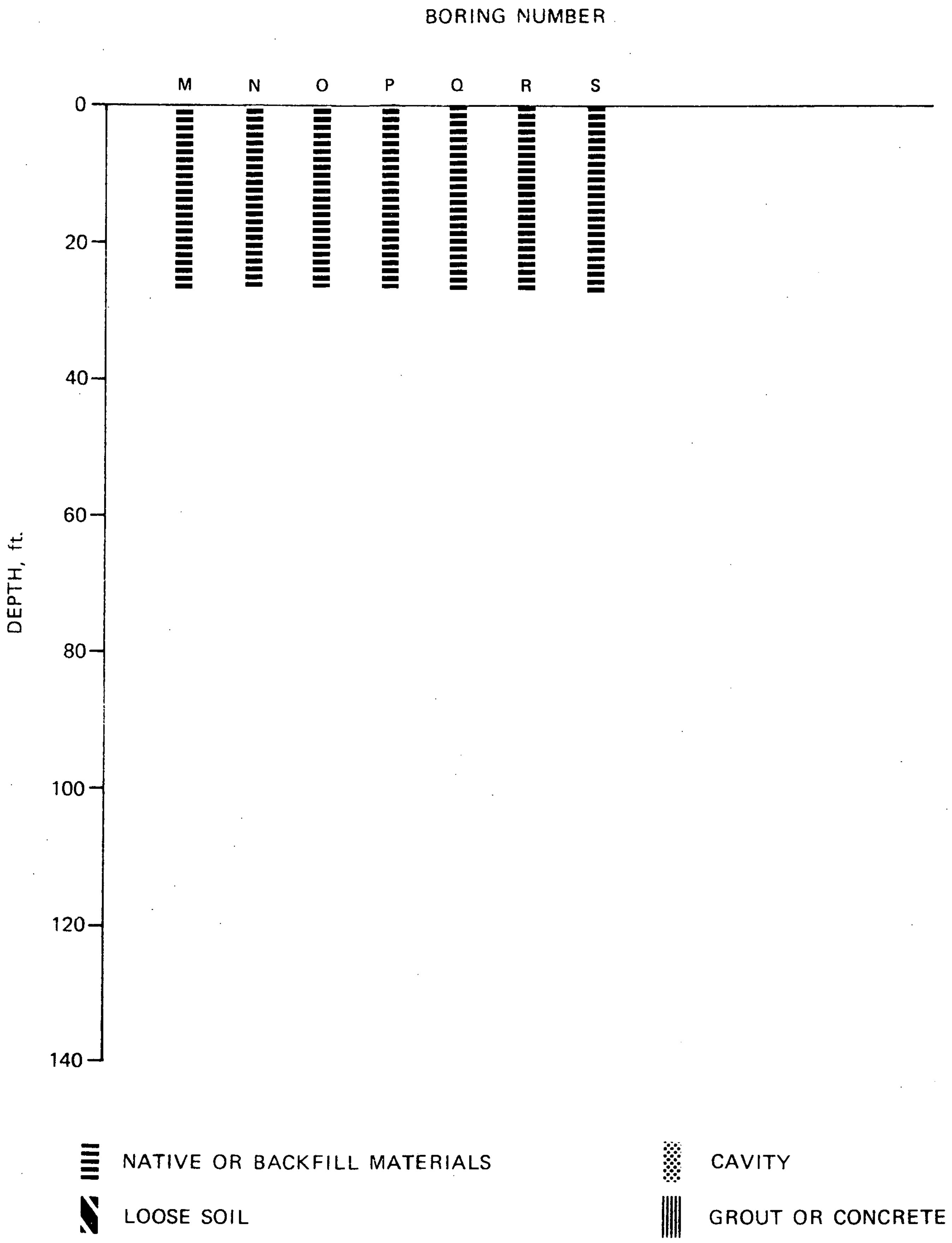
Project No. 411301
SONGS 2 & 3

Fig. C-3c



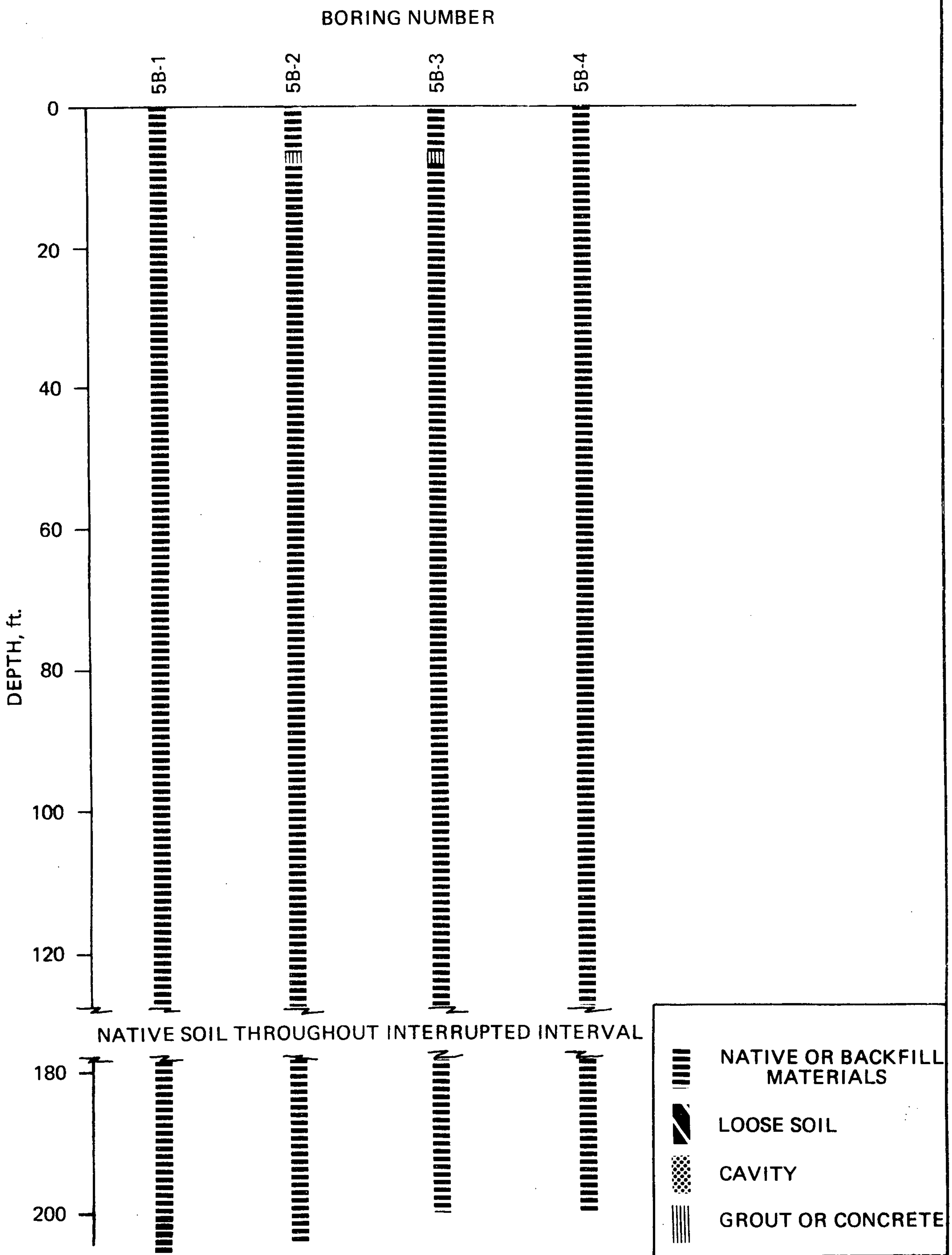
Project: SONGS 2&3	GRAPHIC LOGS, WELL NO. 5	Fig.
Project No. 411301	EXPLORATORY BORINGS	C-3d

WOODWARD-CLYDE CONSULTANTS



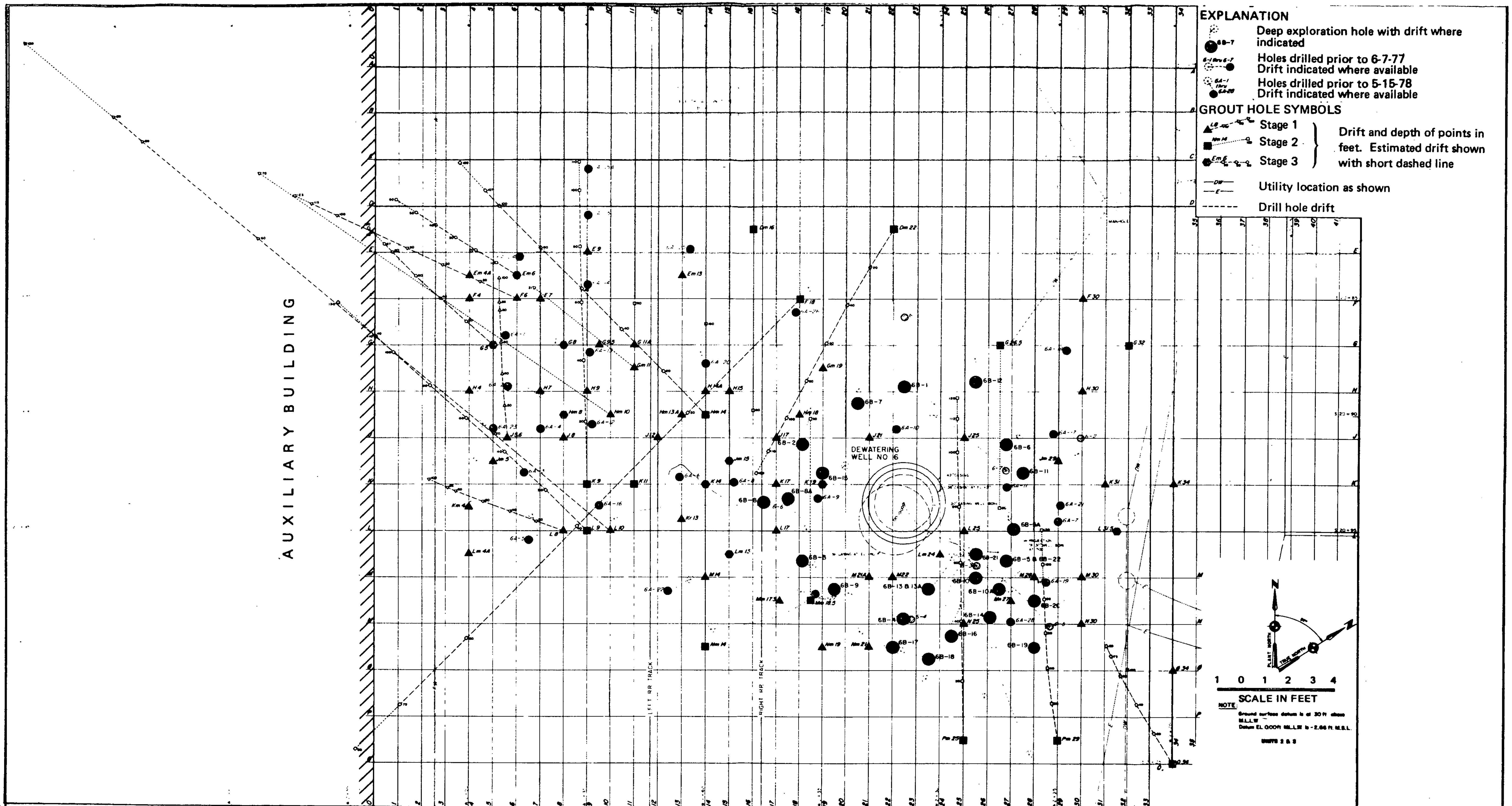
Project:	SONGS 2&3	GRAPHIC LOGS, WELL NO. 5	Fig.
Project No	411301	EXPLORATORY BORINGS	C-3e

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 5	Fig.
Project No.	411301	EXPLORATION BORINGS	C-3f

WOODWARD – CLYDE CONSULTANTS



WOODWARD-CLYDE CONSULTANTS

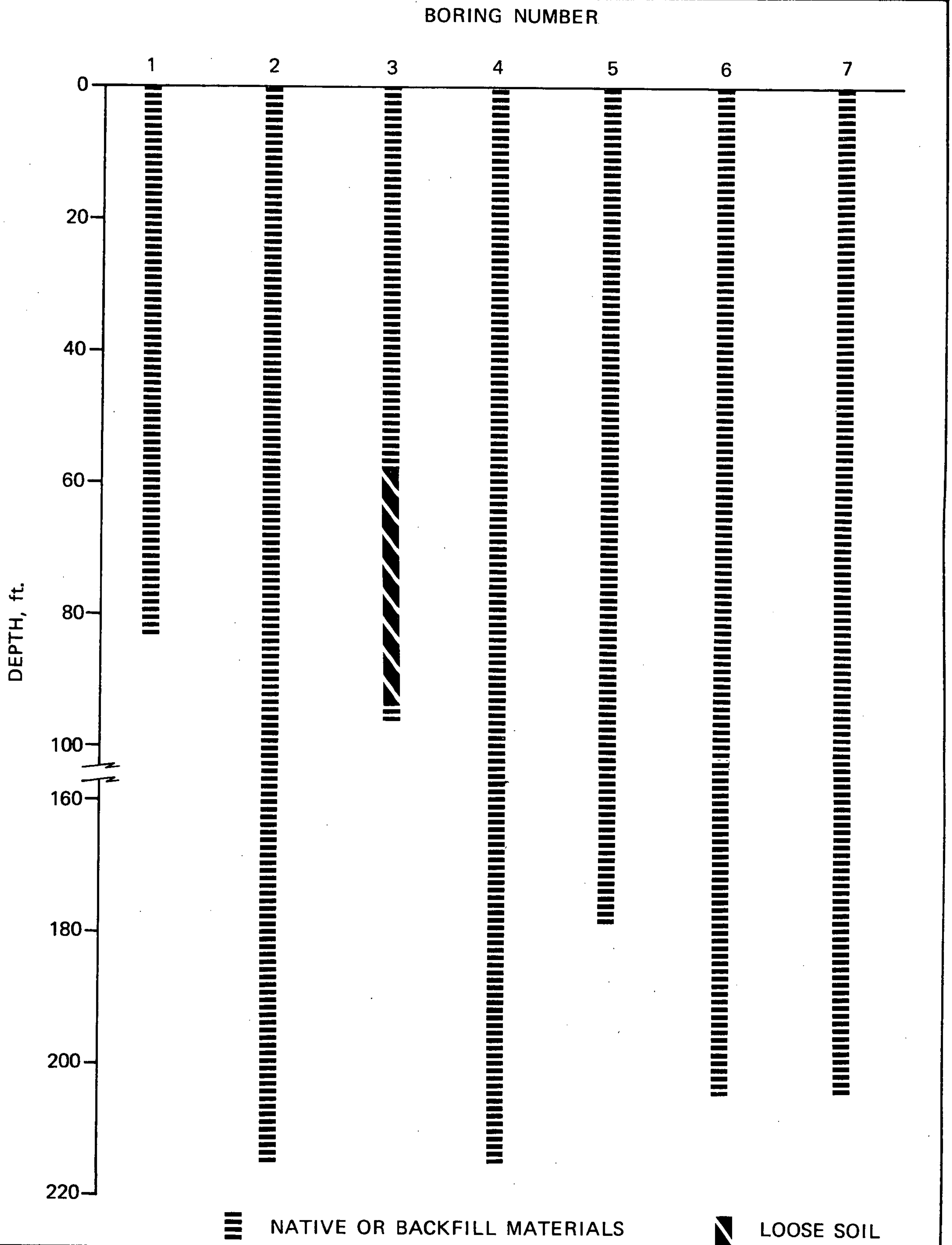
DEWATERING WELL NO. 6

LOCATION OF DRILL HOLES

Project No. 411301

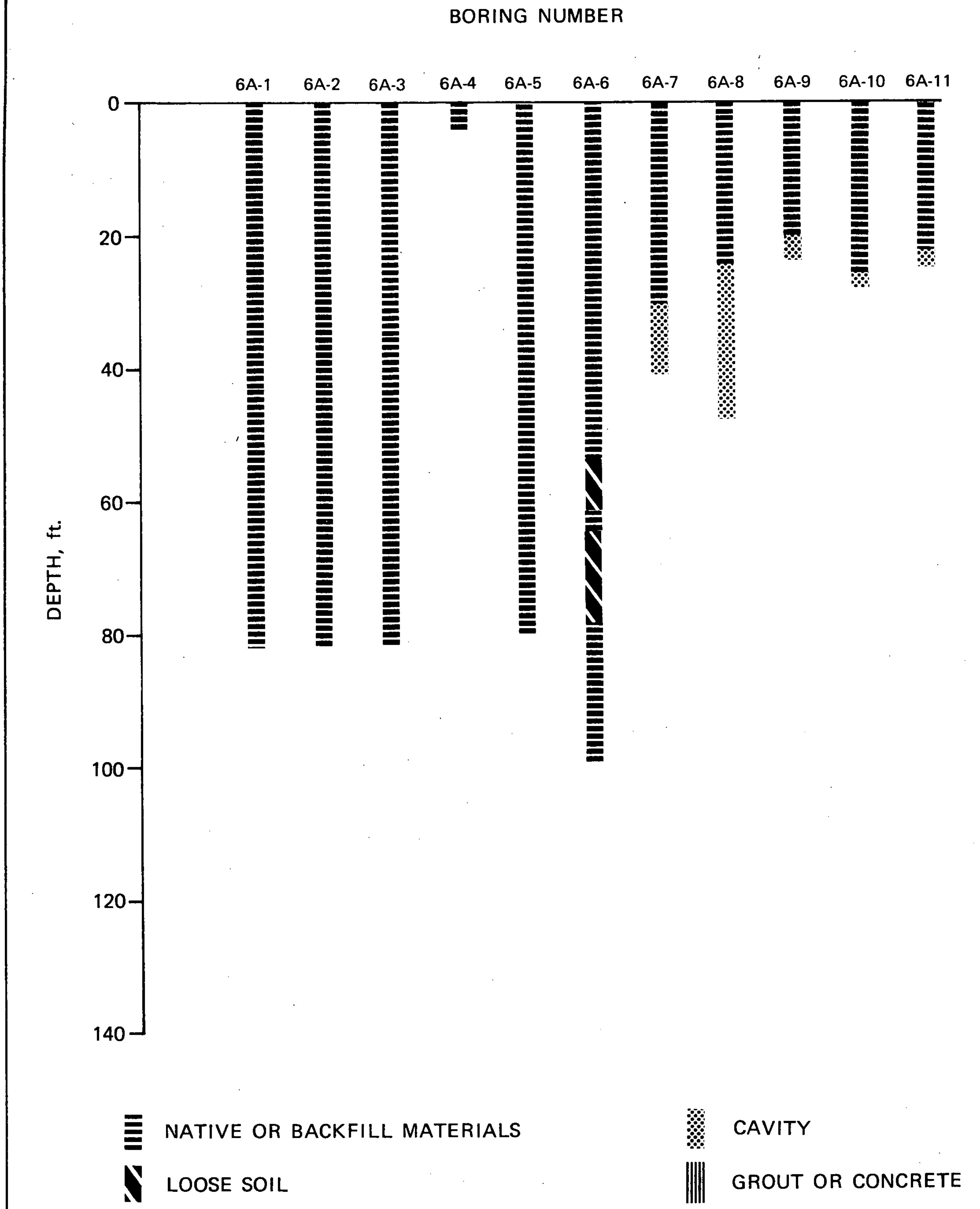
SONGS 2 & 3

Fig. C-4a



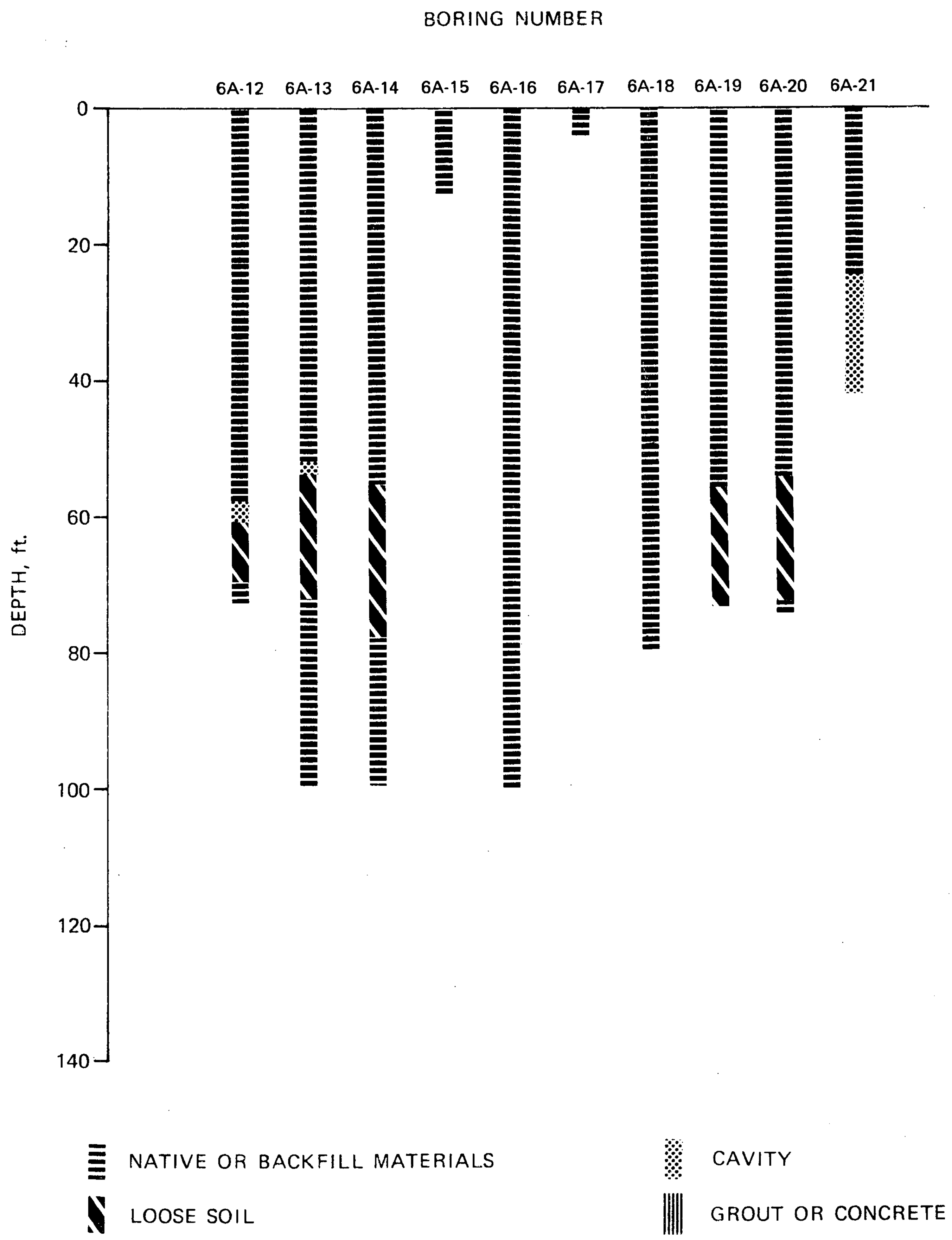
Project:	SONGS 2&3	GRAPHIC LOGS, WELL NO. 6	Fig.
Project No.	41130I	EXPLORATORY BORINGS	C-4b

WOODWARD—CLYDE CONSULTANTS



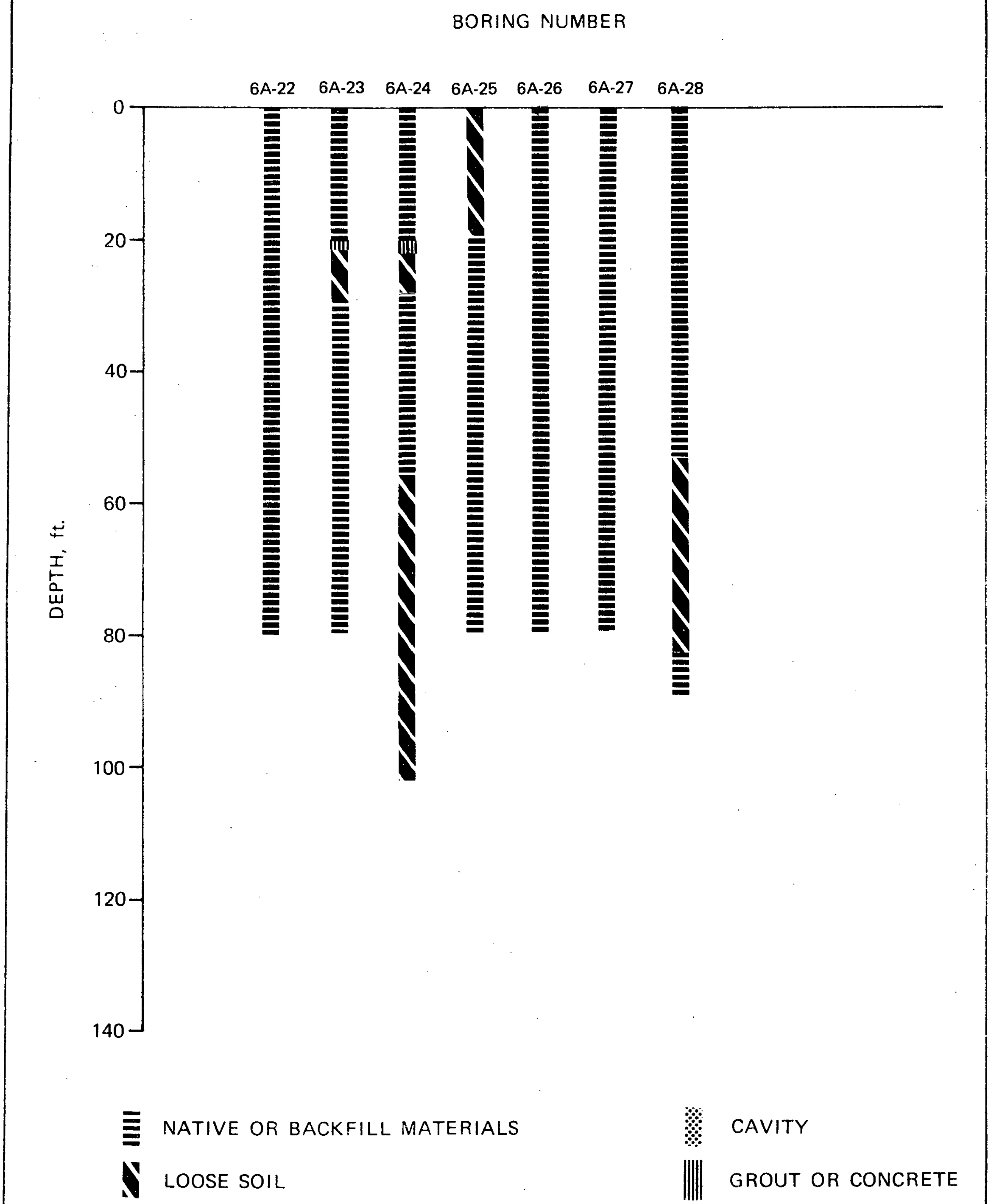
Project: Project No.	SONGS 2&3 411301	GRAPHIC LOGS, WELL NO. 6 EXPLORATORY BORINGS	Fig. C-4c

WOODWARD—CLYDE CONSULTANTS



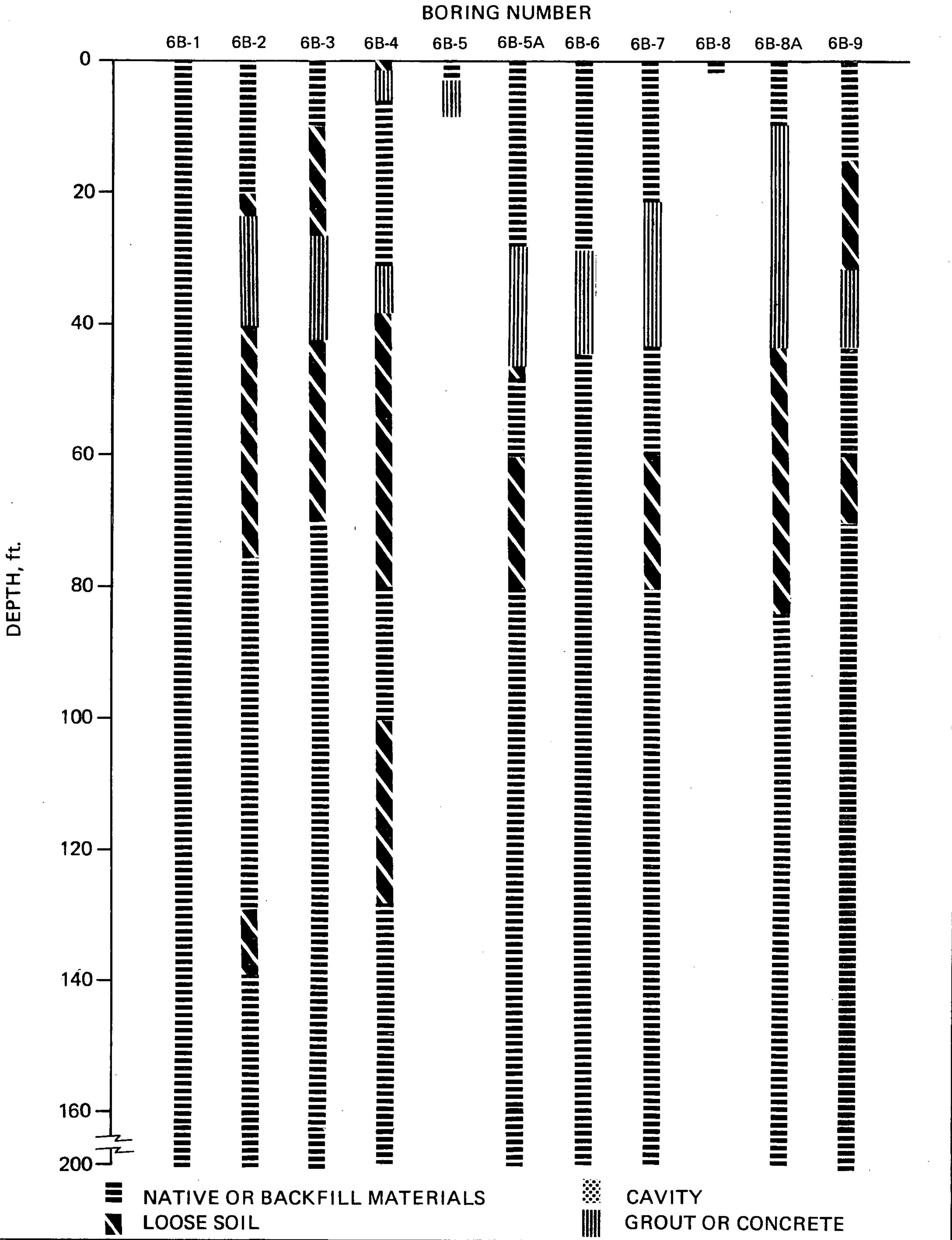
Project:	SONGS 2&3	GRAPHIC LOGS, WELL NO. 6	Fig.
Project No.	411301	EXPLORATORY BORINGS	C-4d

WOODWARD–CLYDE CONSULTANTS



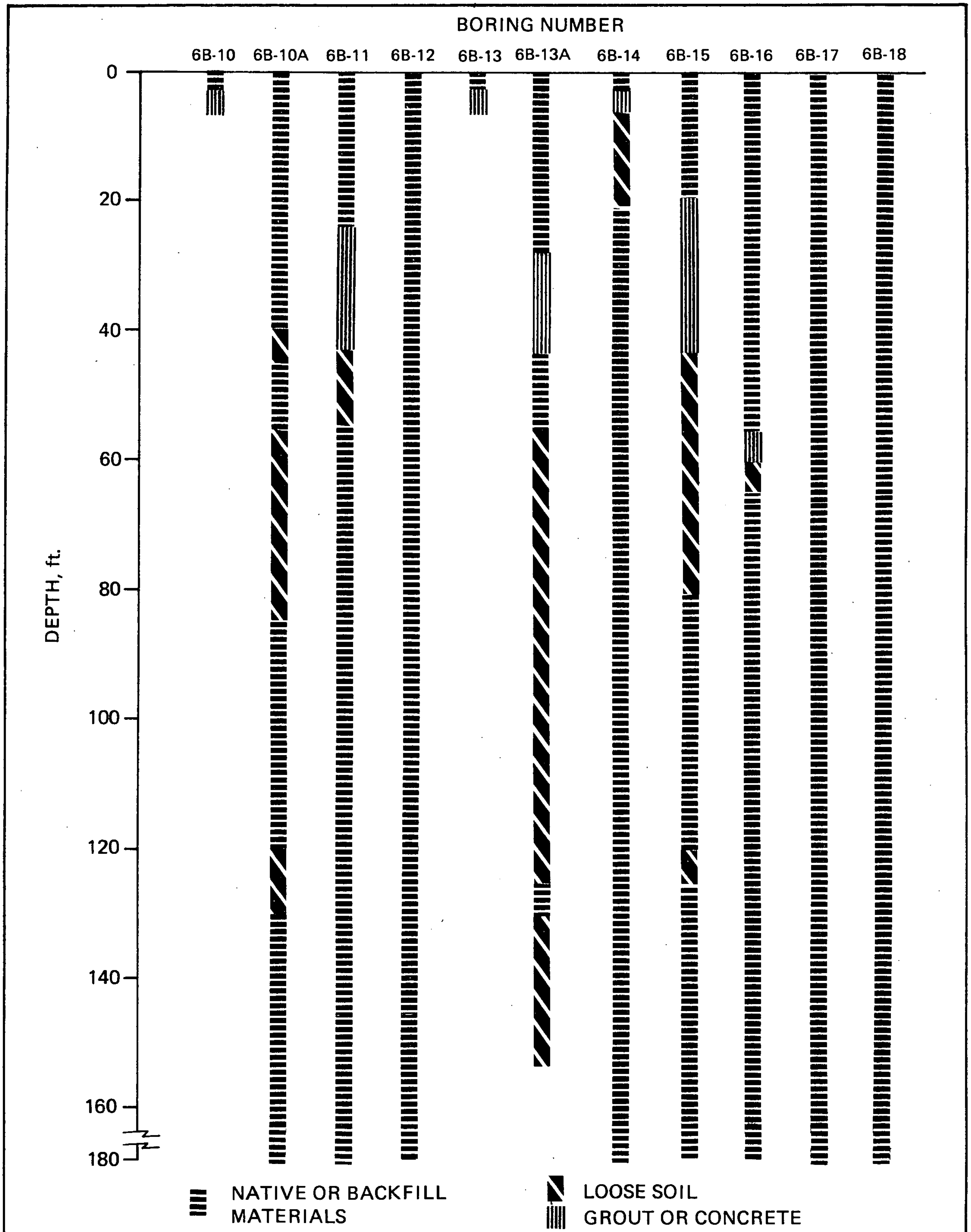
Project:	SONGS 2&3	GRAPHIC LOGS, WELL NO. 6	Fig.
Project No.	411301	EXPLORATORY BORINGS	C-4e

WOODWARD–CLYDE CONSULTANTS



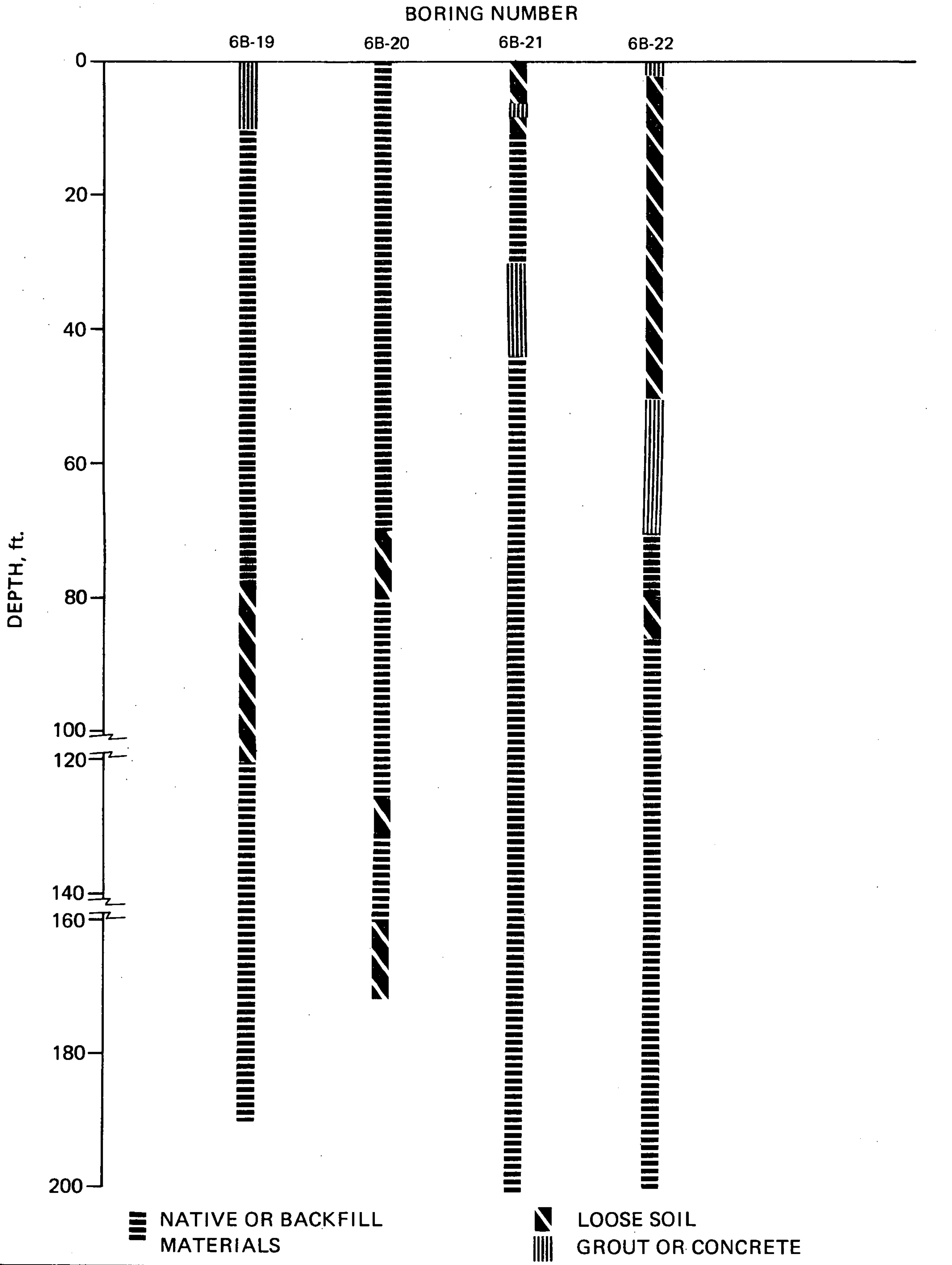
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 6	Fig.
Project No.	411301	DEEP EXPLORATION BORINGS	C-4f

WOODWARD – CLYDE CONSULTANTS



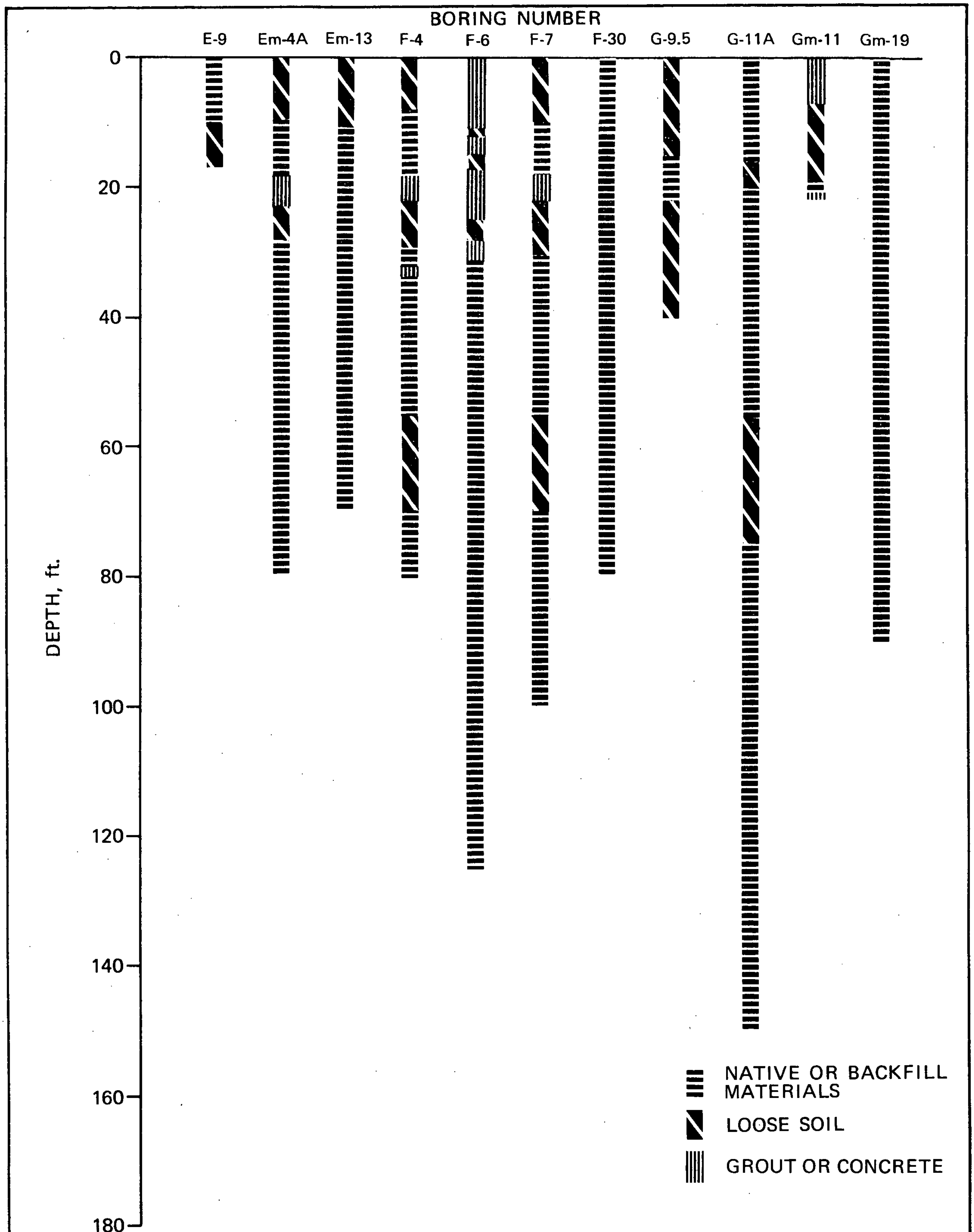
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 6	Fig.
Project No.	411301	DEEP EXPLORATION BORINGS	C-4g

WOODWARD—CLYDE CONSULTANTS



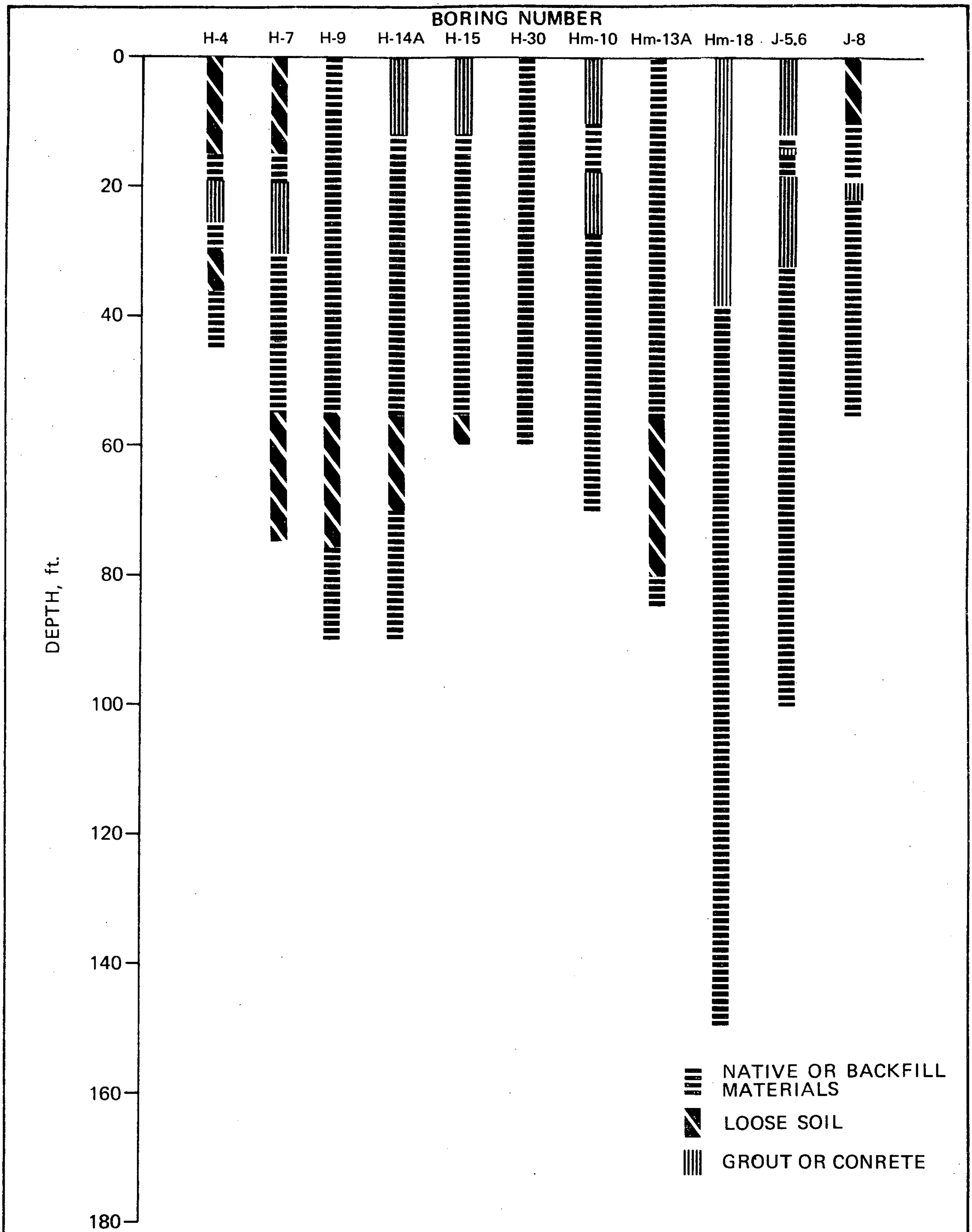
Project: SONGS 2 & 3 Project No. 411301	GRAPHIC LOGS, WELL NO. 6 DEEP EXPLORATION BORINGS	Fig. C-4h

WOODWARD – CLYDE CONSULTANTS



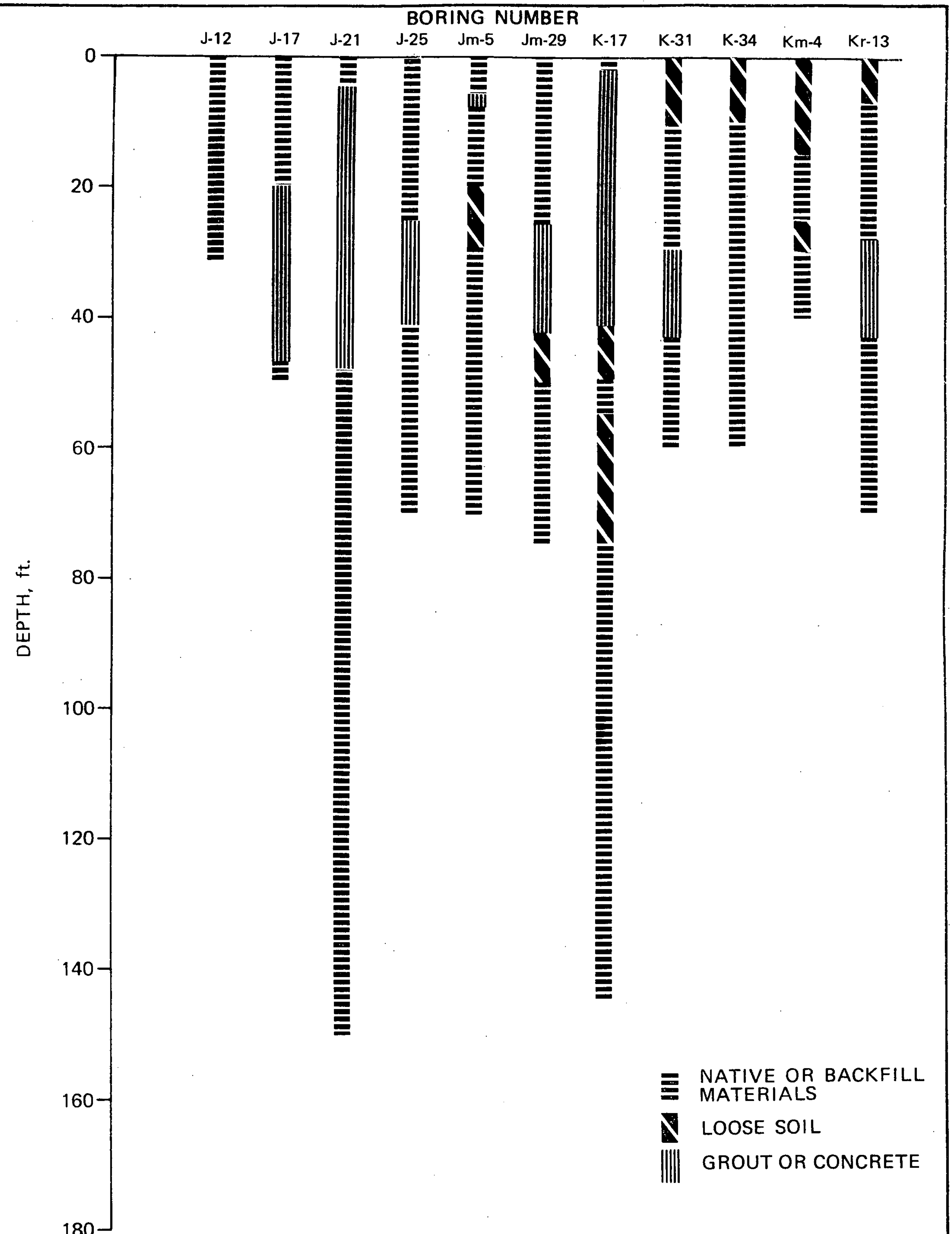
Project:	SONGS 2&3	GRAPHIC LOGS–STAGE I, WELL NO. 6	Fig.
Project No.	41130I	EXPLORATION/GROUTING BORINGS	C-4i

WOODWARD–CLYDE CONSULTANTS



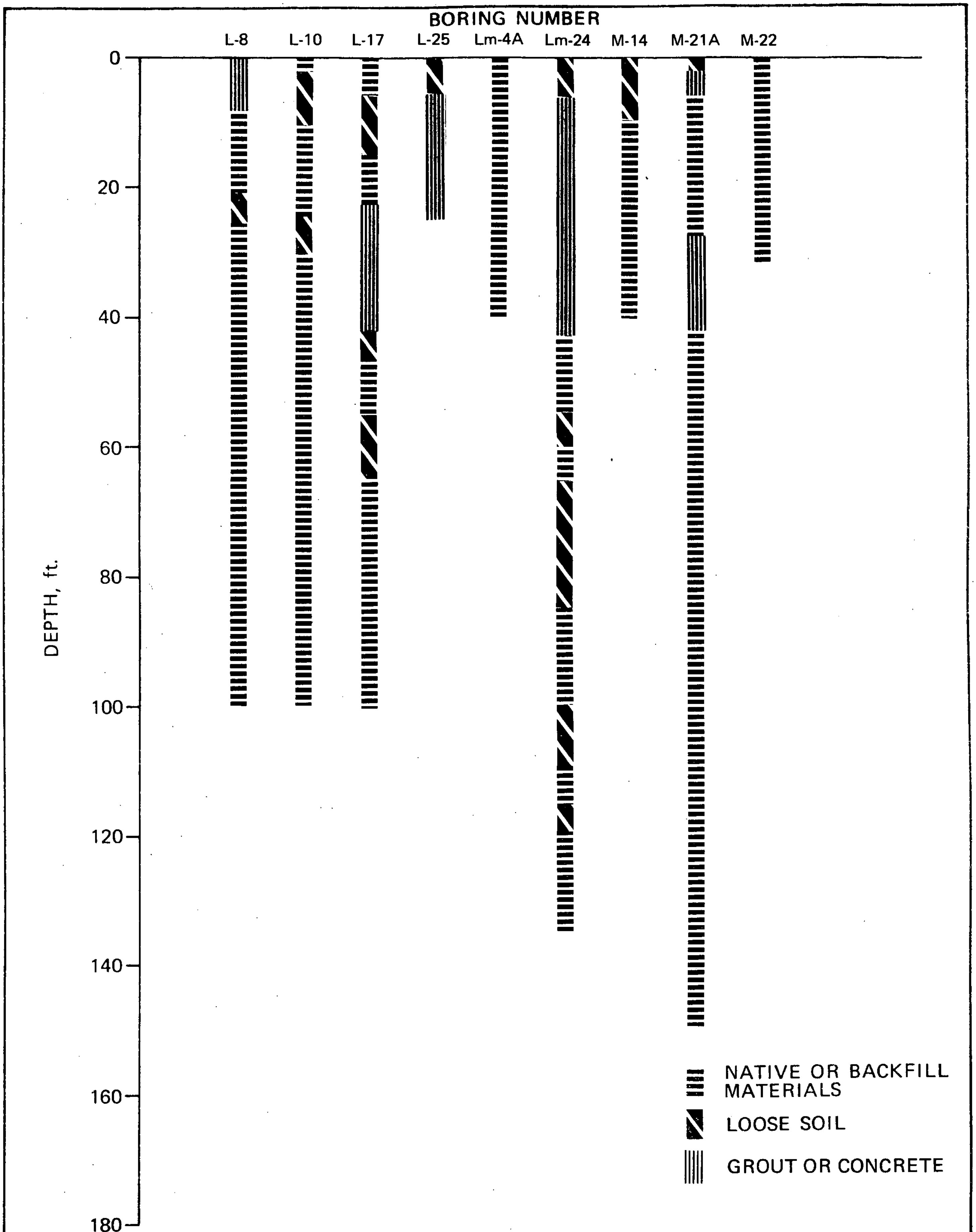
Project: Project No.	SONGS 2&3 411301	GRAPHIC LOGS–STAGE I, WELL NO. 6 EXPLORATION/GROUTING BORINGS	Fig. C-4j

WOODWARD–CLYDE CONSULTANTS



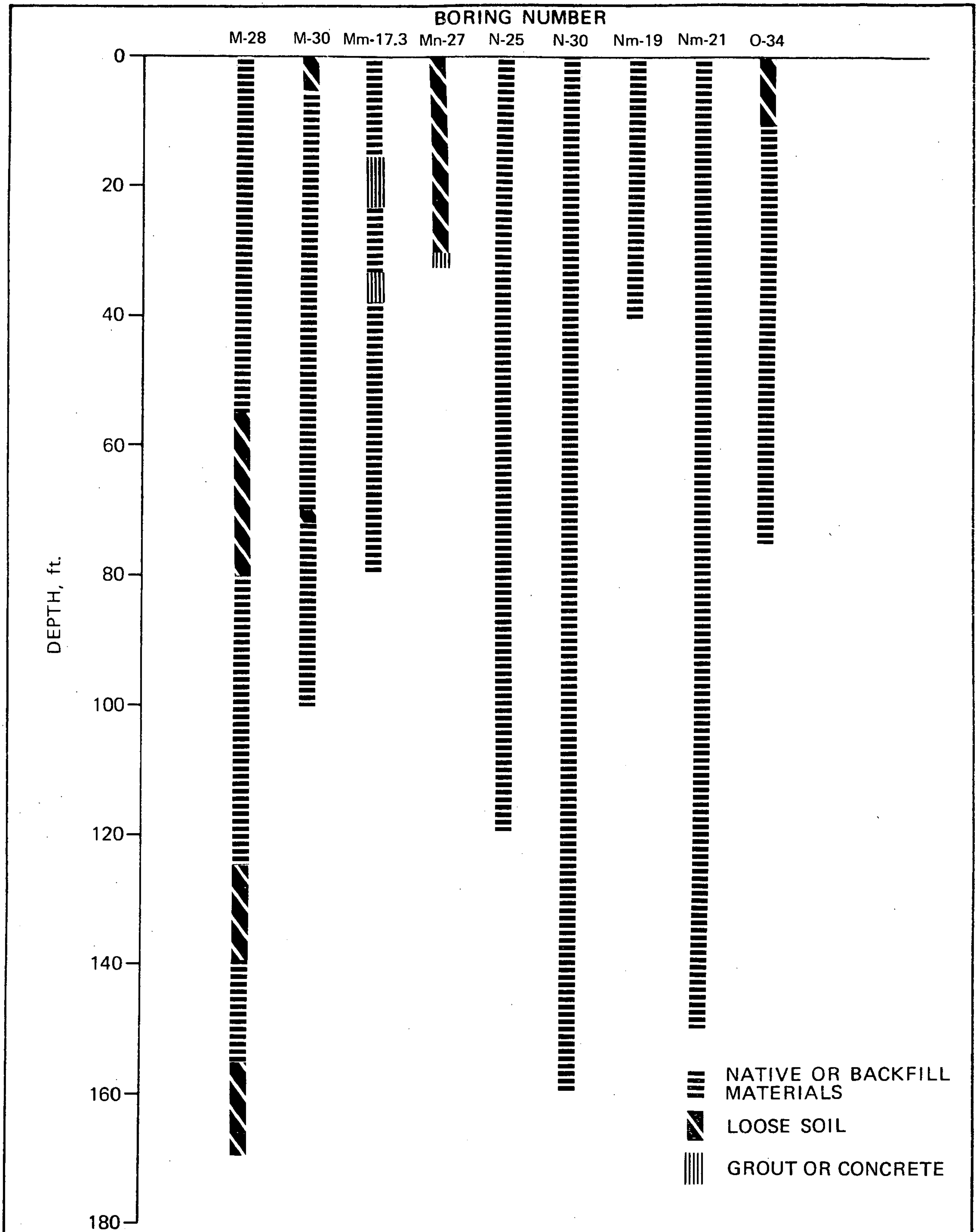
Project:	SONGS 2&3	GRAPHIC LOGS–STAGE I, WELL NO. 6	Fig.
Project No.	411301	EXPLORATION/GROUTING BORINGS	C-4k

WOODWARD–CLYDE CONSULTANTS



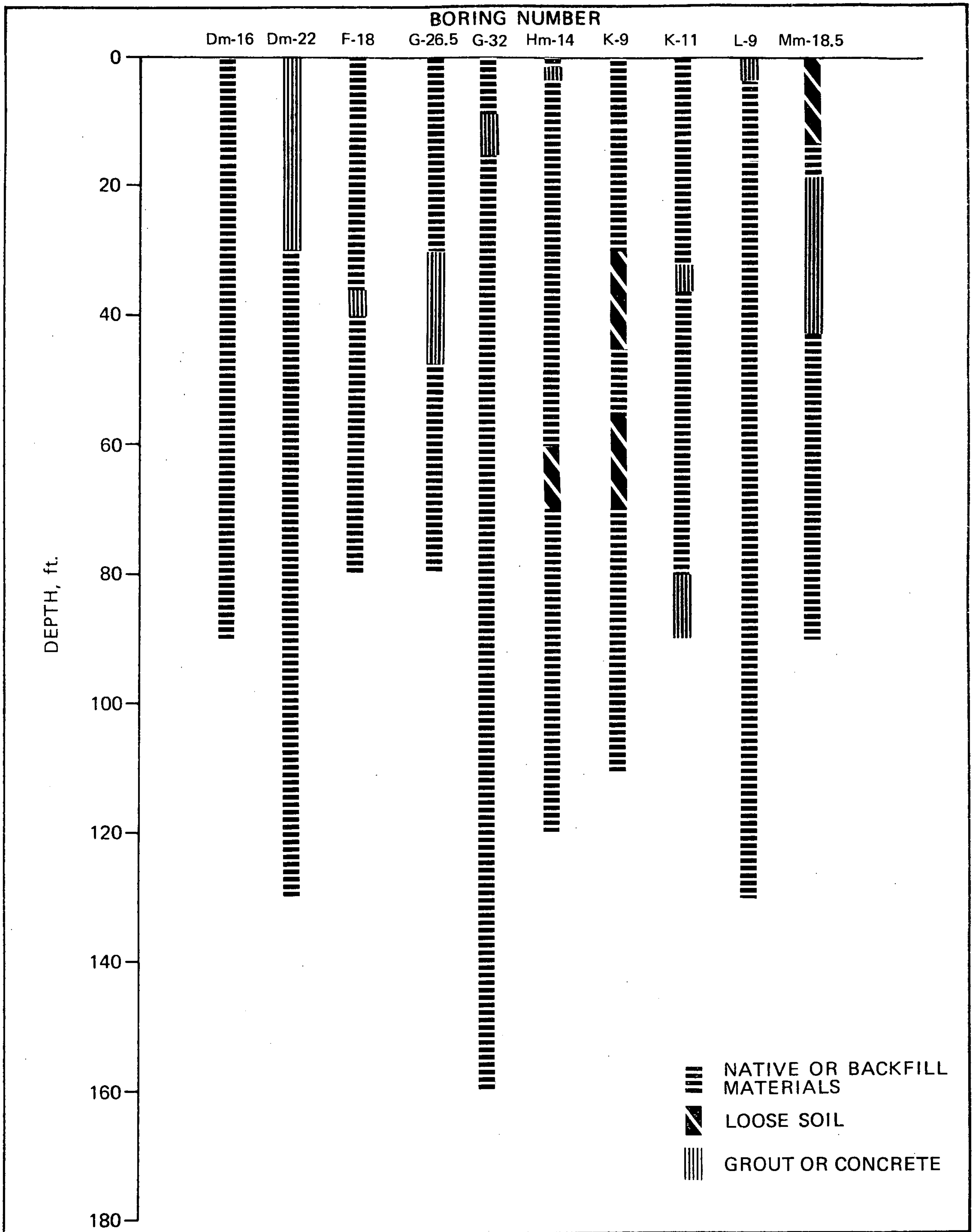
Project:	SONGS 2&3	GRAPHIC LOGS–STAGE I, WELL NO. 6	Fig.
Project No.	411301	EXPLORATION/GROUTING BORINGS	C-41

WOODWARD–CLYDE CONSULTANTS



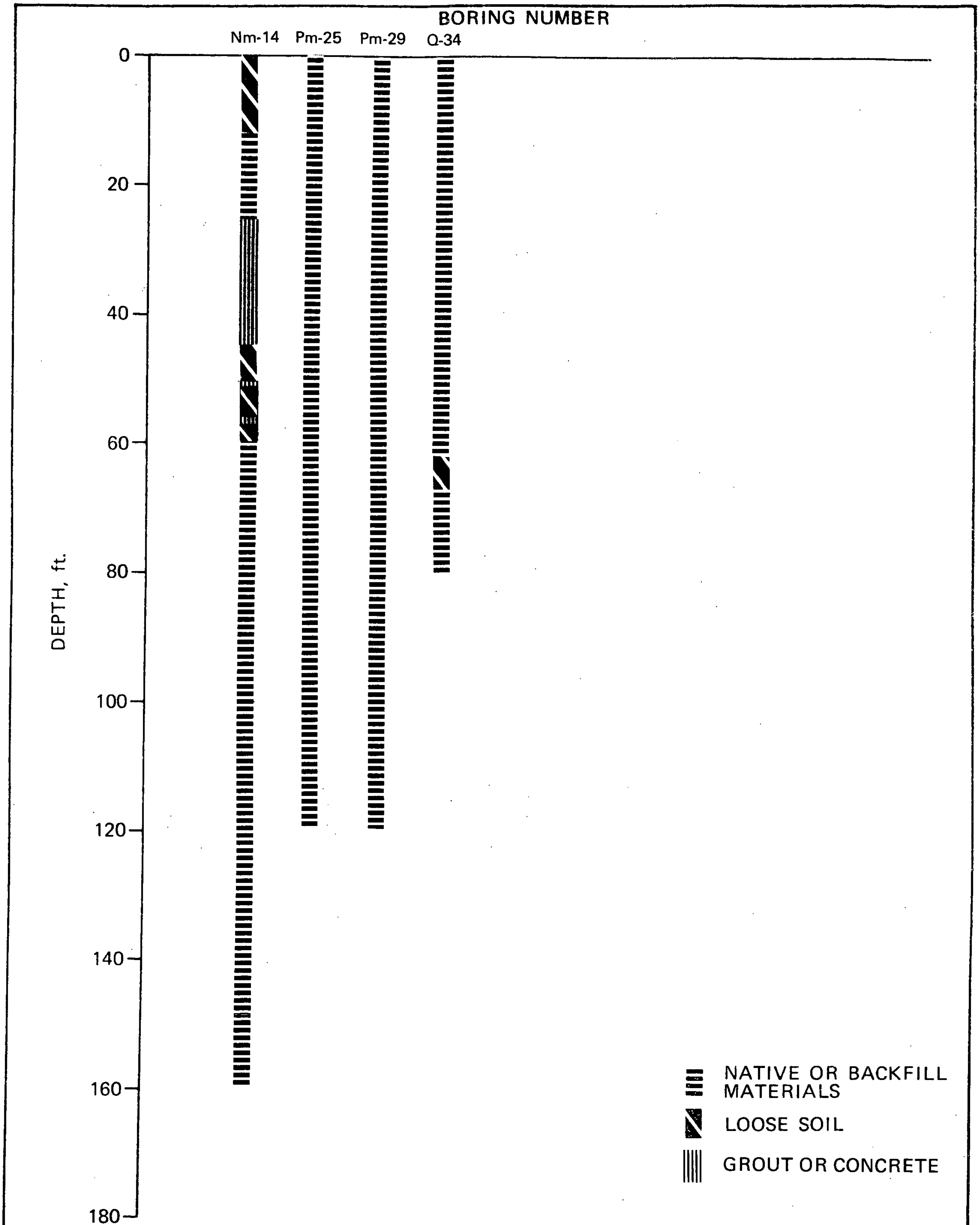
Project:	SONGS 2&3	GRAPHIC LOGS—STAGE I, WELL NO. 6	Fig.
Project No.	41130I	EXPLORATION/GROUTING BORINGS	C-4m

WOODWARD—CLYDE CONSULTANTS



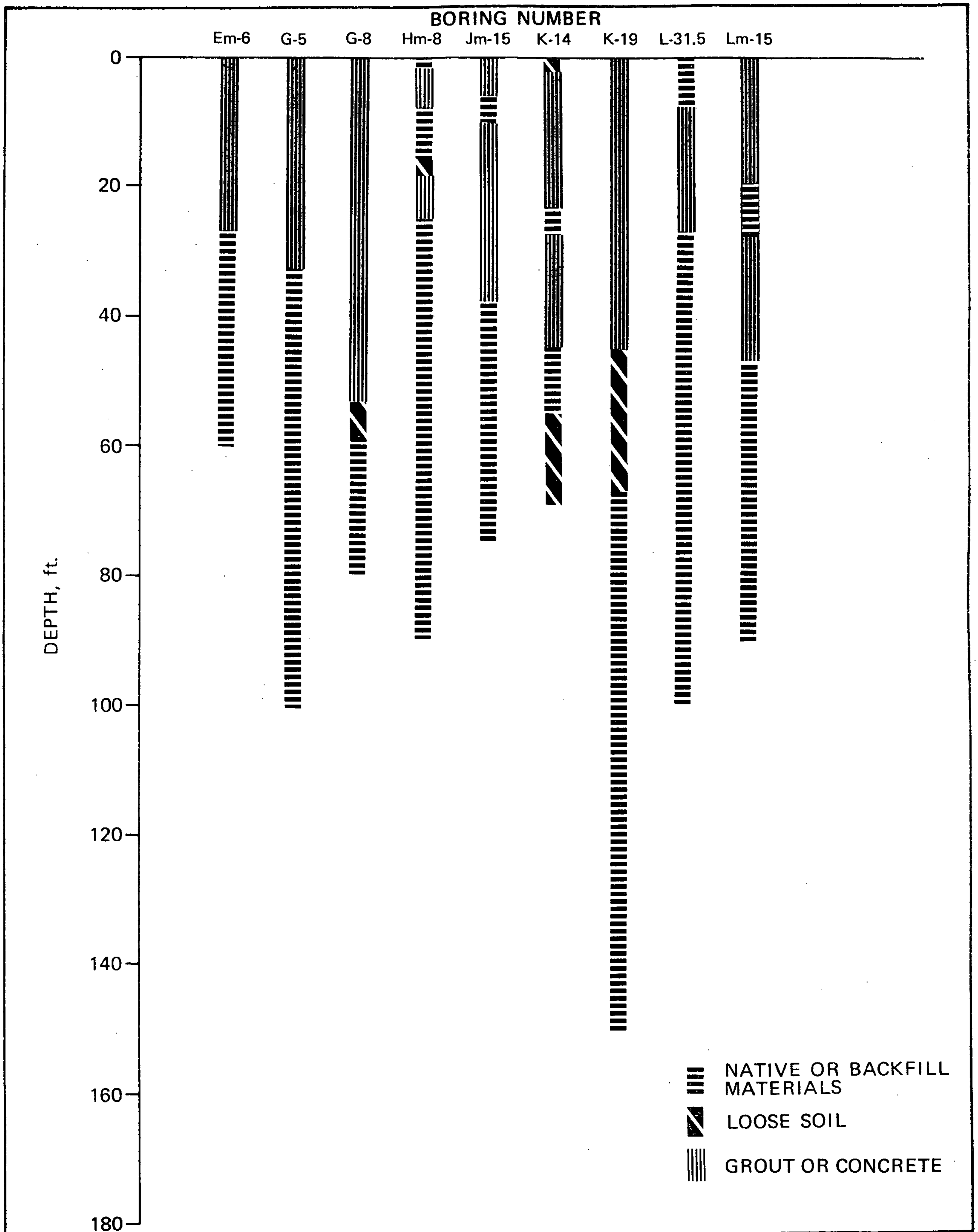
Project:	SONGS 2&3	GRAPHIC LOGS–STAGE II, WELL NO. 6	Fig.
Project No.	411301	EXPLORATION/GROUTING BORINGS	C-4n

WOODWARD–CLYDE CONSULTANTS



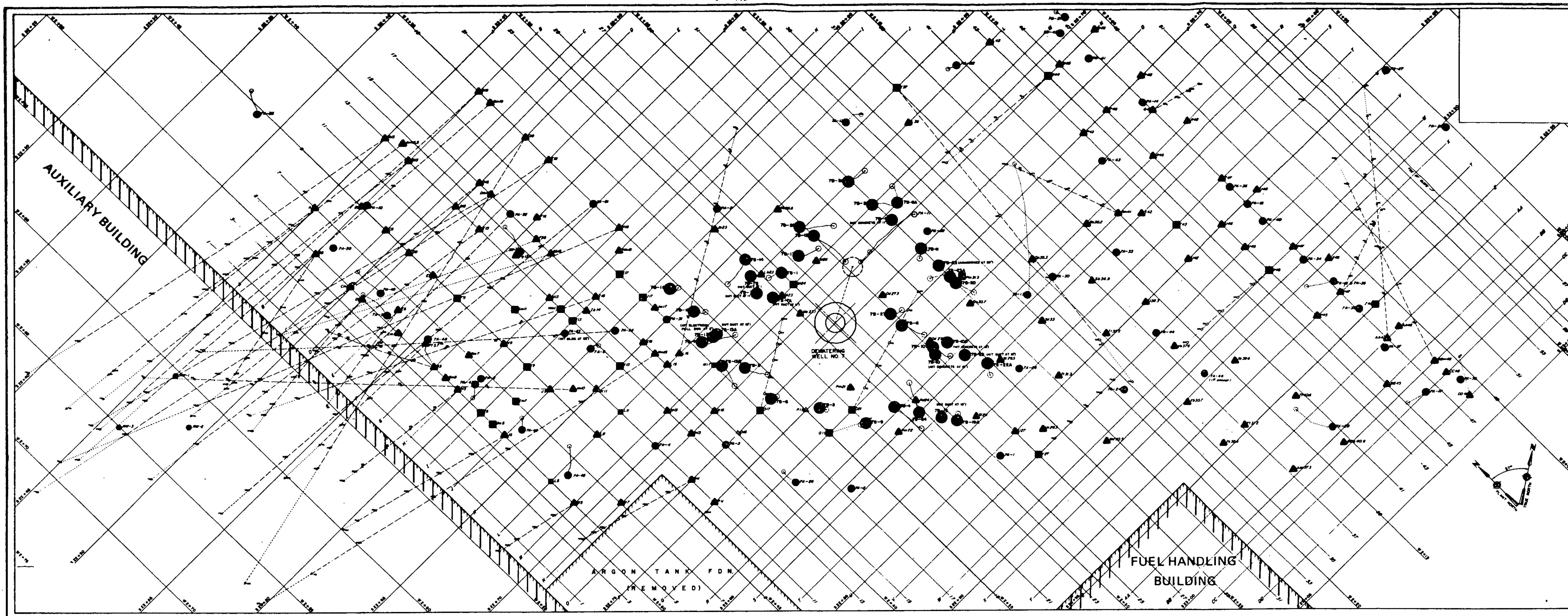
Project:	SONGS 2&3	GRAPHIC LOGS—STAGE II, WELL NO. 6	Fig.
Project No.	411301	EXPLORATION/GROUTING BORINGS	C-4o

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2&3	GRAPHIC LOGS—STAGE III, WELL NO. 6	Fig.
Project No.	411301	EXPLORATION/GROUTING BORINGS	C-4p

WOODWARD—CLYDE CONSULTANTS



EXPLANATION

7B-3 Deep exploration hole with drift

7A-2 Previous exploration drill hole

GROUT HOLE SYMBOLS

▲ Primary

■ Secondary

● Exploration-Inside radwaste bldg. elev. 9.5 ft.

----- Drill hole drift

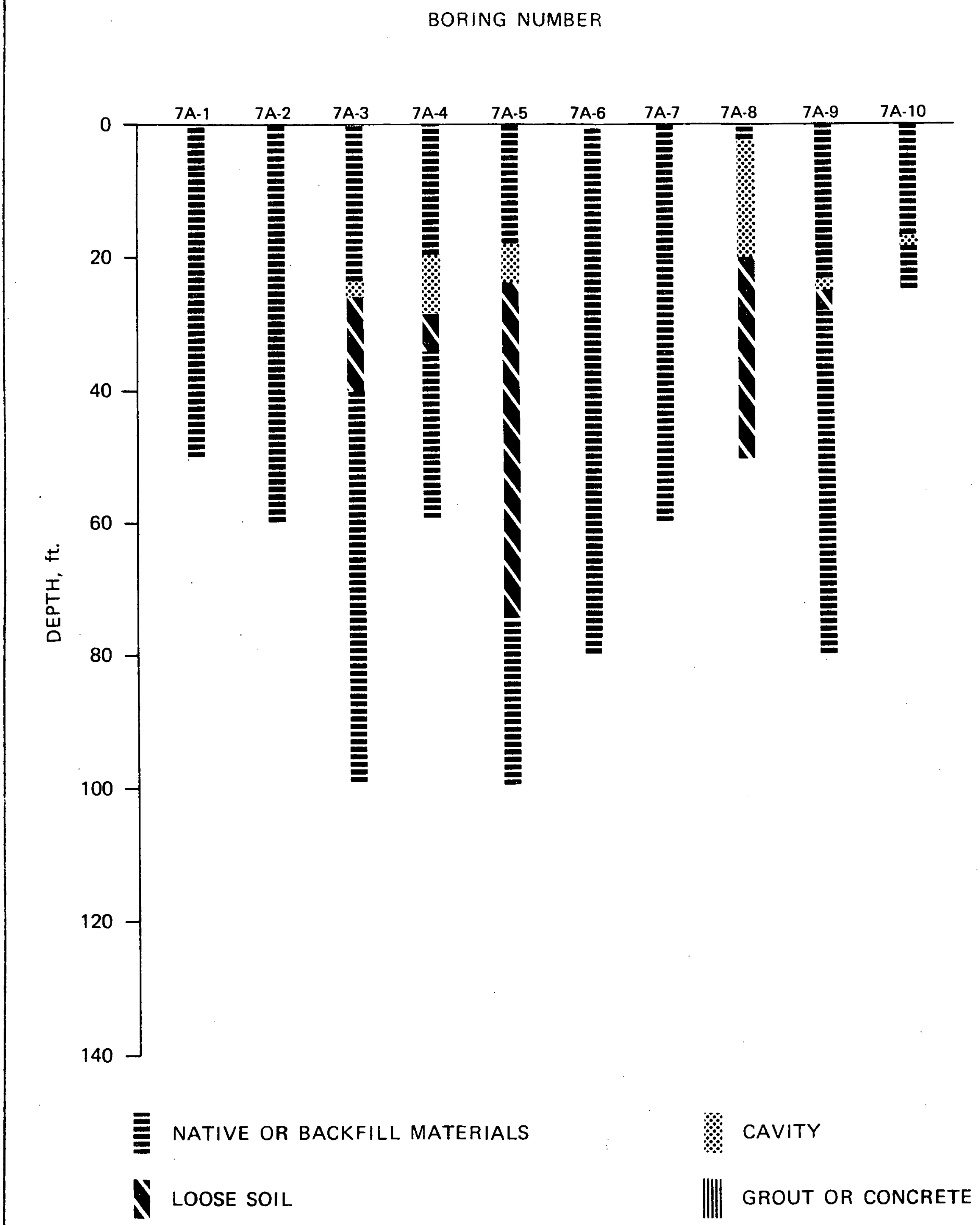
1 0 1 2 3 4 5 10

SCALE IN FEET

WOODWARD-CLYDE CONSULTANTS

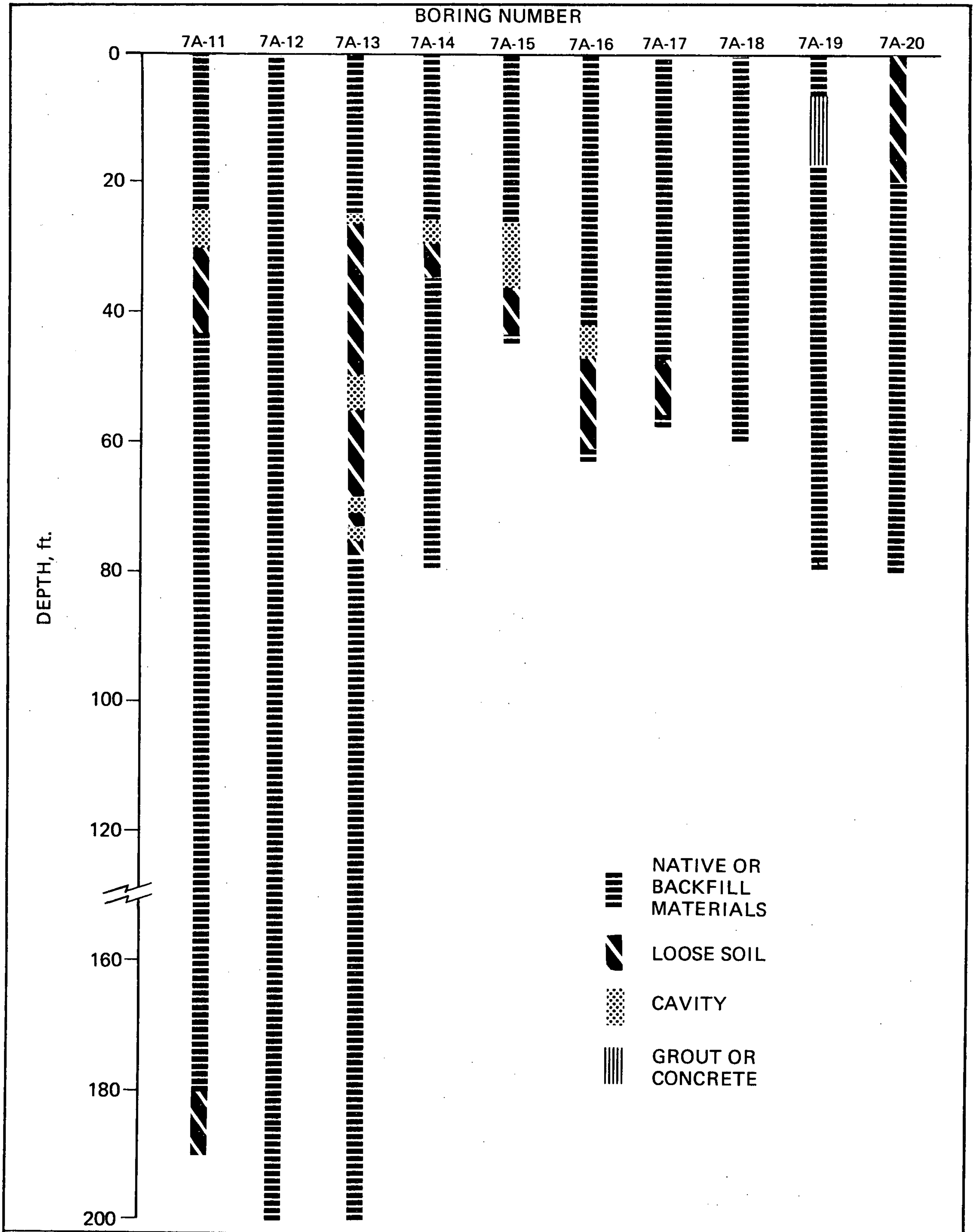
DEWATERING WELL NO 7
LOCATION OF DRILL HOLES

Project No. 411301	Fig.
SONGS 2 & 3	C-5a



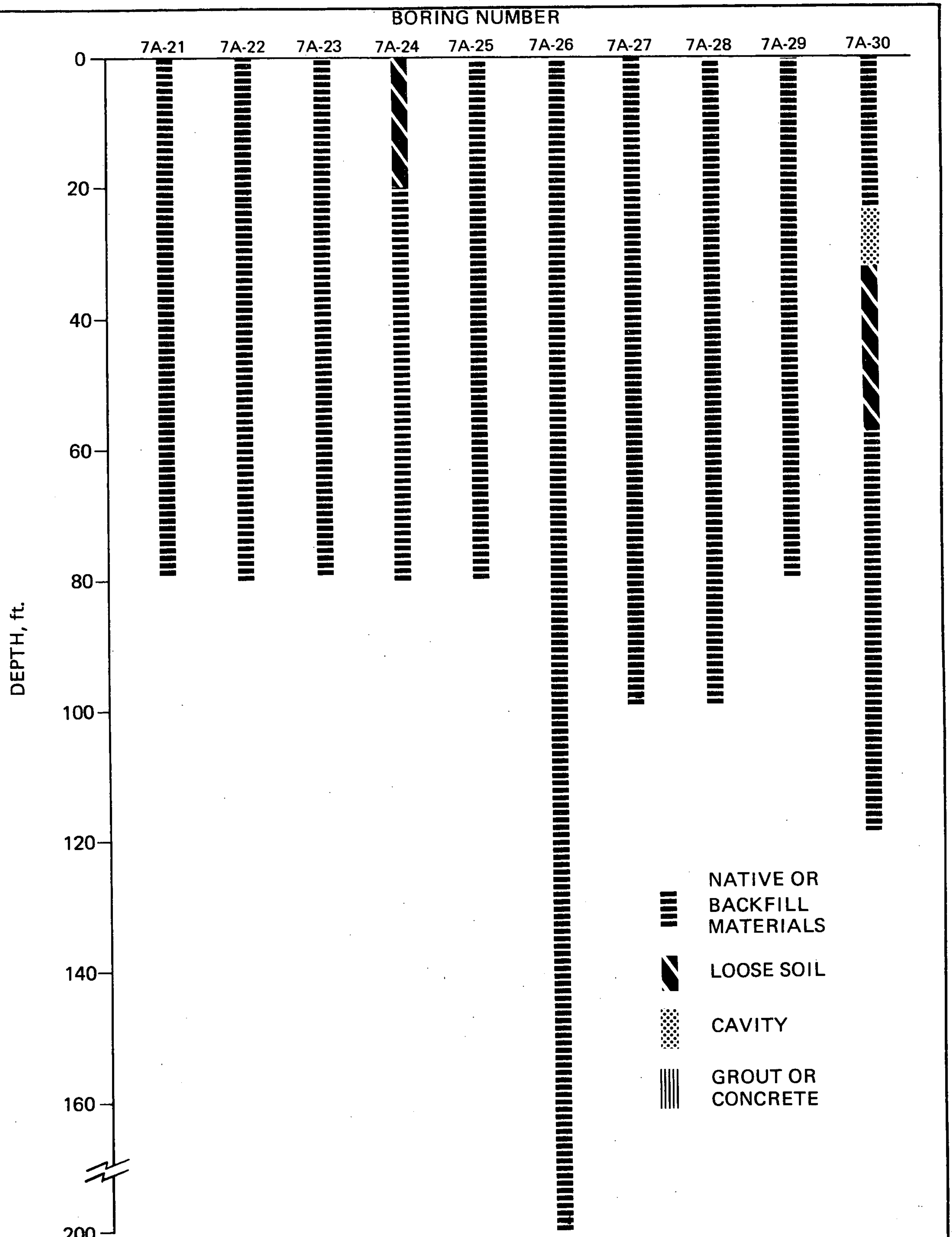
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 7	Fig.
Project No.	411301	EXPLORATORY BORINGS	C-5b

WOODWARD—CLYDE CONSULTANTS



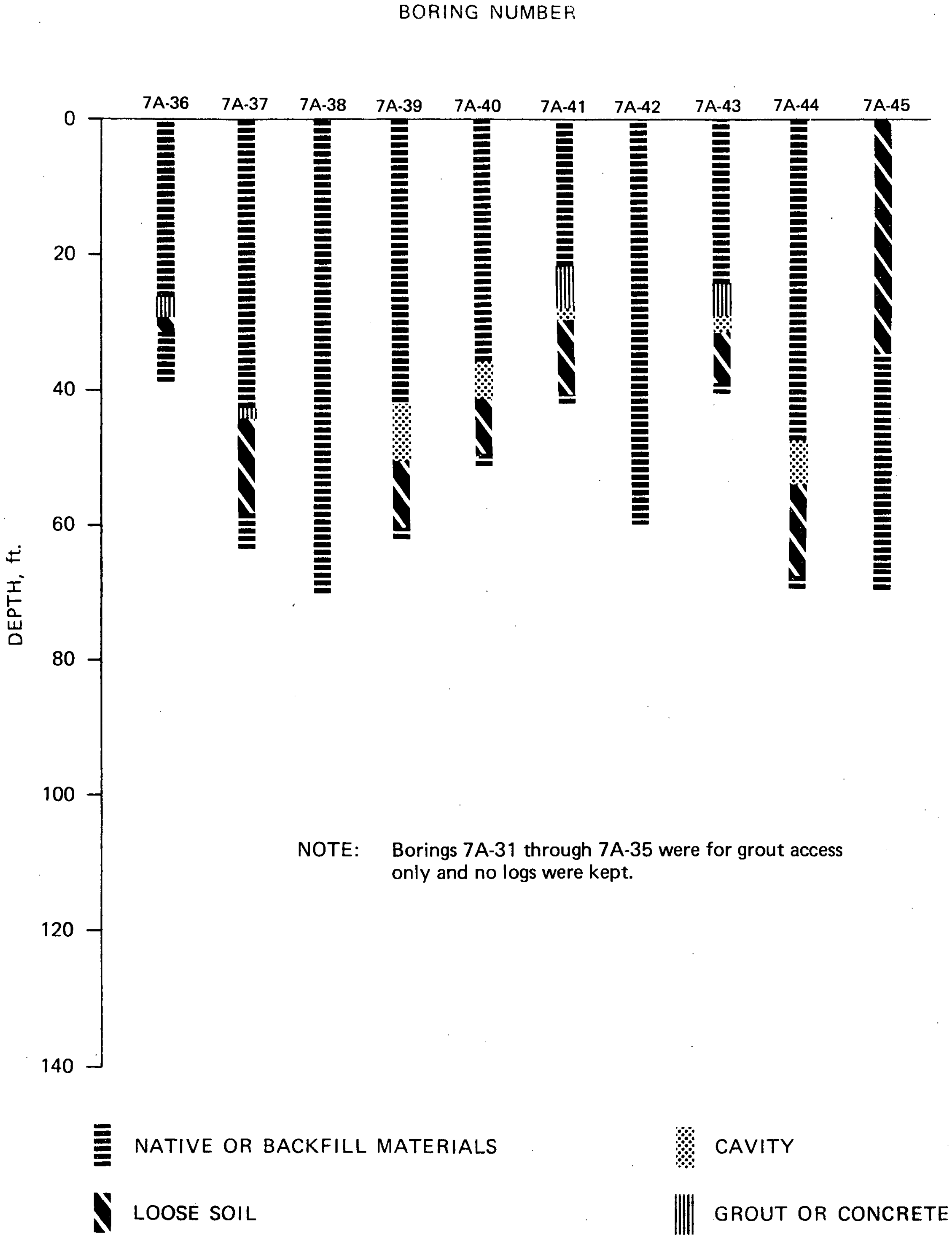
Project: **SONGS 2 & 3** Project No. **411301**	**GRAPHIC LOGS, WELL NO. 7 EXPLORATORY BORINGS**	Fig. **C-5c**

WOODWARD – CLYDE CONSULTANTS



Project: **SONGS 2 & 3** Project No. **41130I**	**GRAPHIC LOGS, WELL NO. 7 EXPLORATORY BORINGS**	Fig. **C-5d**

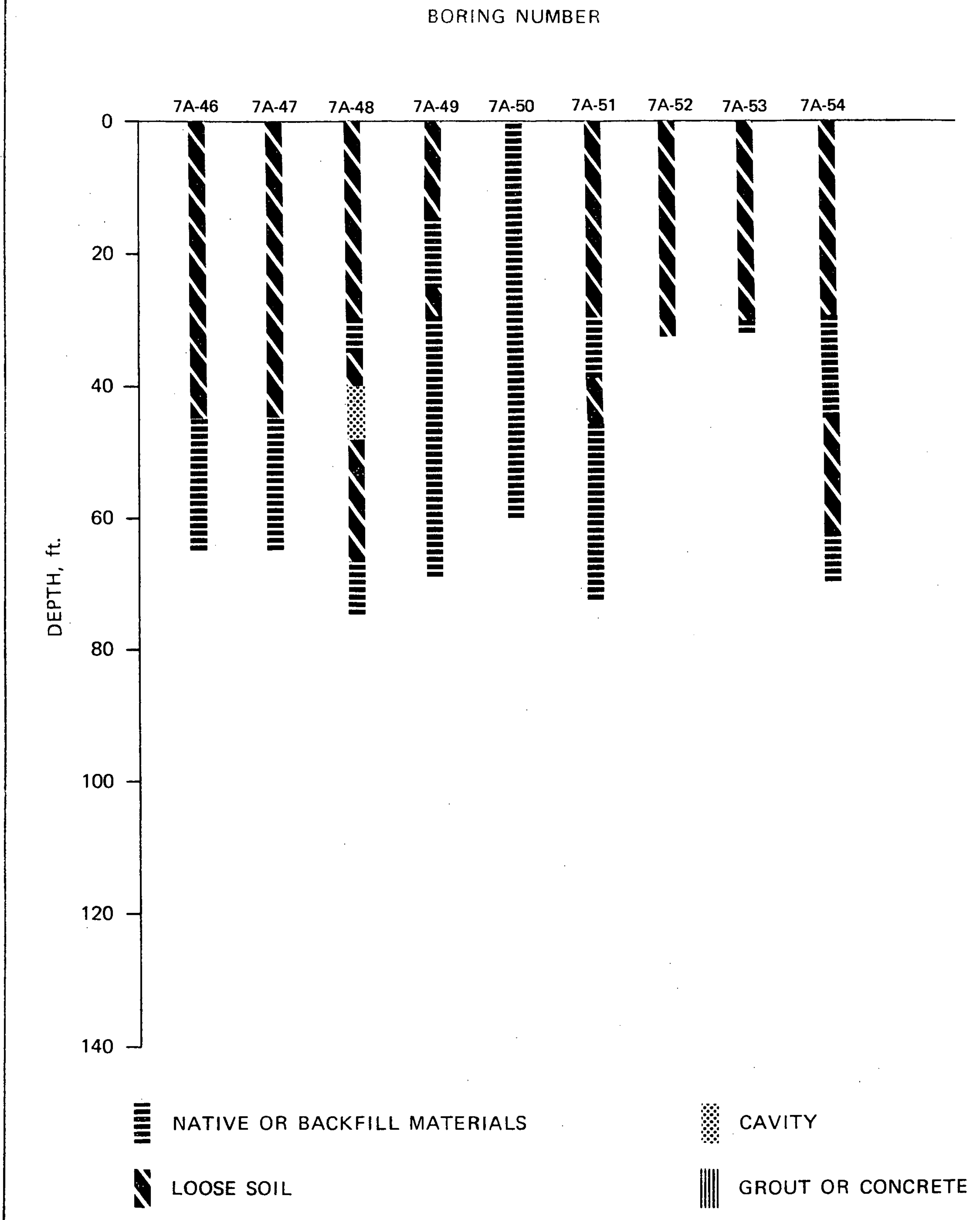
WOODWARD—CLYDE CONSULTANTS



NOTE: Borings 7A-31 through 7A-35 were for grout access only and no logs were kept.

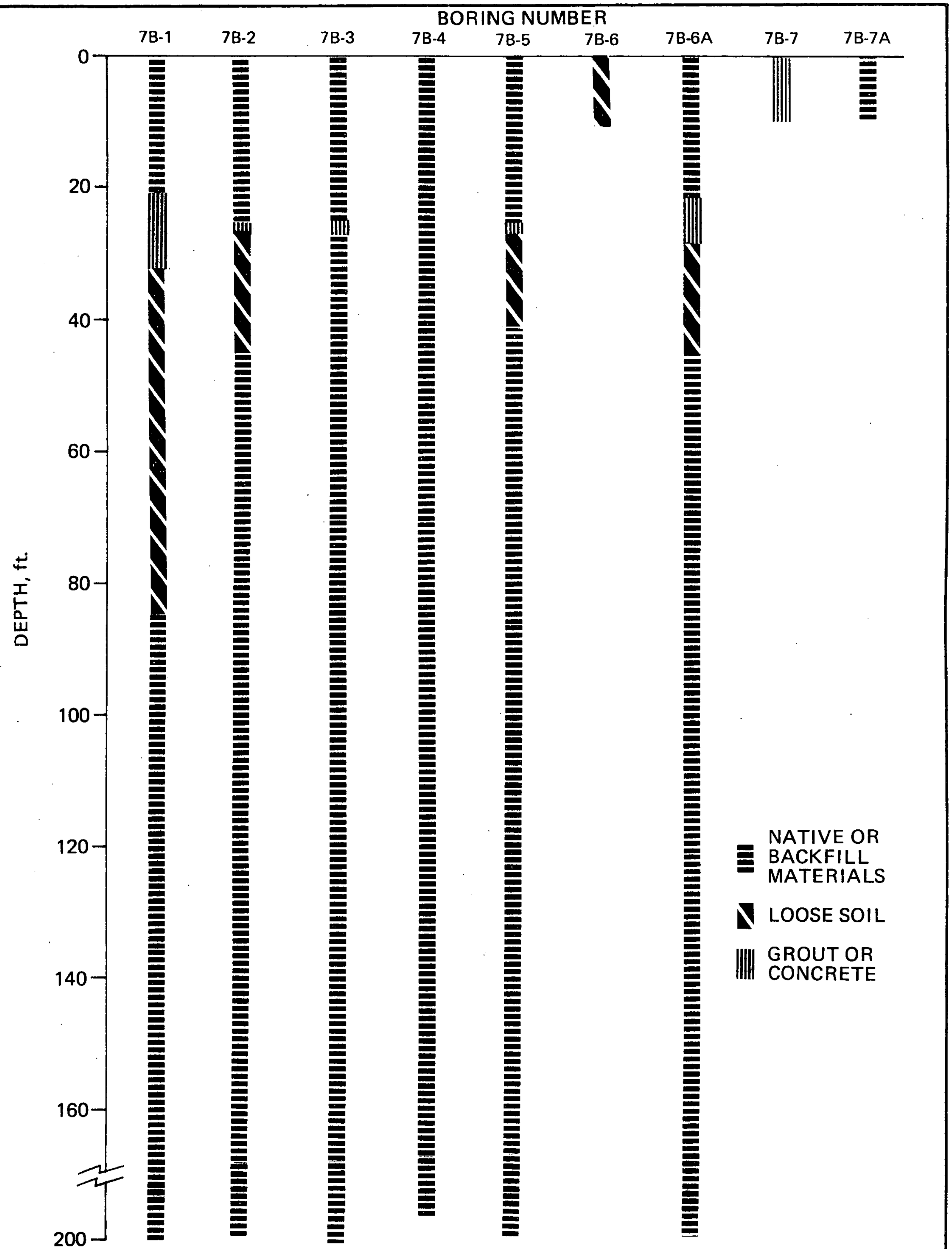
Project: Project No.	SONGS 2 & 3 411301	**GRAPHIC LOGS, WELL NO. 7** **EXPLORATORY BORINGS**	Fig. **C-5e**

WOODWARD-CLYDE CONSULTANTS



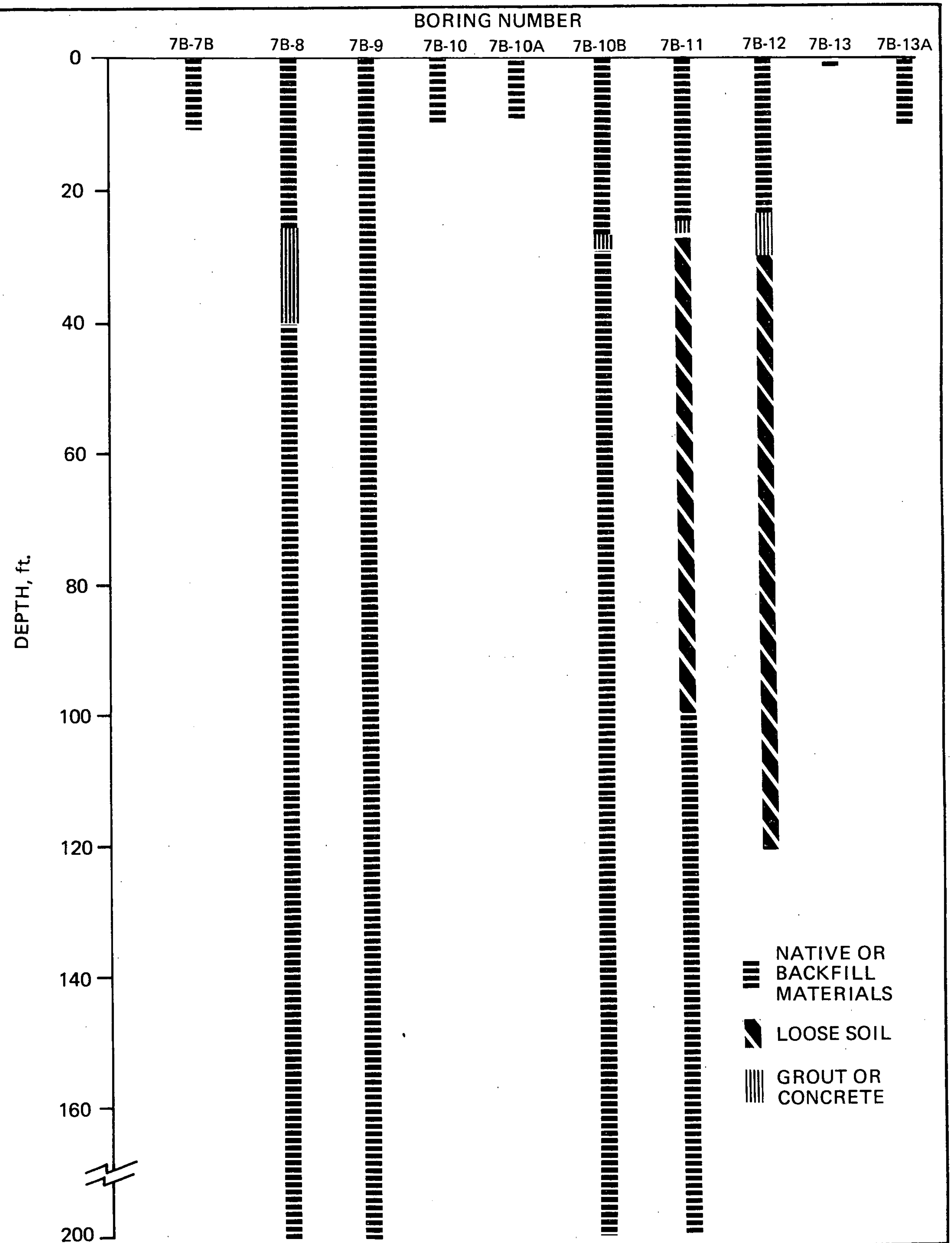
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 7 EXPLORATORY BORINGS	Fig. C-5f
Project No.	411301		

WOODWARD–CLYDE CONSULTANTS



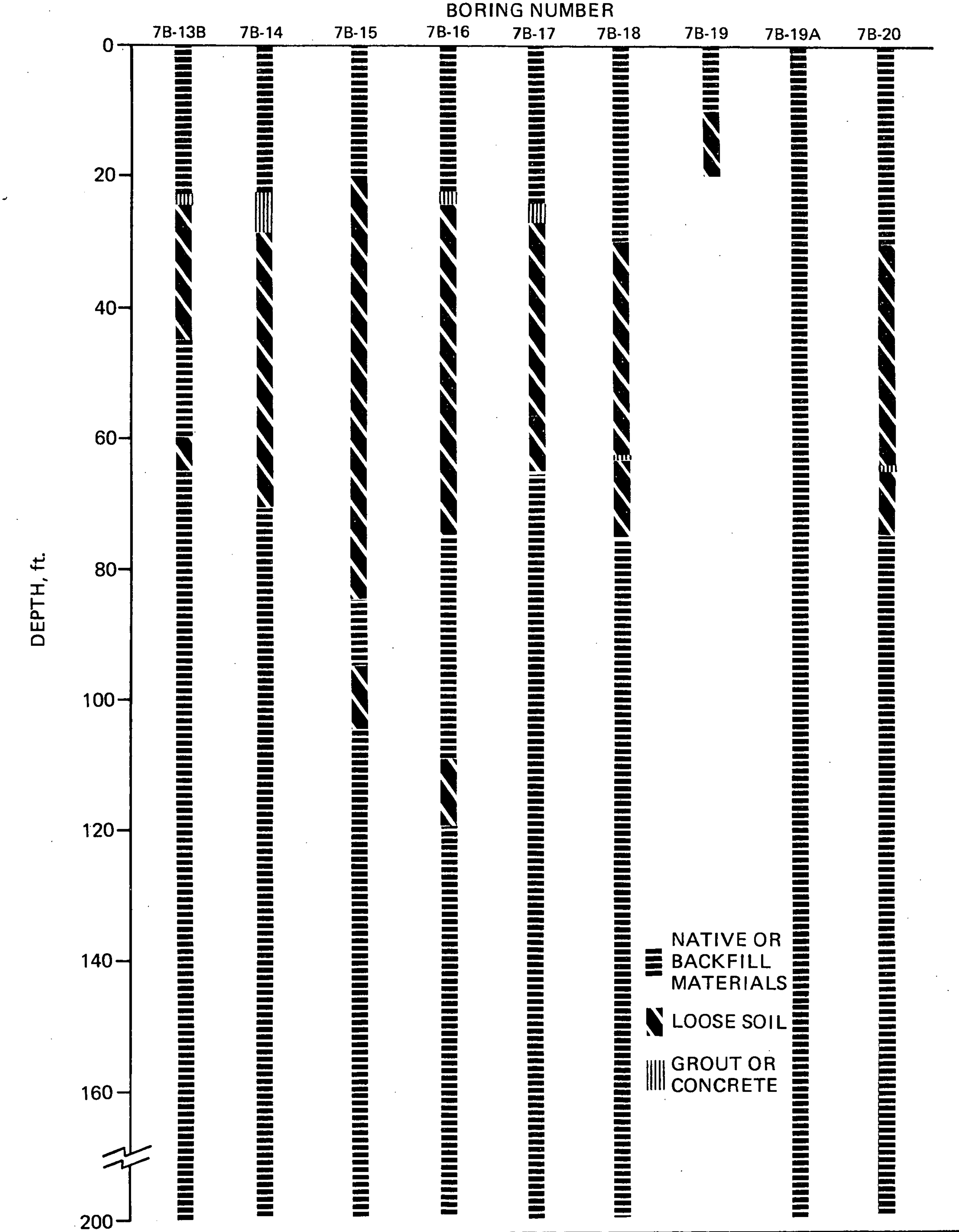
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 7	Fig.
Project No.	41130I	DEEP EXPLORATION BORINGS	C-5g

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 7	Fig.
Project No.	41130I	DEEP EXPLORATION BORINGS	C-5h

WOODWARD – CLYDE CONSULTANTS

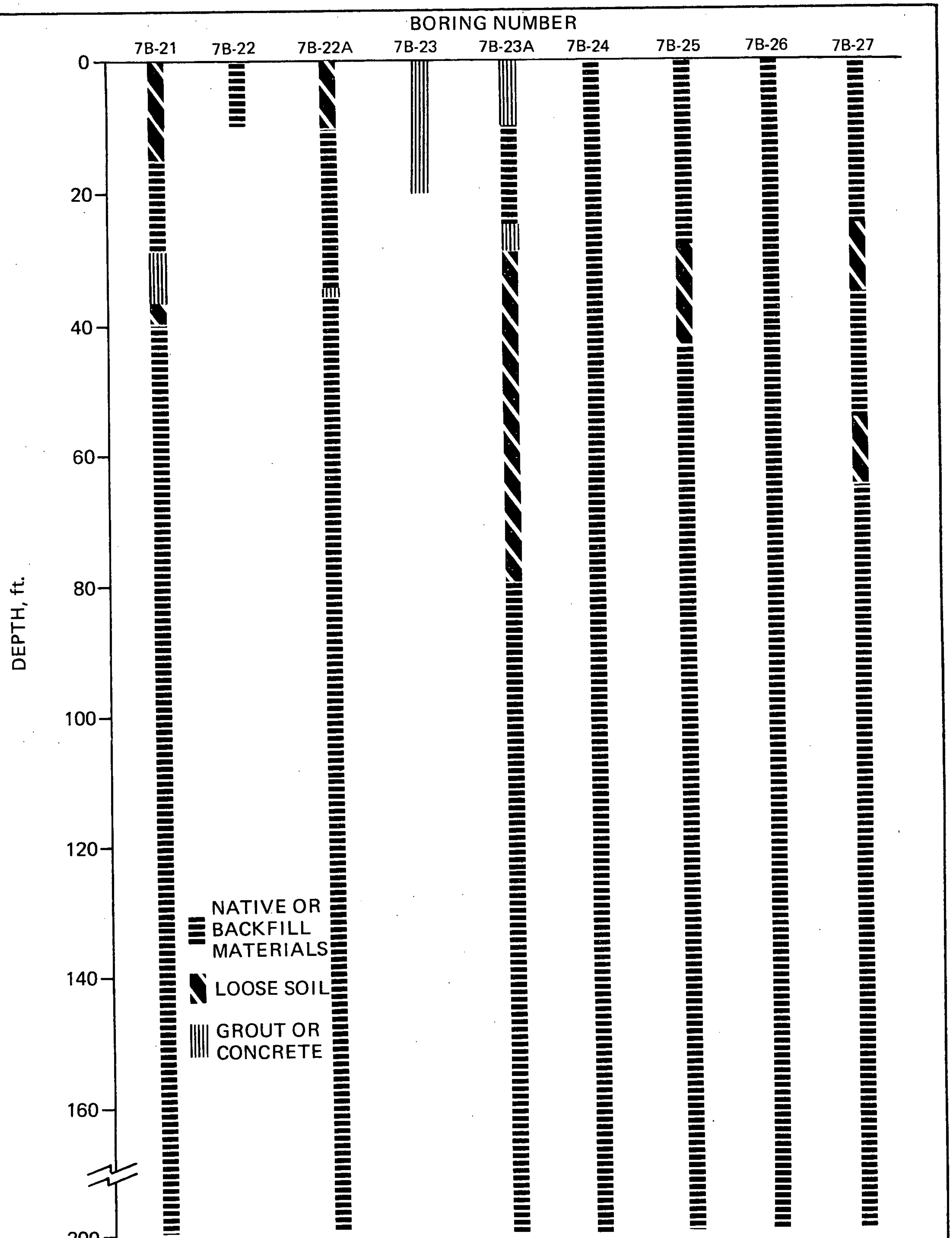


Project: **SONGS 2 & 3**
Project No. **41130I**

GRAPHIC LOGS, WELL NO. 7
DEEP EXPLORATION BORINGS

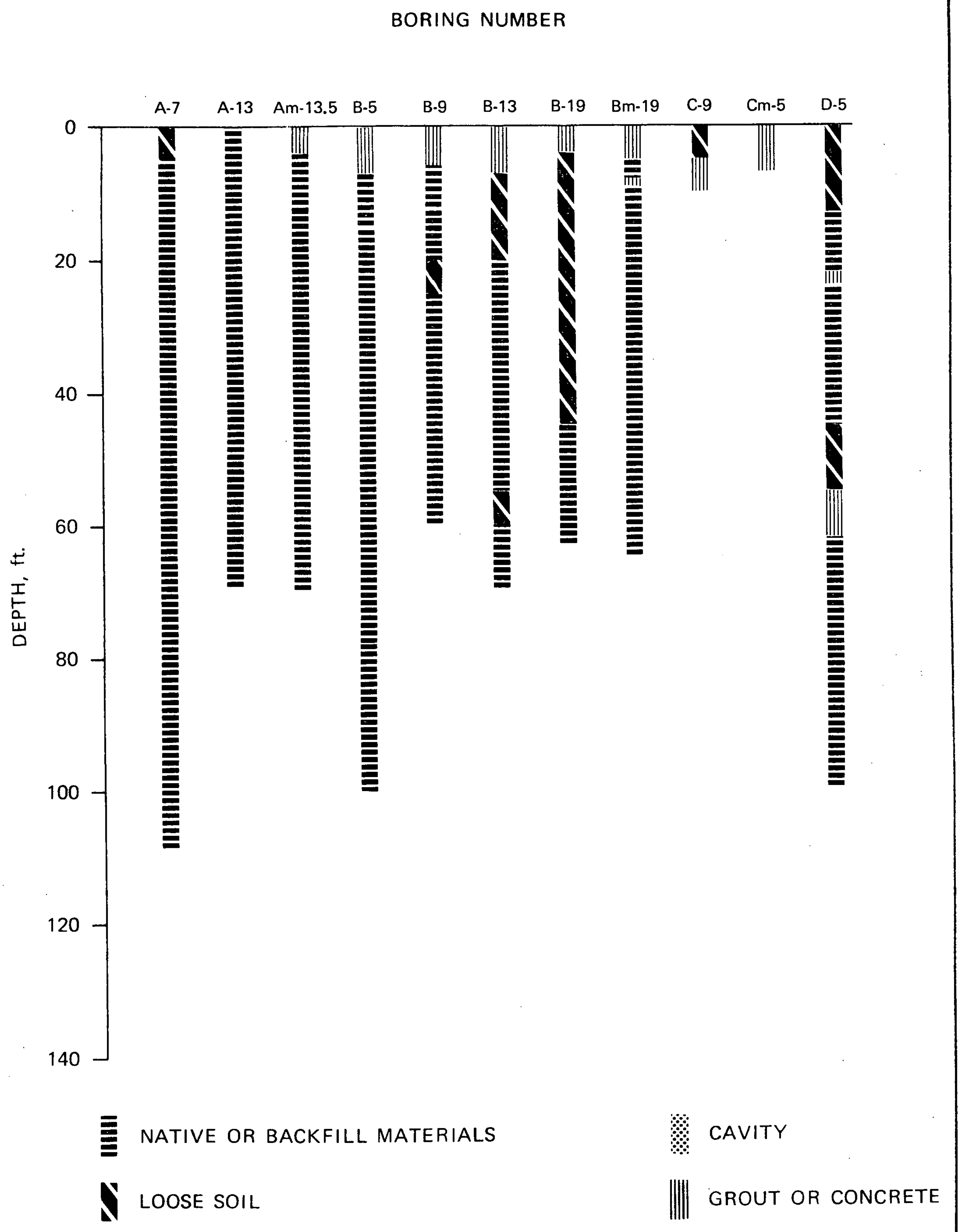
Fig. **C-5i**

WOODWARD – CLYDE CONSULTANTS



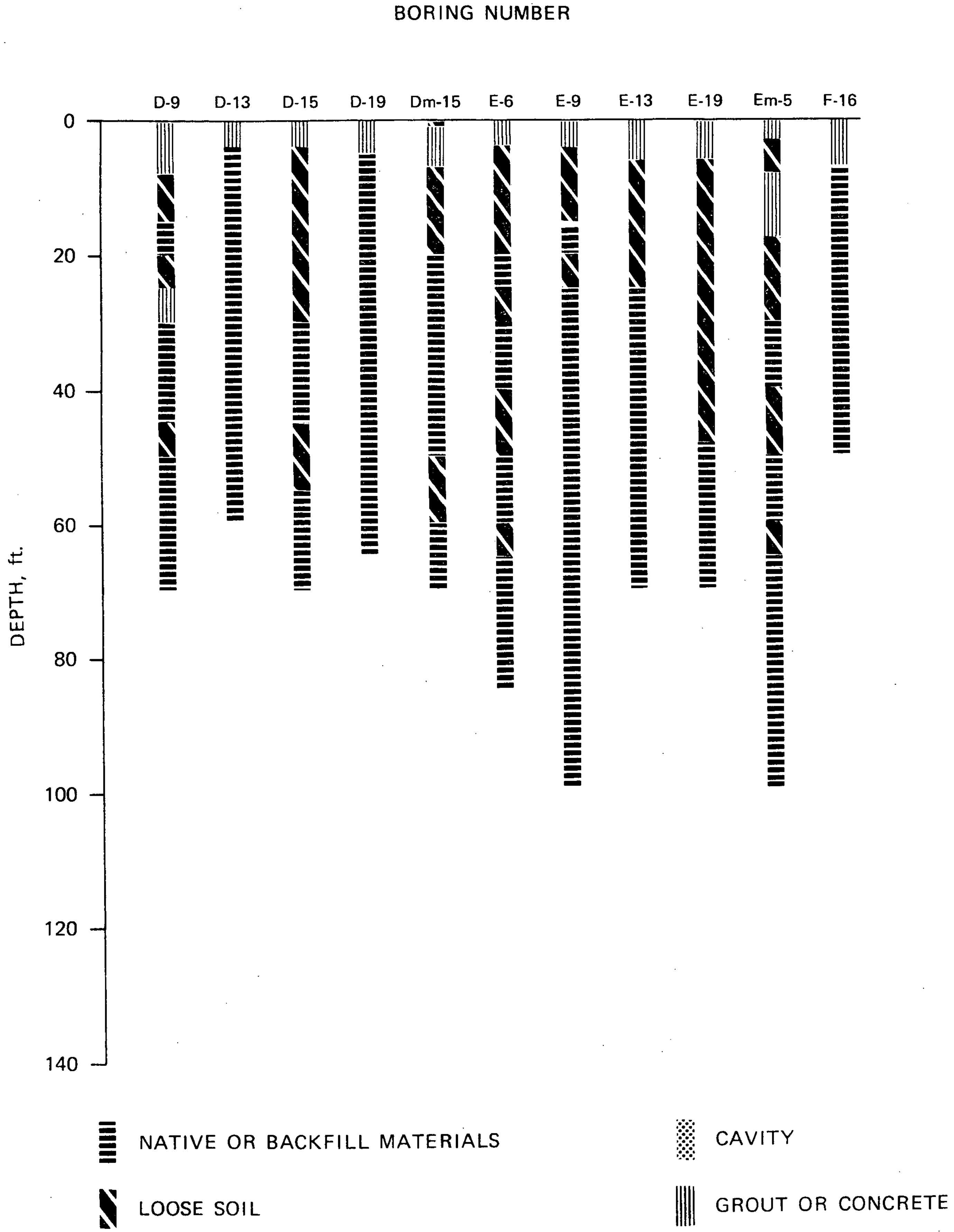
Project: **SONGS 2 & 3** Project No. **41130I**	**GRAPHIC LOGS, WELL NO. 7** **DEEP EXPLORATION BORINGS**	Fig. **C-5j**

WOODWARD – CLYDE CONSULTANTS



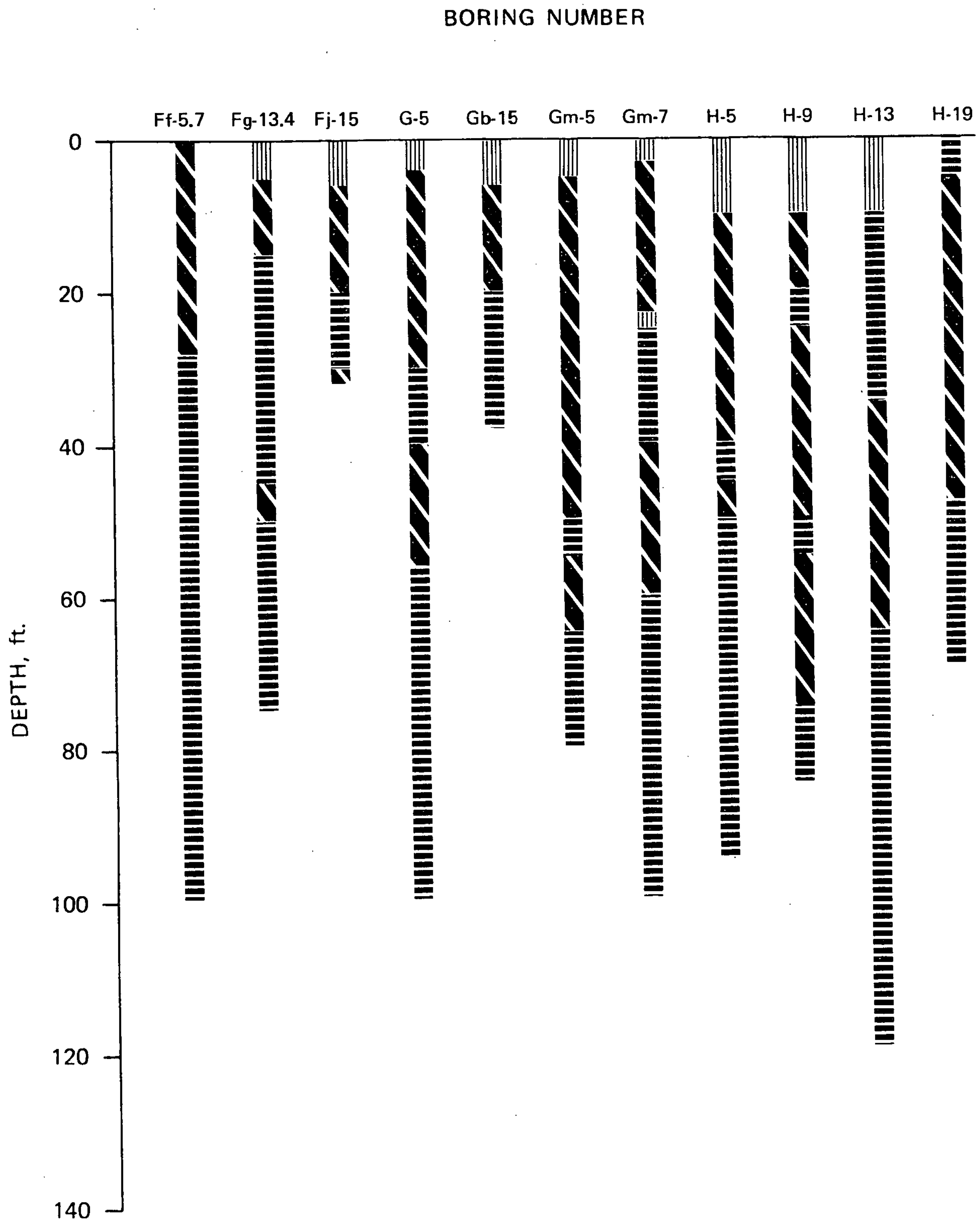
Project:	SONGS 2 & 3	GRAPHIC LOGS—STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5k

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS—STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-51

WOODWARD–CLYDE CONSULTANTS



NATIVE OR BACKFILL MATERIALS

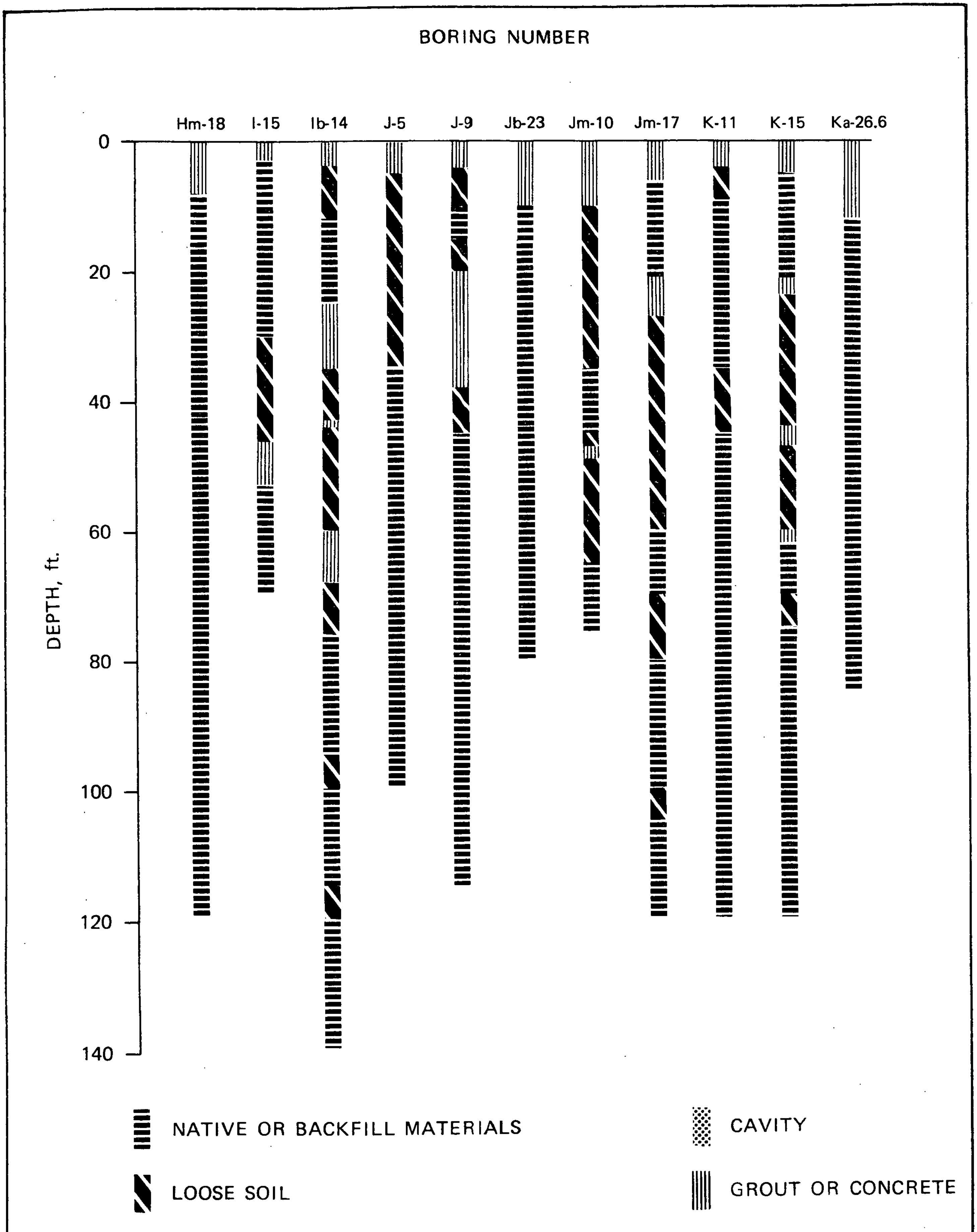
LOOSE SOIL

CAVITY

GROUT OR CONCRETE

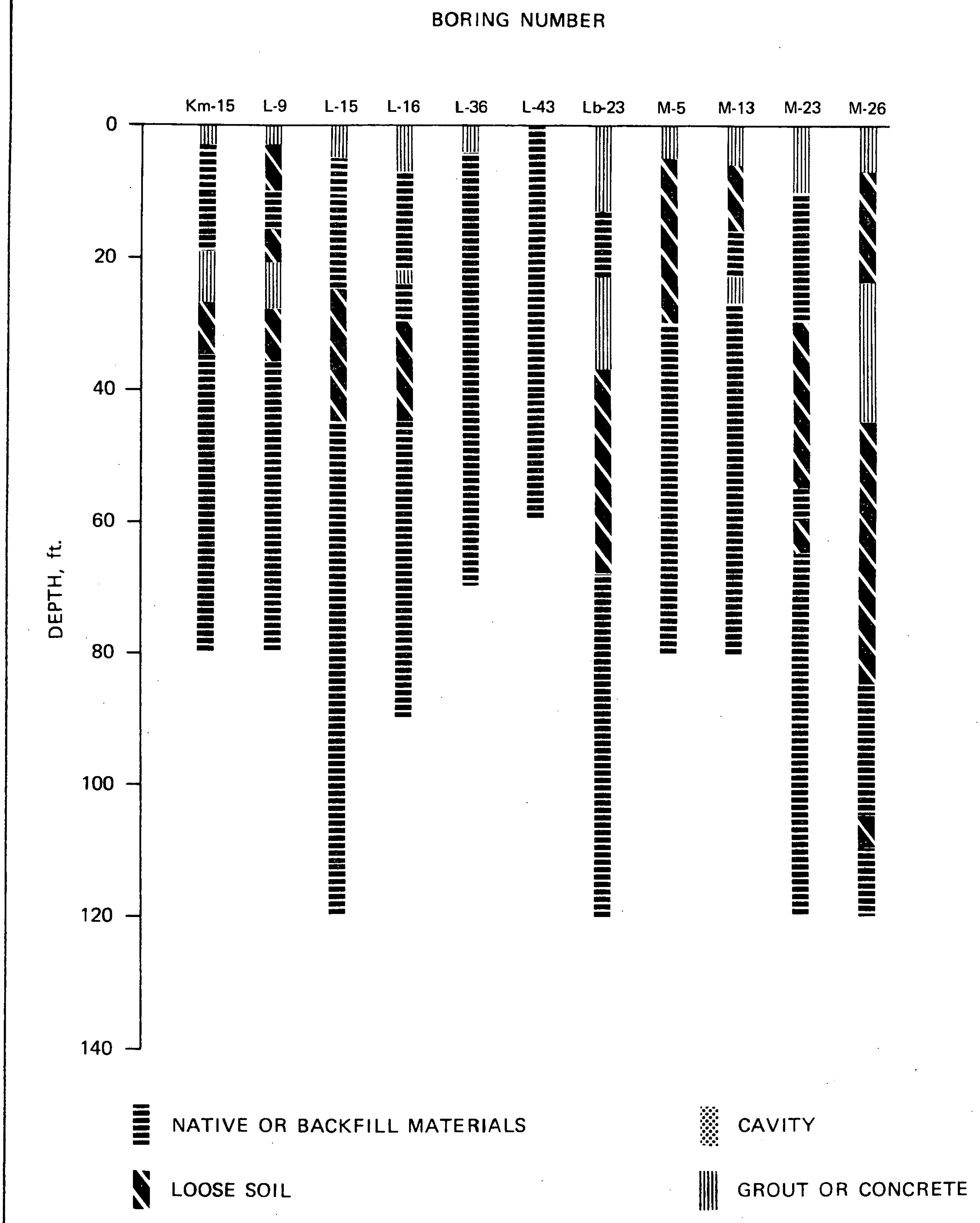
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5m

WOODWARD–CLYDE CONSULTANTS



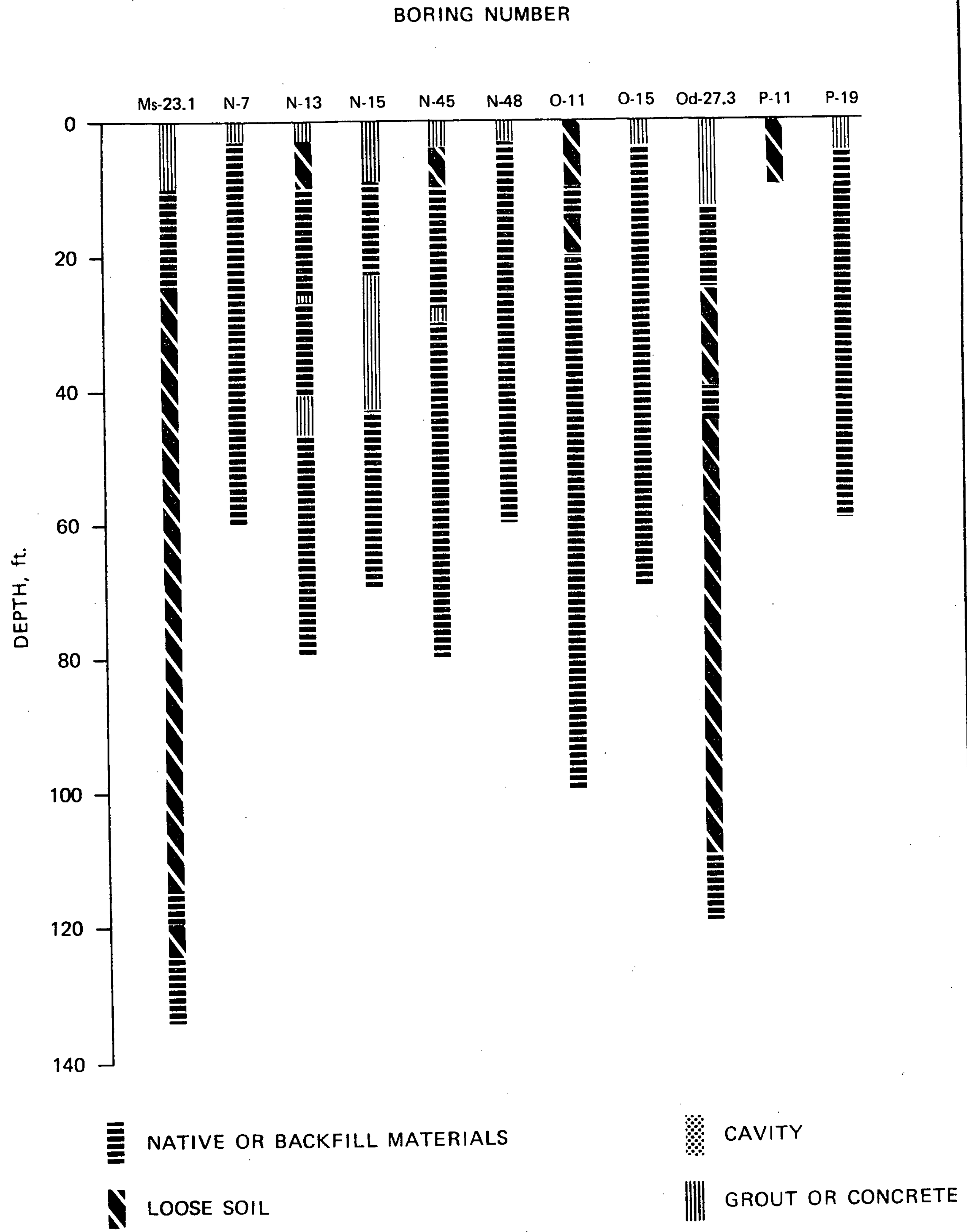
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5n

WOODWARD–CLYDE CONSULTANTS



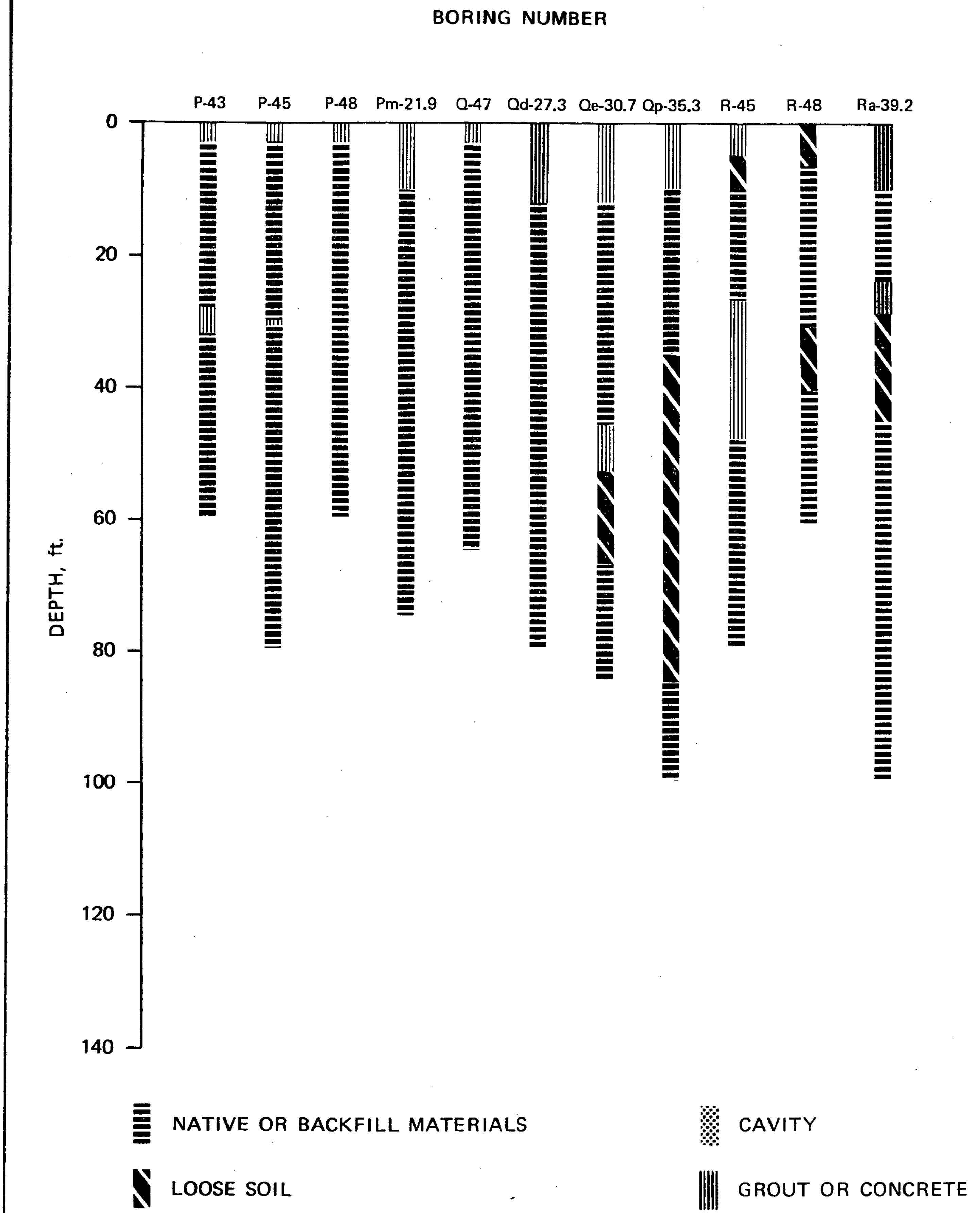
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5o

WOODWARD–CLYDE CONSULTANTS



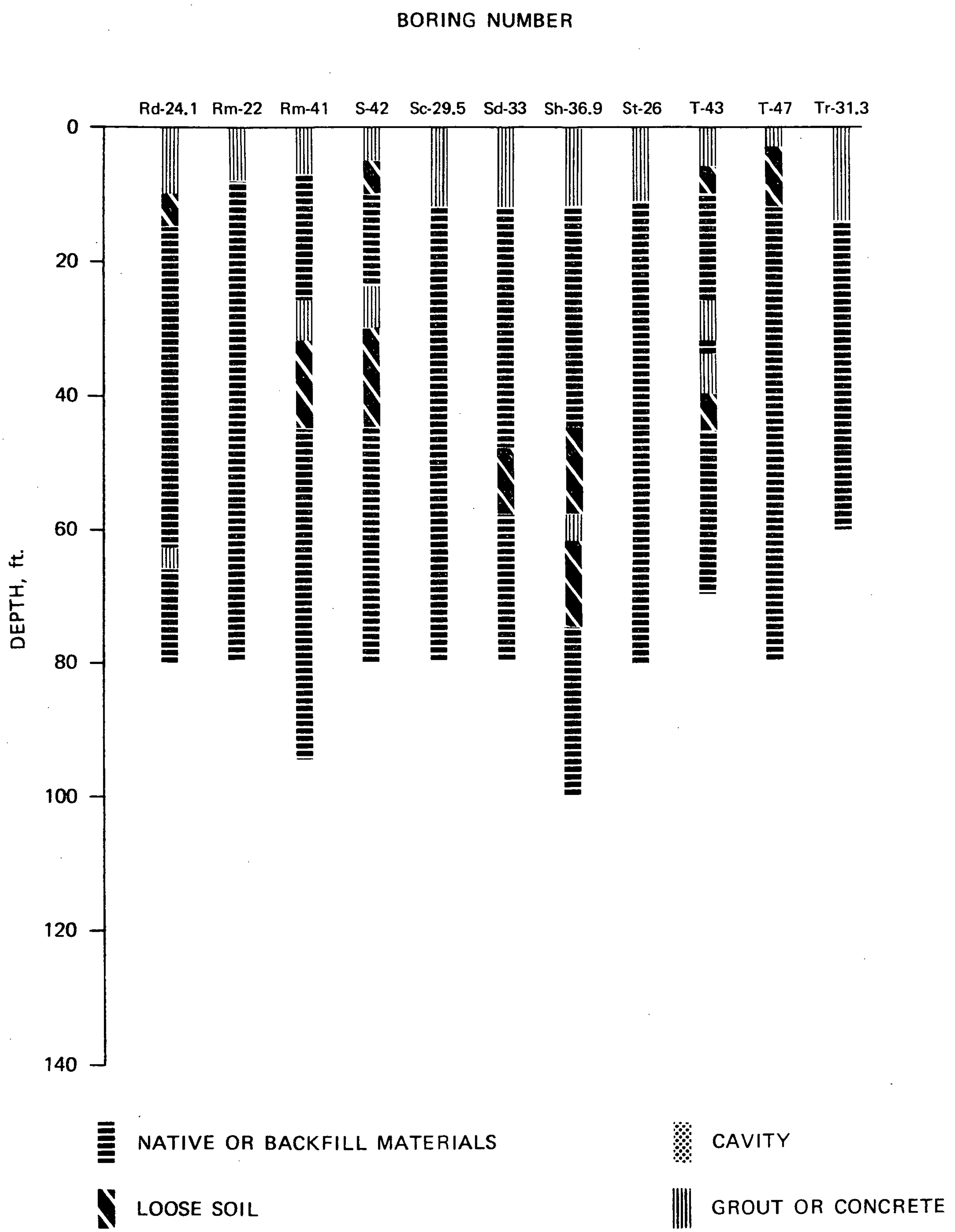
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5p

WOODWARD–CLYDE CONSULTANTS



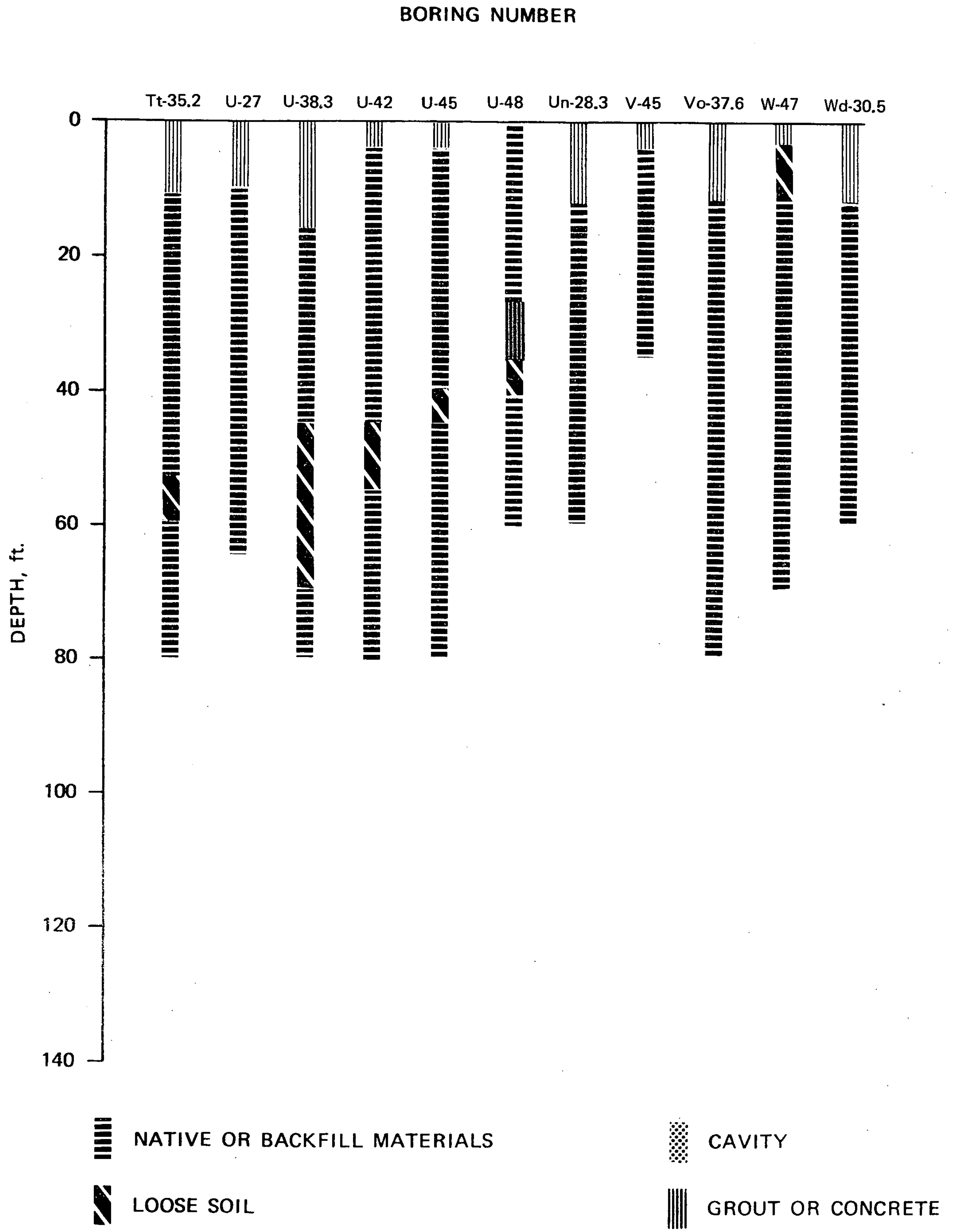
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5q

WOODWARD–CLYDE CONSULTANTS



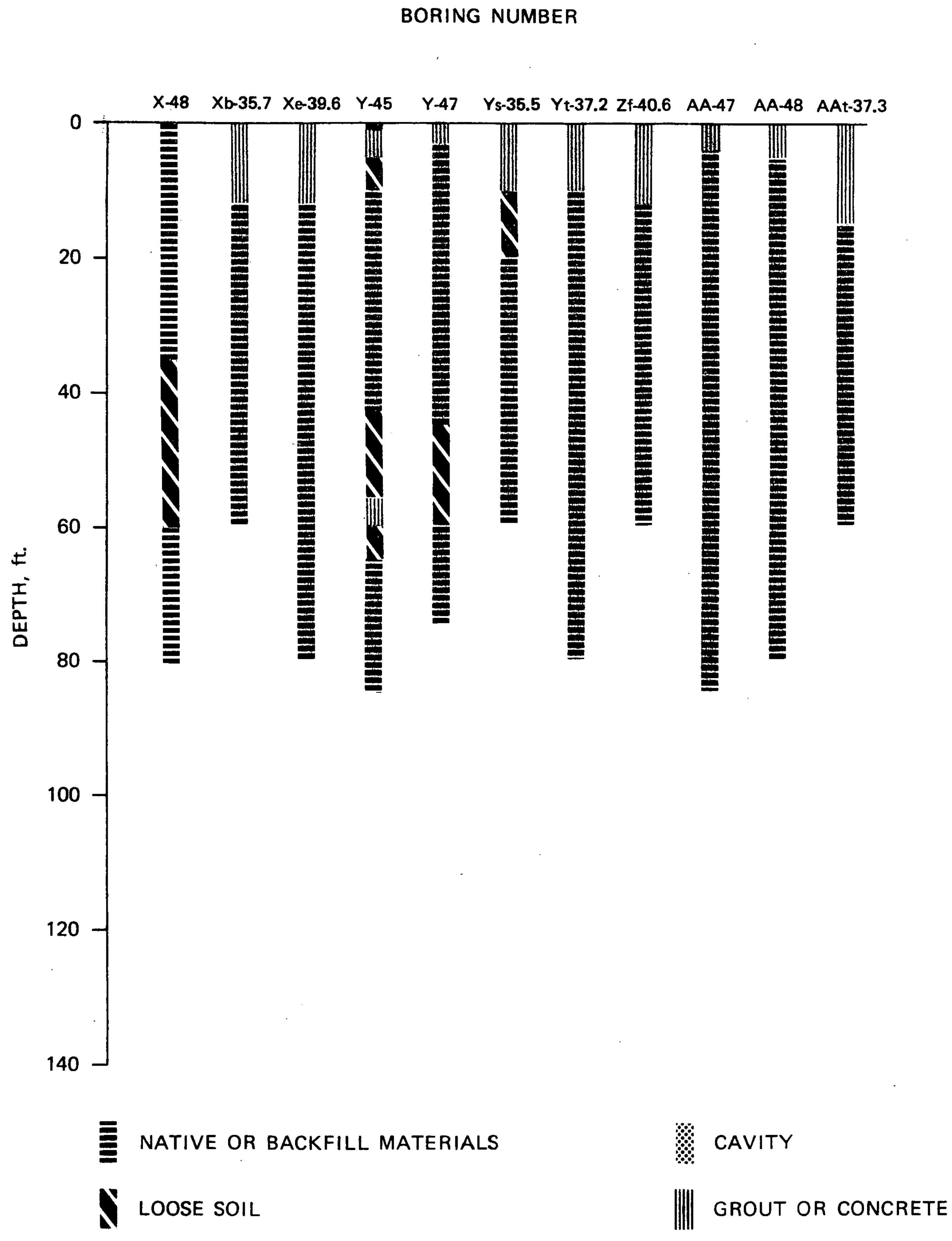
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5r

WOODWARD–CLYDE CONSULTANTS



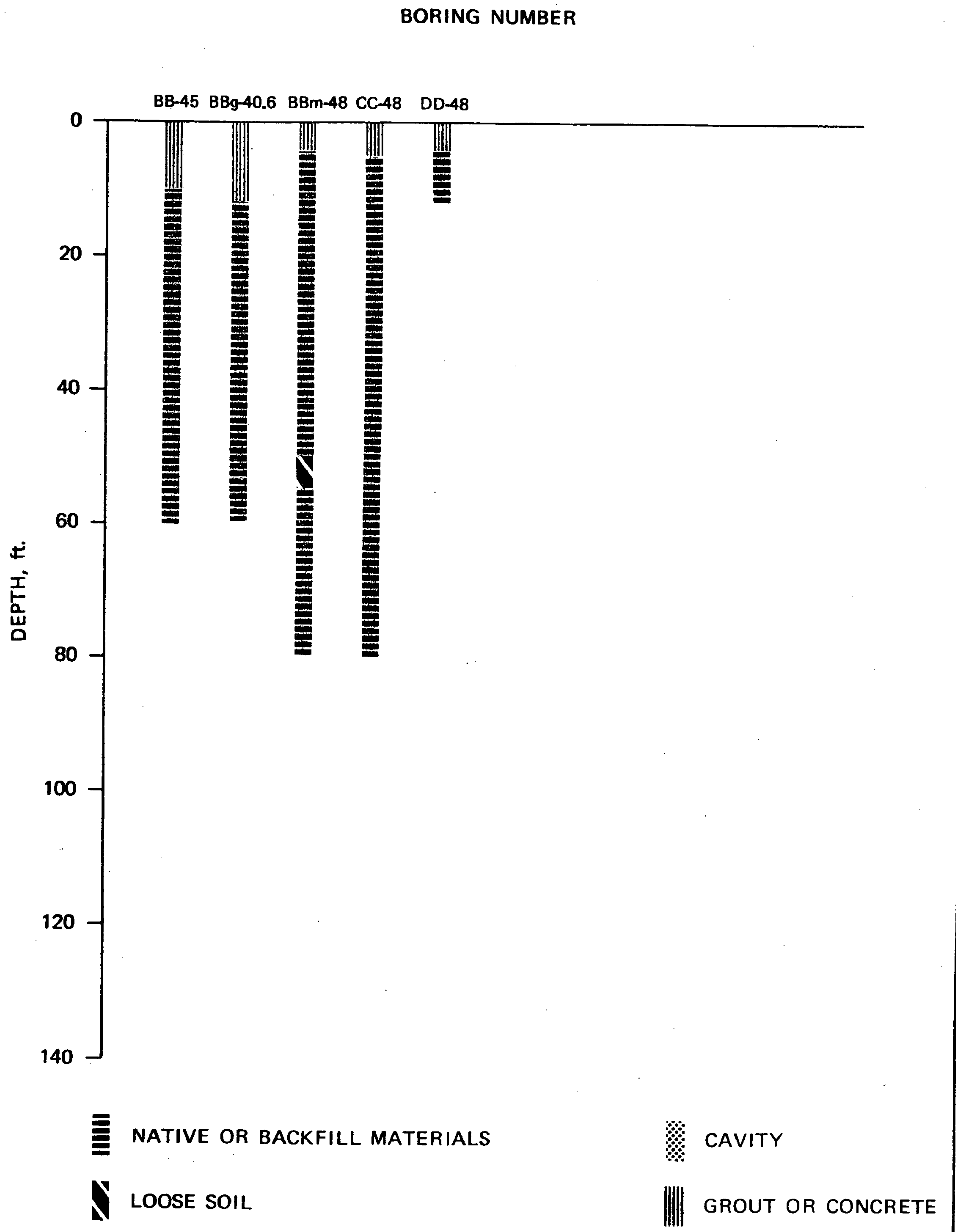
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5s

WOODWARD – CLYDE CONSULTANTS



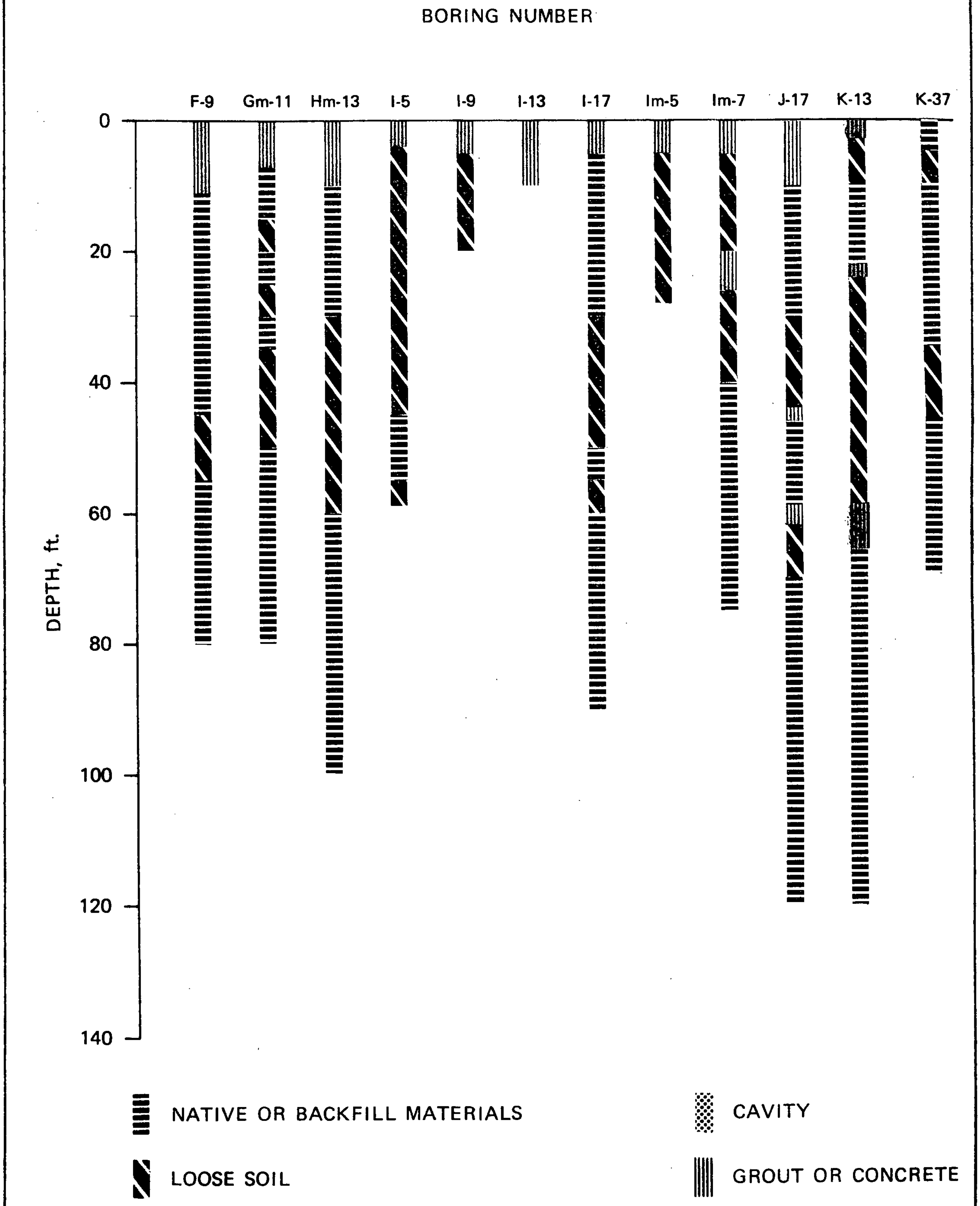
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5t

WOODWARD–CLYDE CONSULTANTS



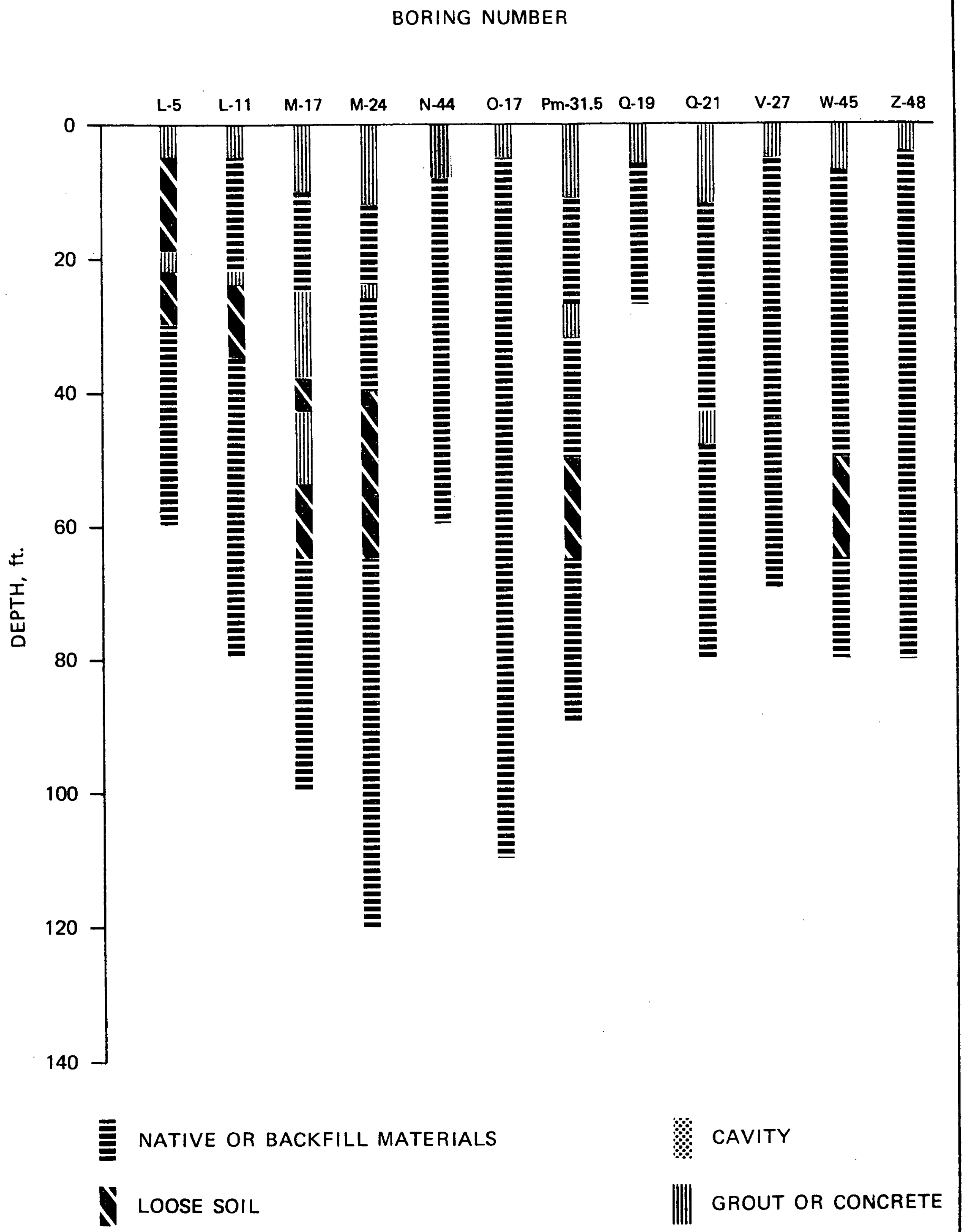
Project:	SONGS 2 & 3	GRAPHIC LOGS–STAGE I, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5u

WOODWARD – CLYDE CONSULTANTS



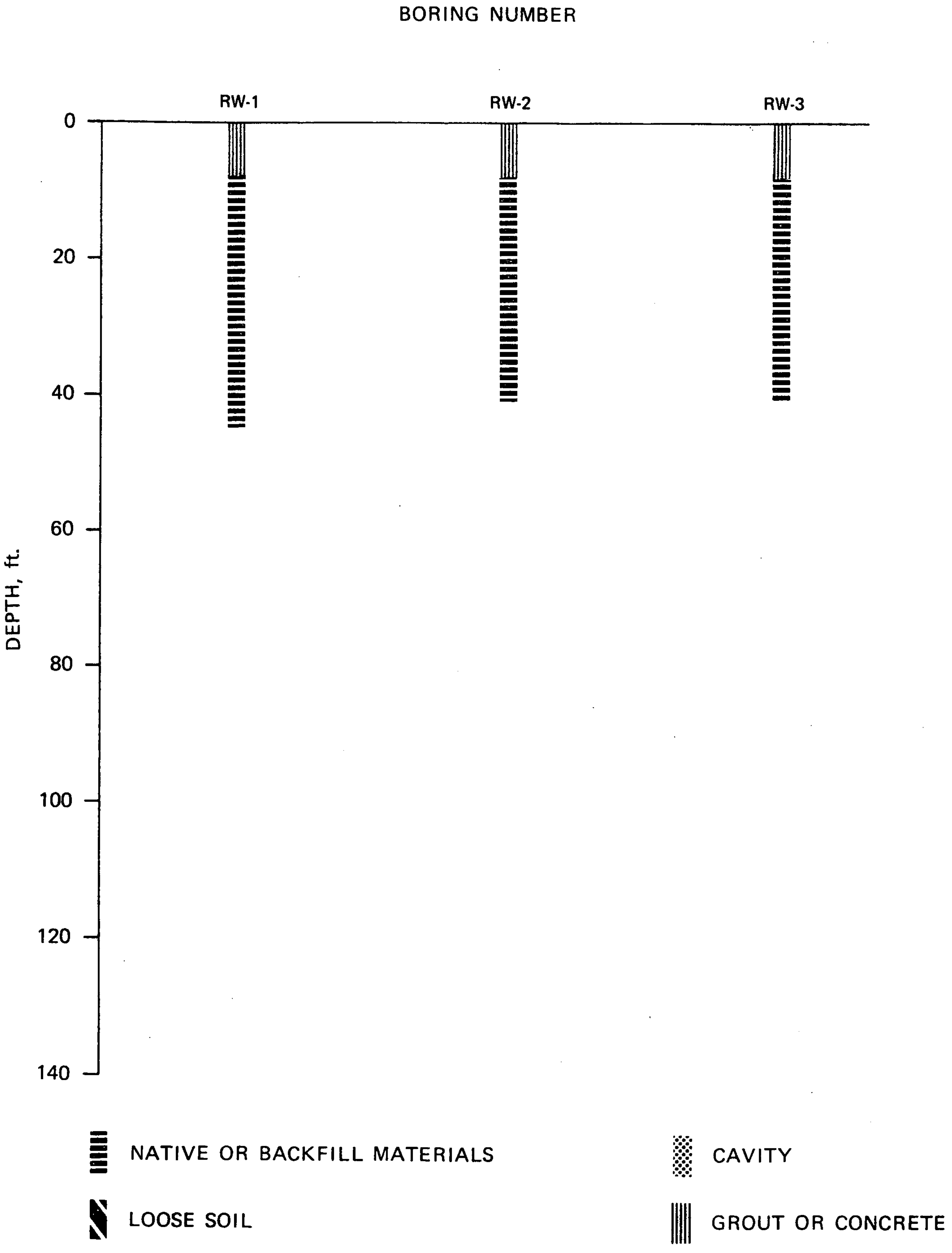
Project:	**SONGS 2 & 3**	**GRAPHIC LOGS–STAGE II, WELL NO. 7**	Fig.
Project No.	**411301**	**EXPLORATION/GROUTING PROGRAM**	**C-5v**

WOODWARD–CLYDE CONSULTANTS



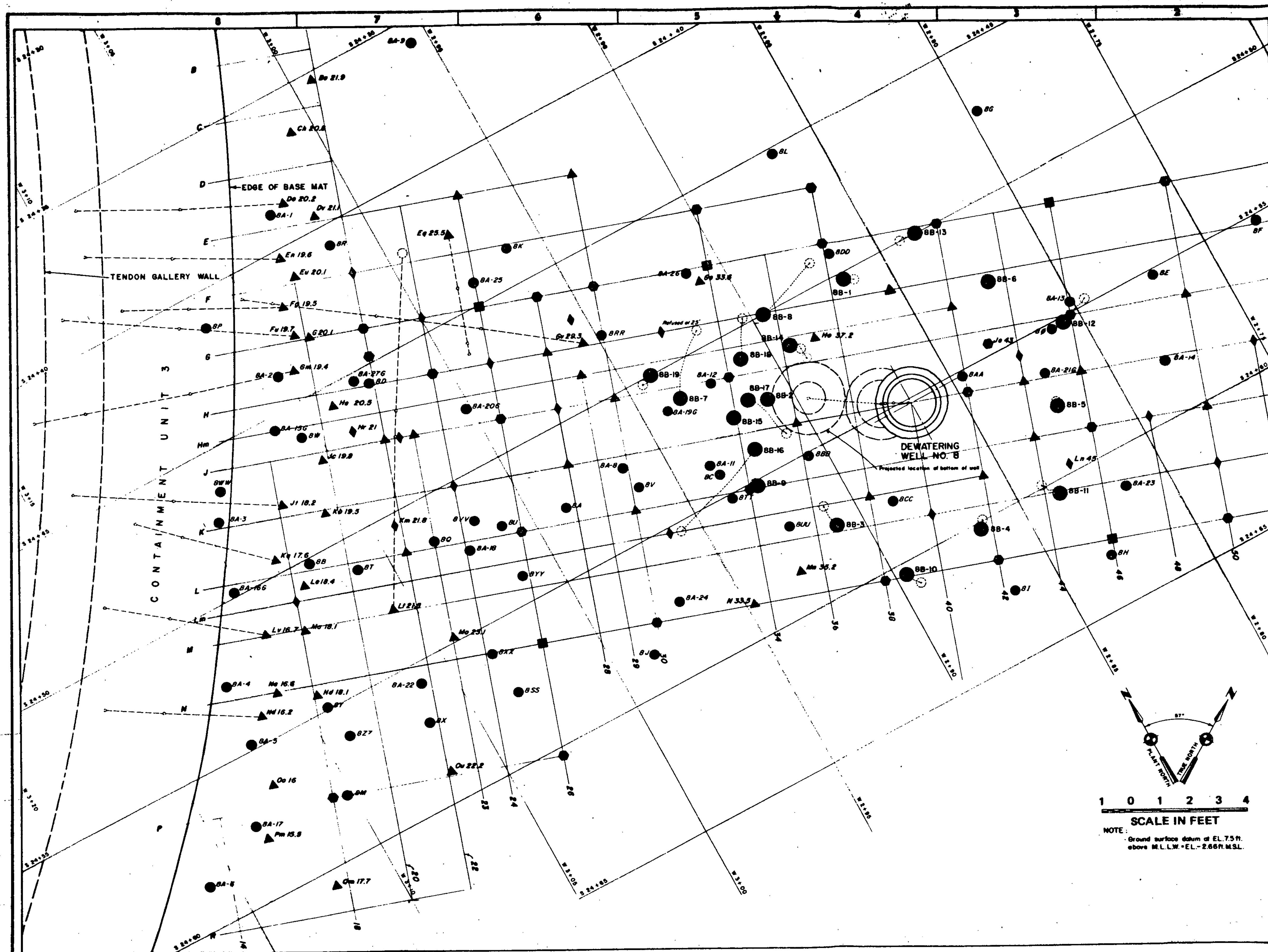
Project:	SONGS 2 & 3	GRAPHIC LOGS—STAGE II, WELL NO. 7 EXPLORATION/GROUTING PROGRAM	Fig. C-5w
Project No.	411301		

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS - STAGE 1, WELL NO. 7	Fig.
Project No.	411301	EXPLORATION/GROUTING PROGRAM	C-5x

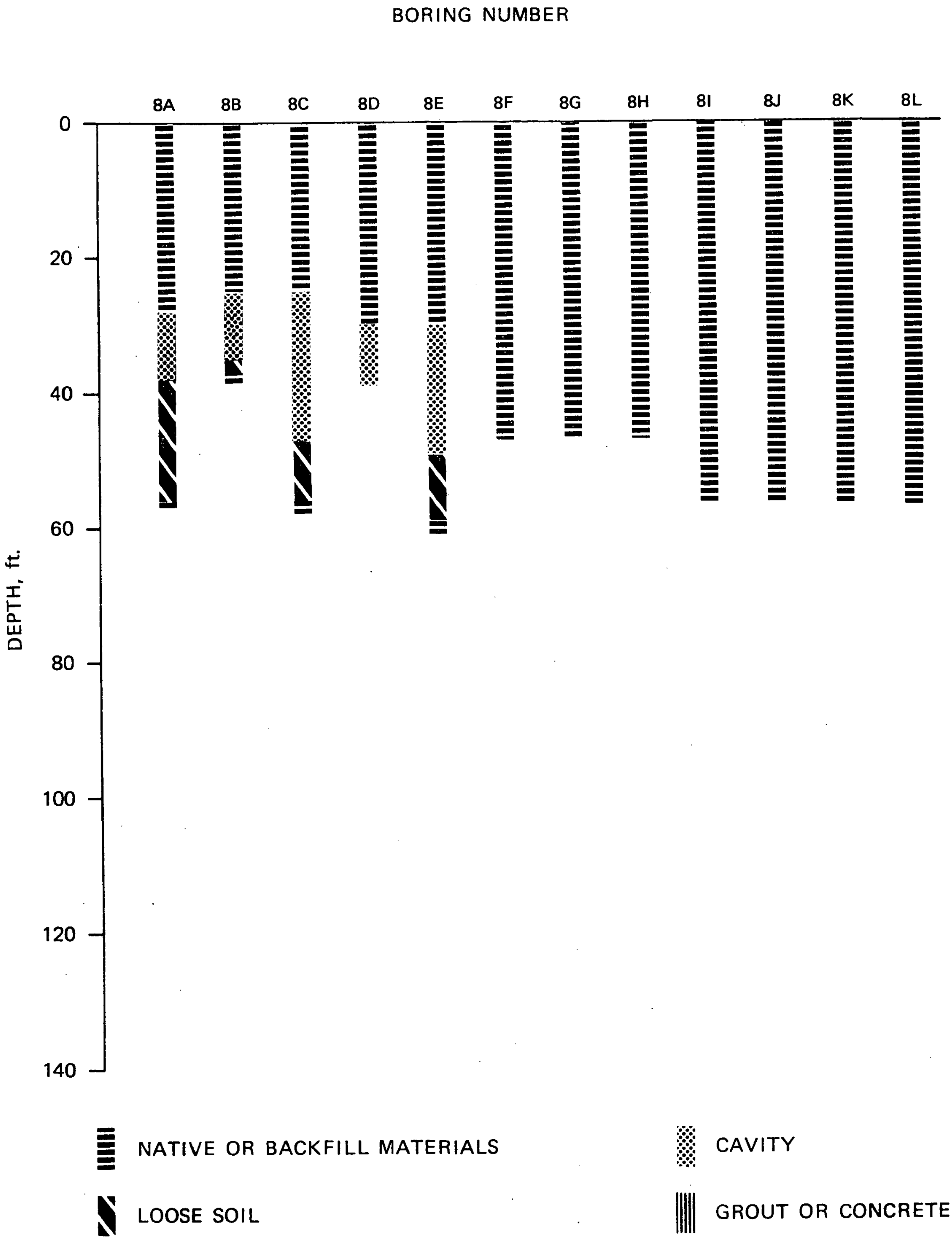
WOODWARD—CLYDE CONSULTANTS



WOODWARD-CLYDE CONSULTANTS

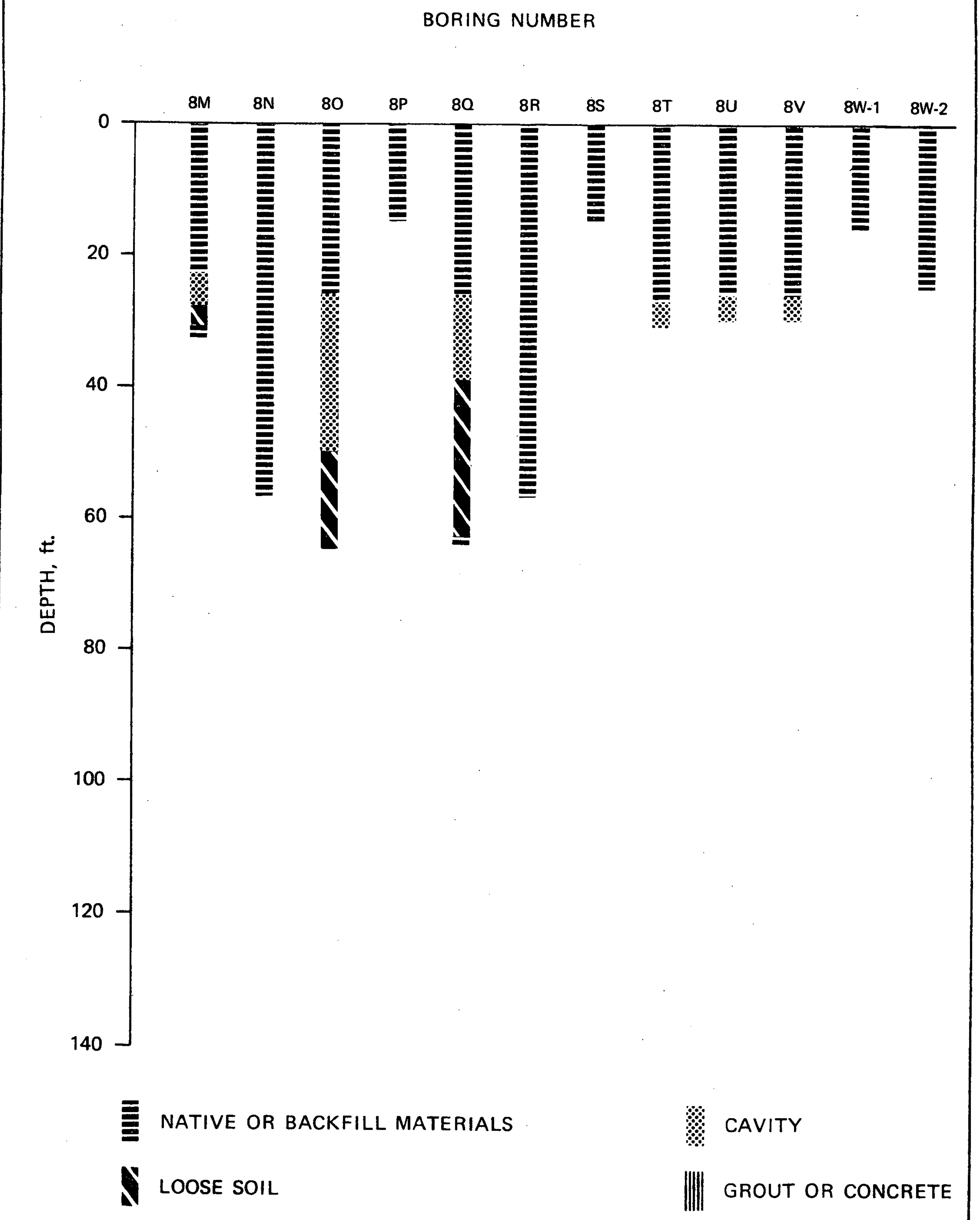
DEWATERING WELL NO. 8
LOCATION OF DRILL HOLES

Project No. 411301	Fig.
SONGS 2 & 3	C-6a



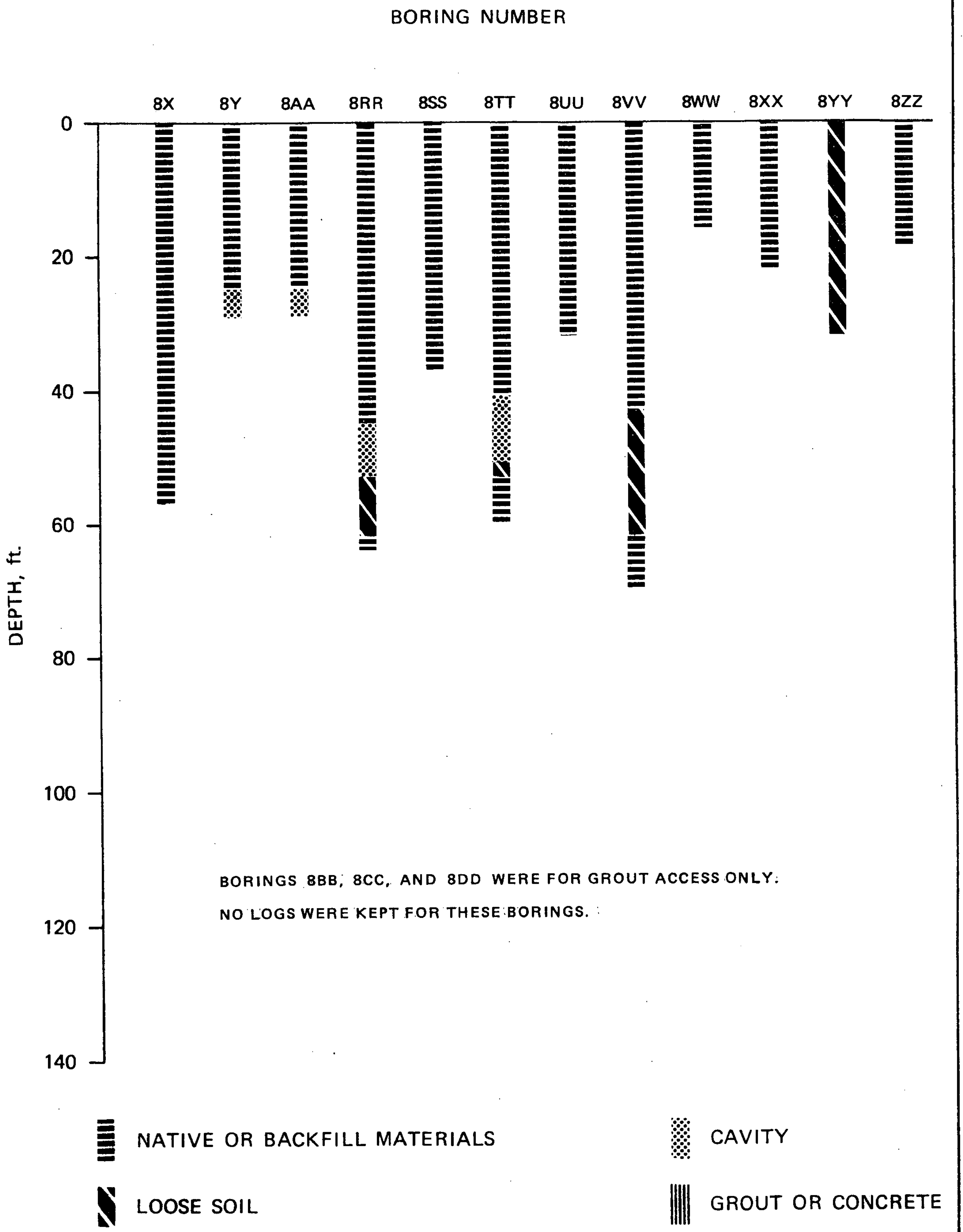
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	EXPLORATION BORINGS	C-6b

WOODWARD—CLYDE CONSULTANTS



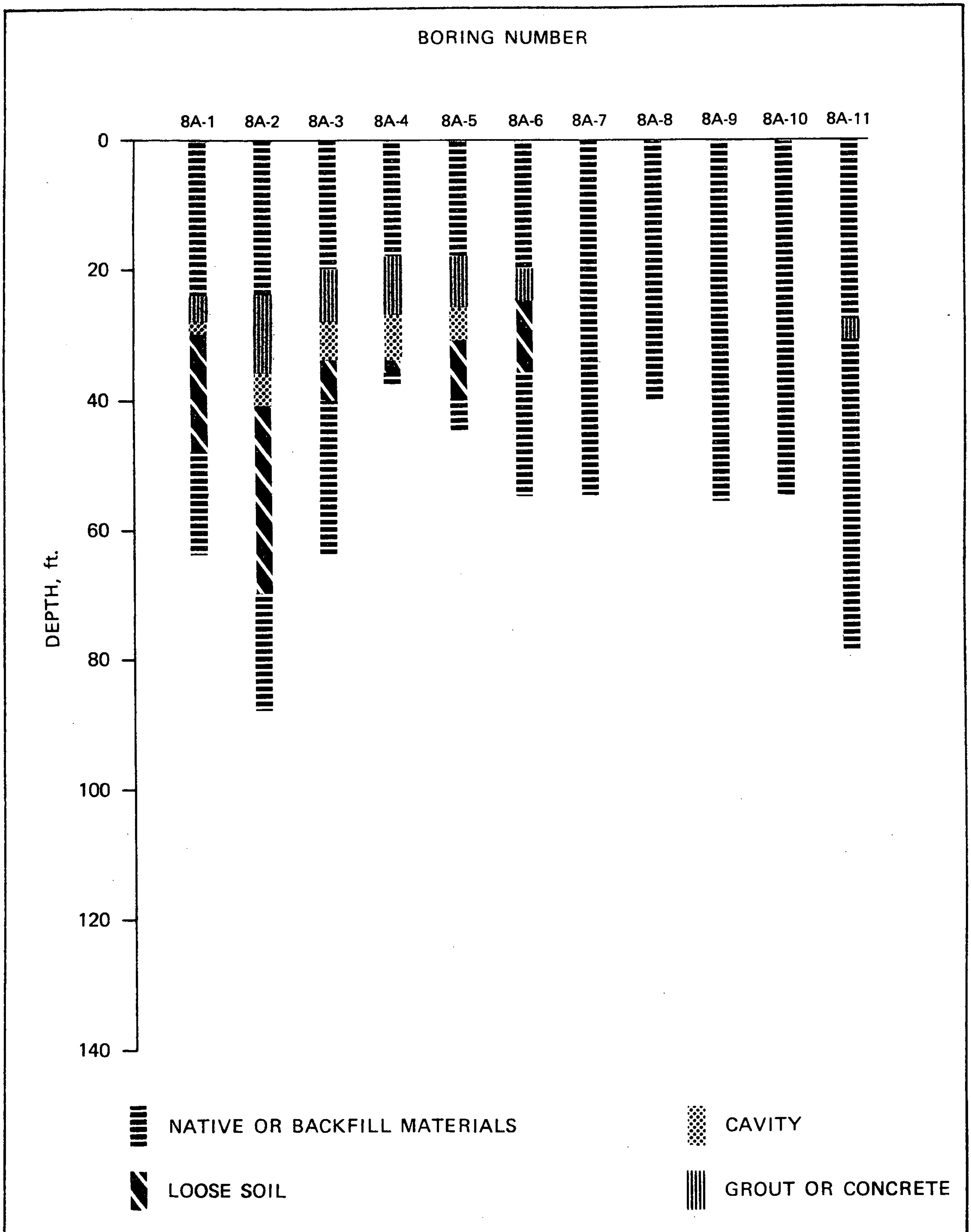
Project: SONGS 2 & 3 Project No. 411301	GRAPHIC LOGS, WELL NO. 8 EXPLORATION BORINGS	Fig. C-6c

WOODWARD—CLYDE CONSULTANTS



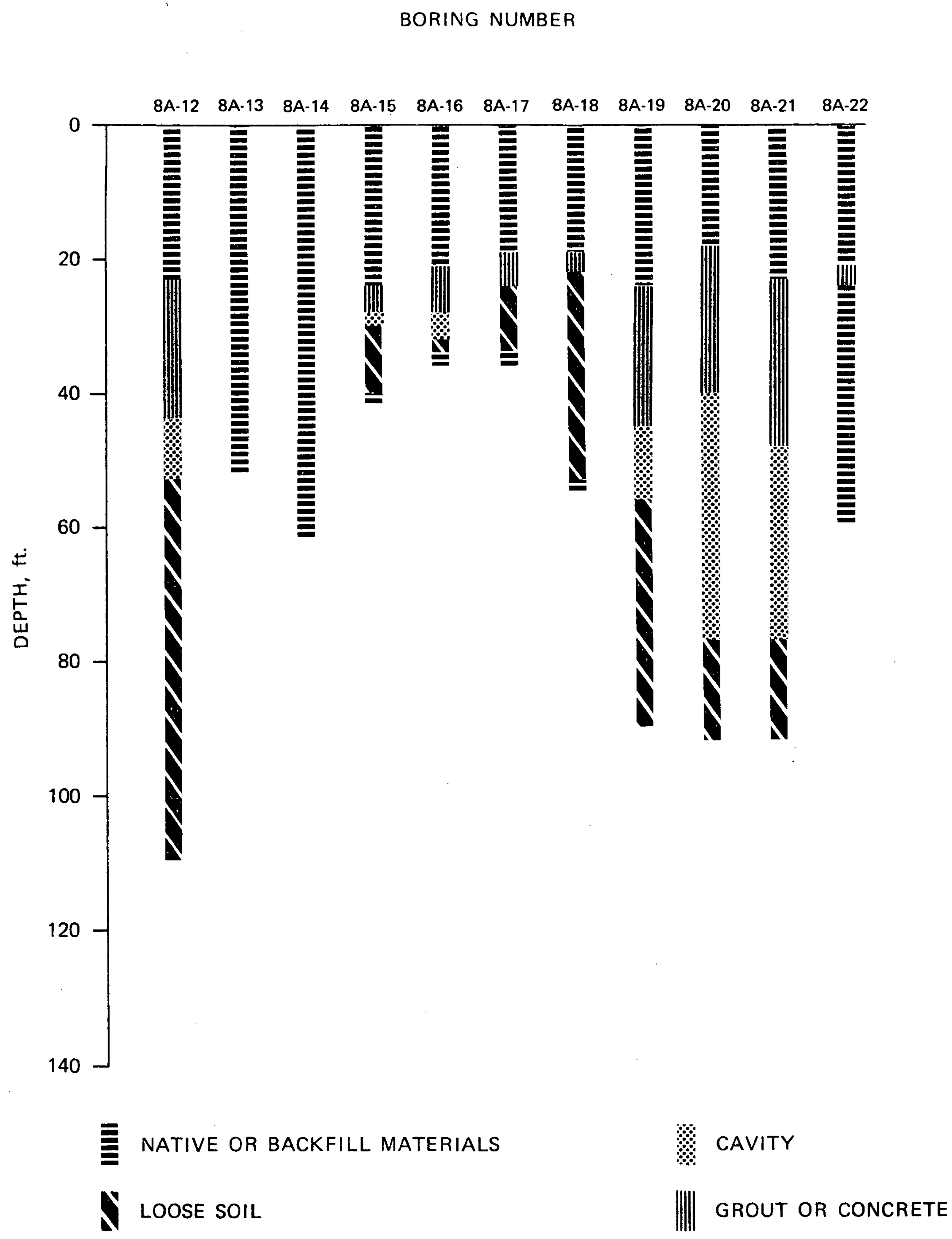
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8 EXPLORATION BORINGS	Fig. C-6d
Project No.	411301		

WOODWARD—CLYDE CONSULTANTS



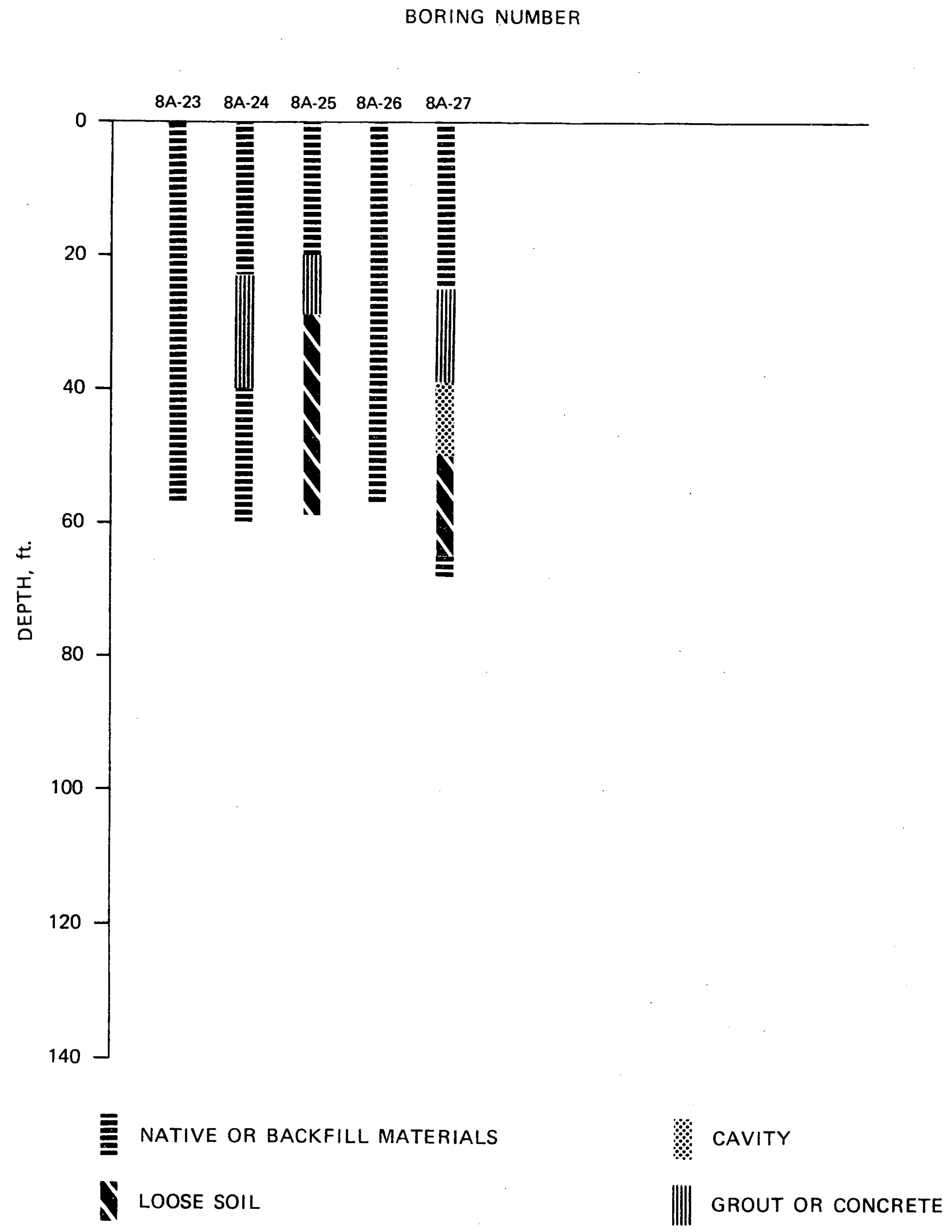
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	EXPLORATION BORINGS	C-6e

WOODWARD—CLYDE CONSULTANTS



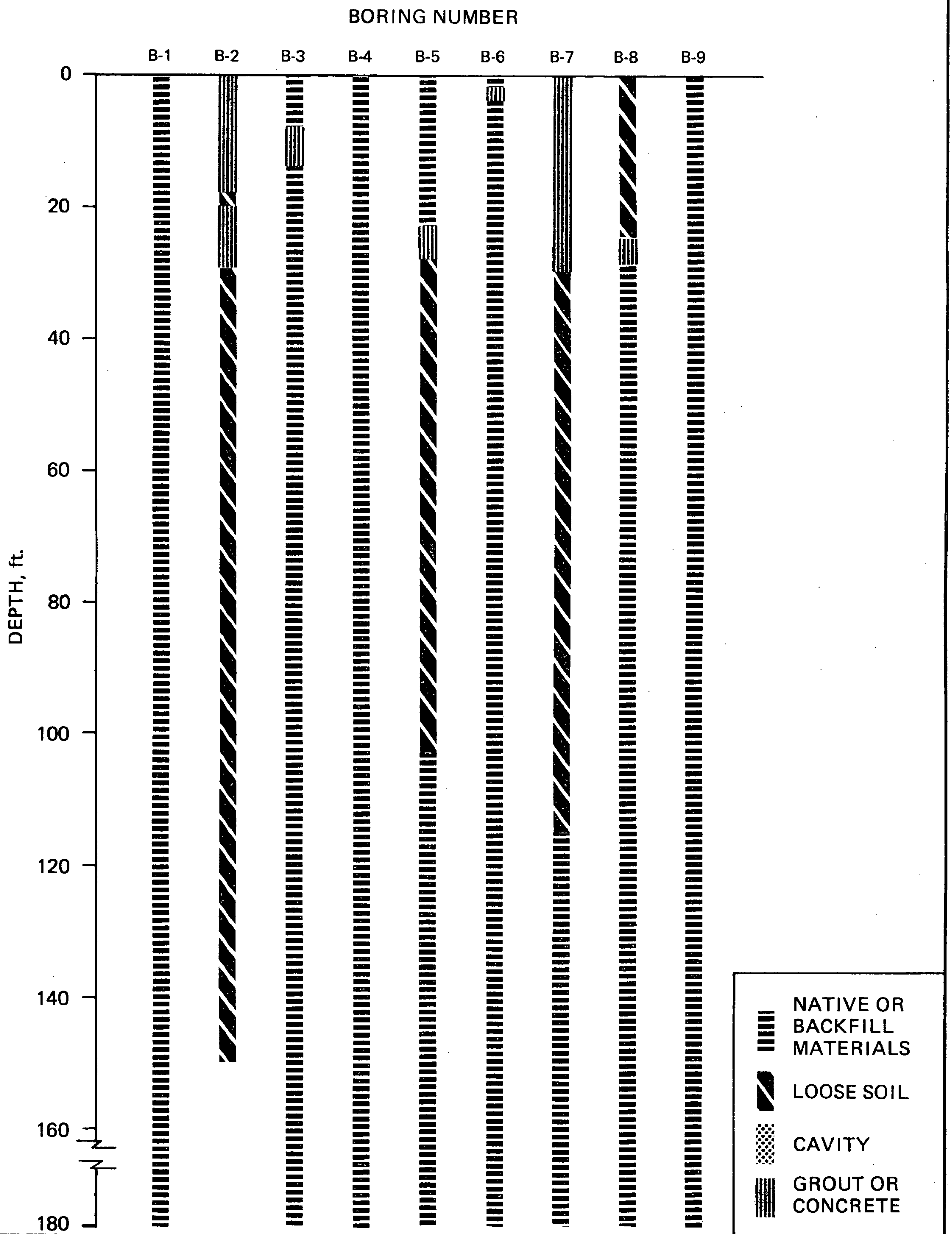
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	EXPLORATION BORINGS	C-6f

WOODWARD–CLYDE CONSULTANTS



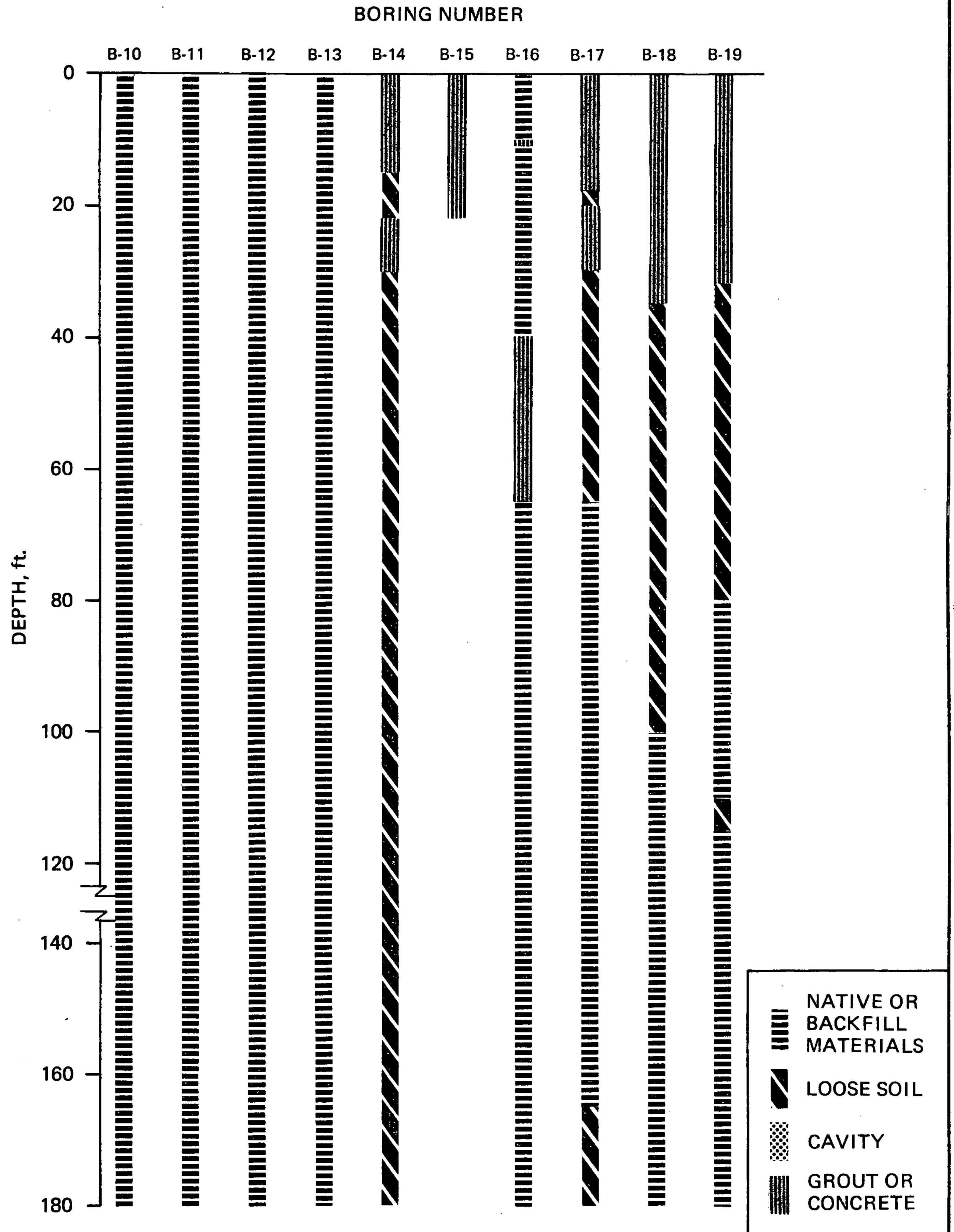
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	EXPLORATION BORINGS	C-6g

WOODWARD–CLYDE CONSULTANTS



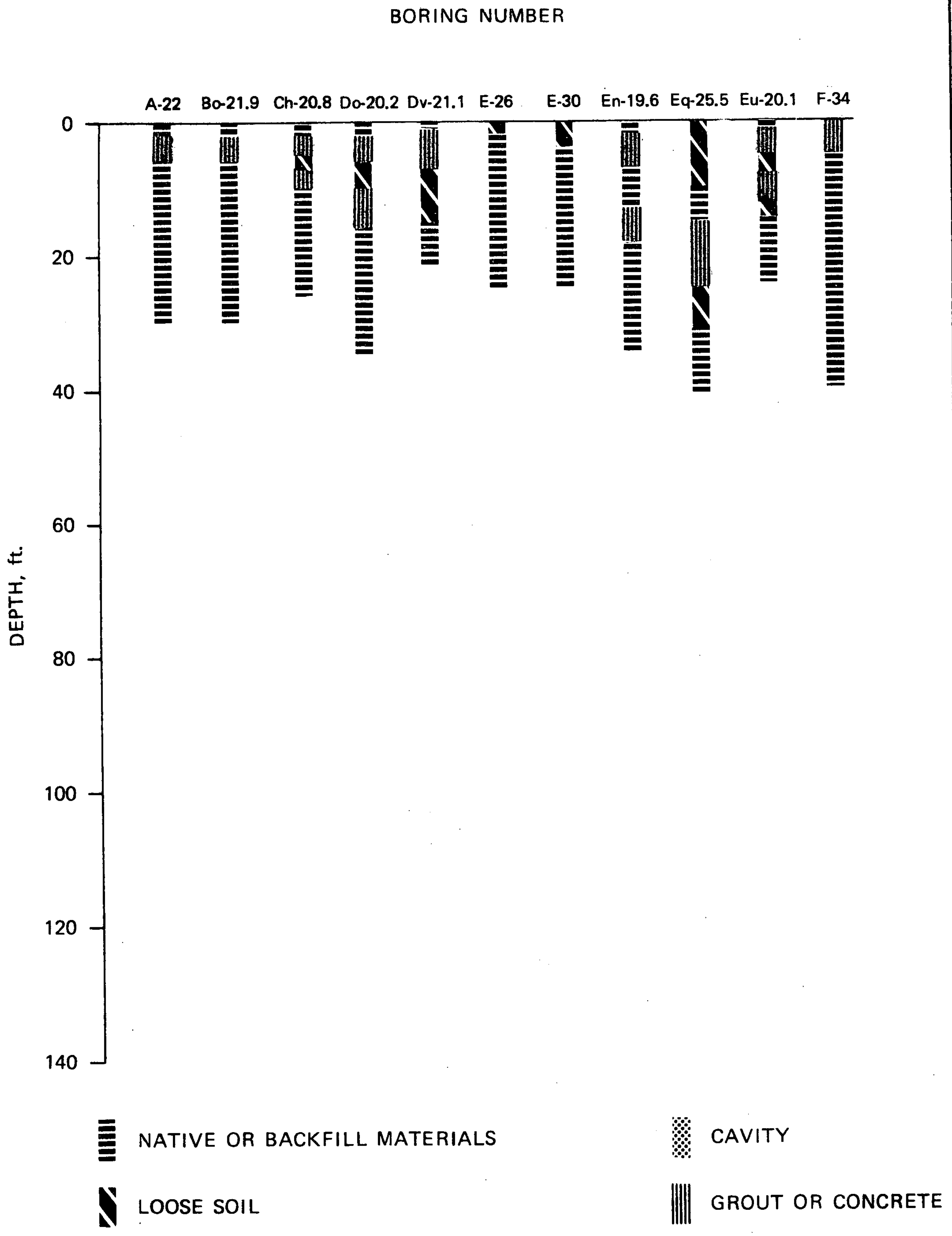
Project: SONGS 2 & 3		GRAPHIC LOGS, WELL NO. 8	Fig.
Project No. 411301		DEEP EXPLORATORY BORINGS	C-6h

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8 DEEP EXPLORATORY BORINGS	Fig. C-6i
Project No.	41130I		

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6j

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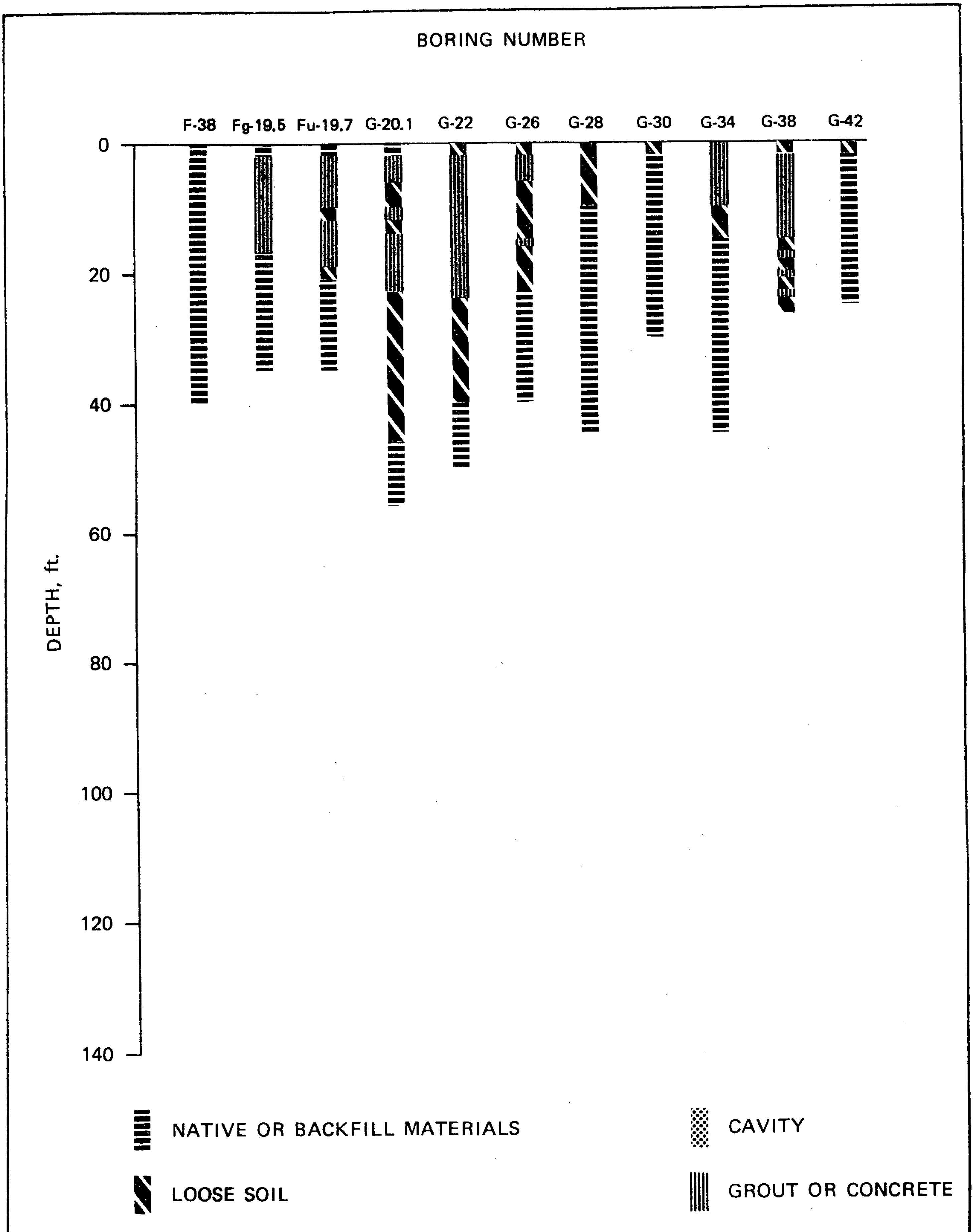

Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6k

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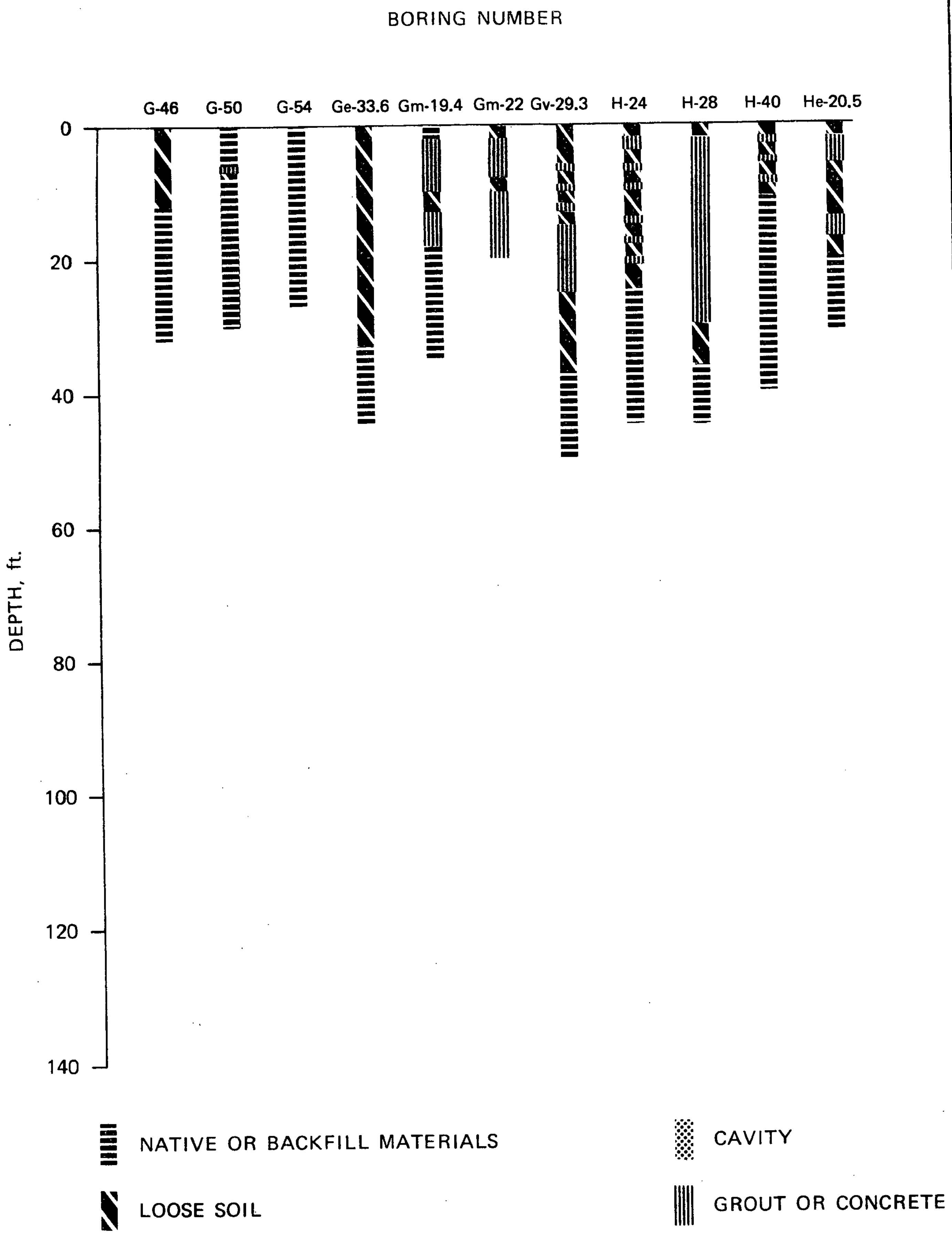

Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-61

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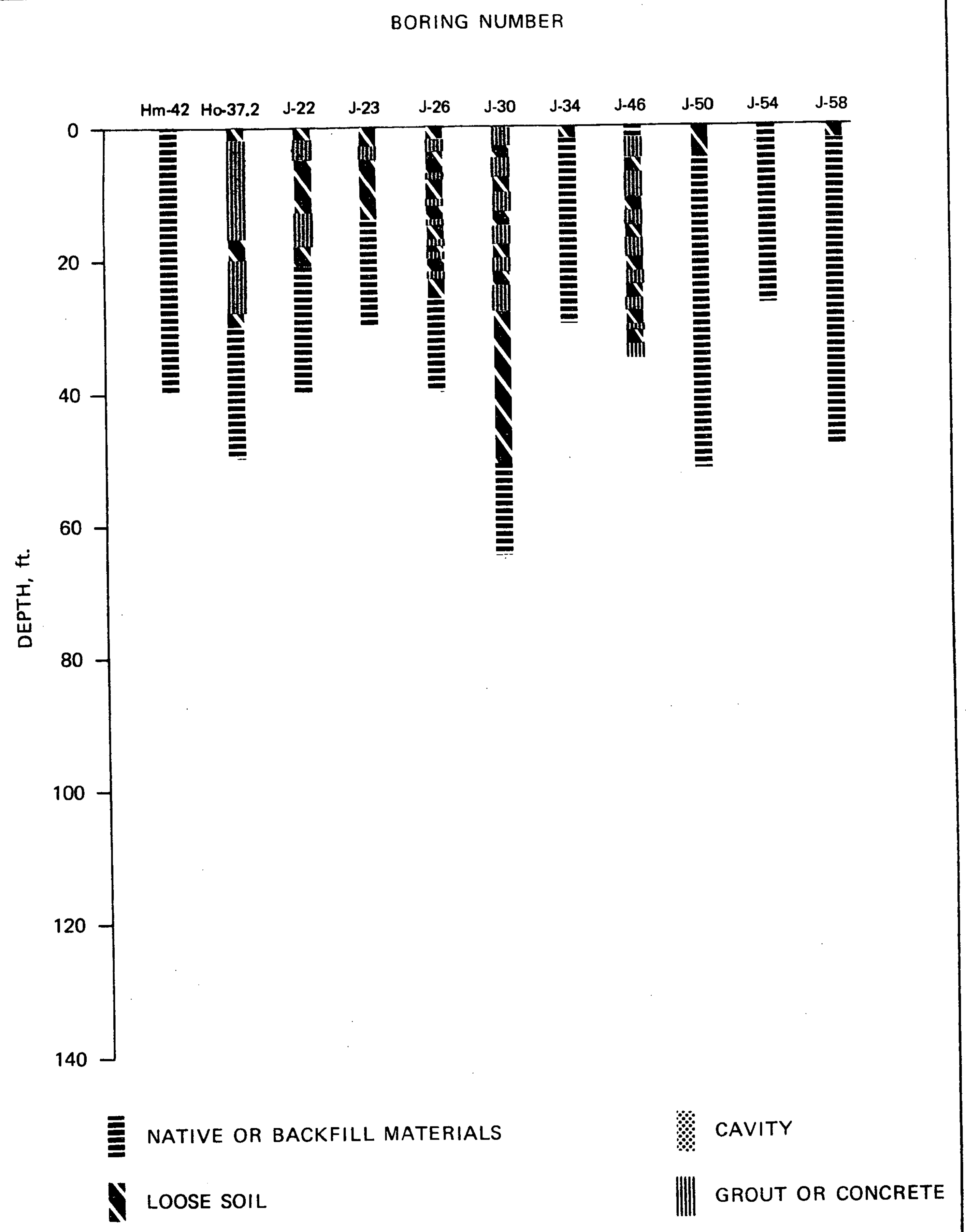

Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6m

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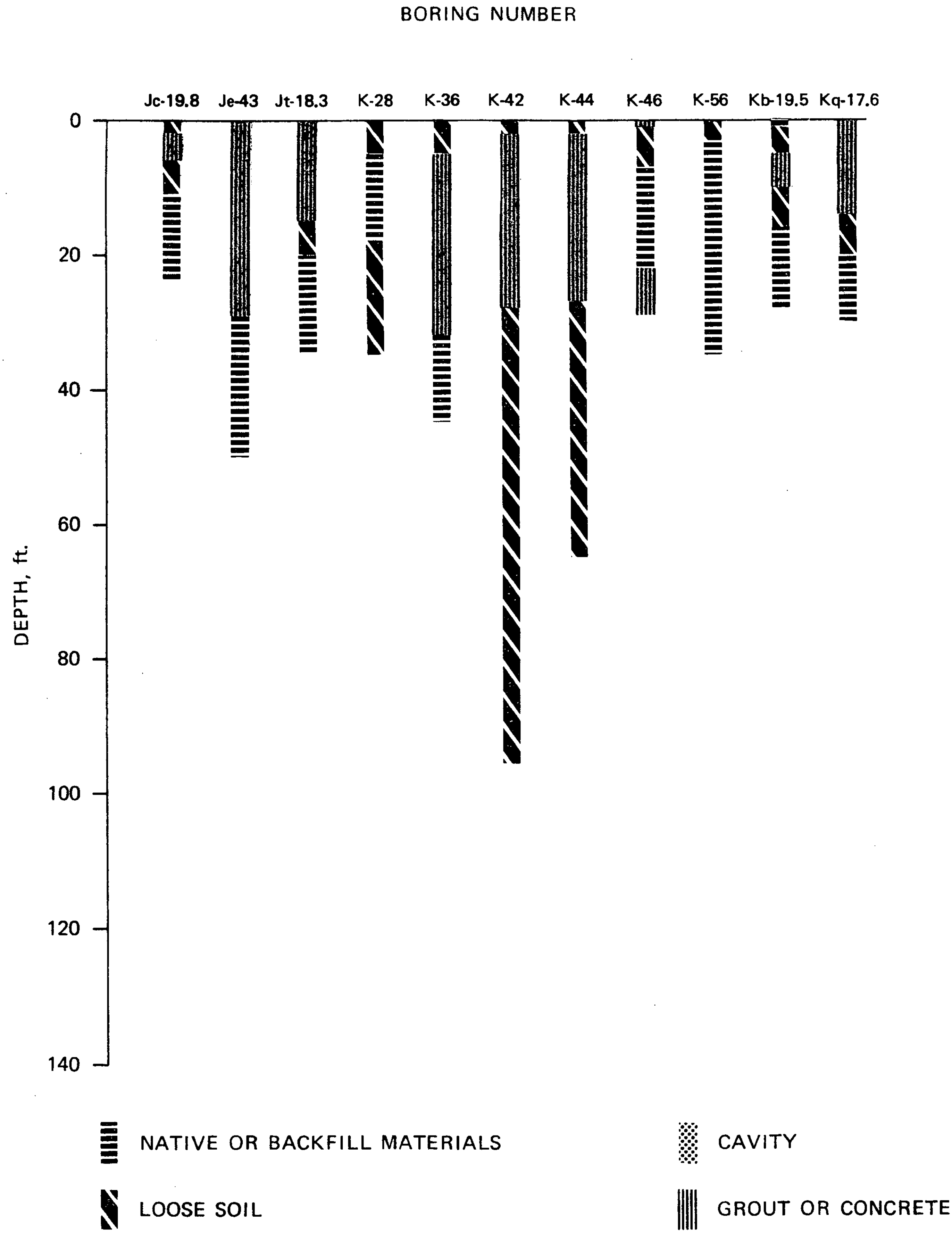

Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6n

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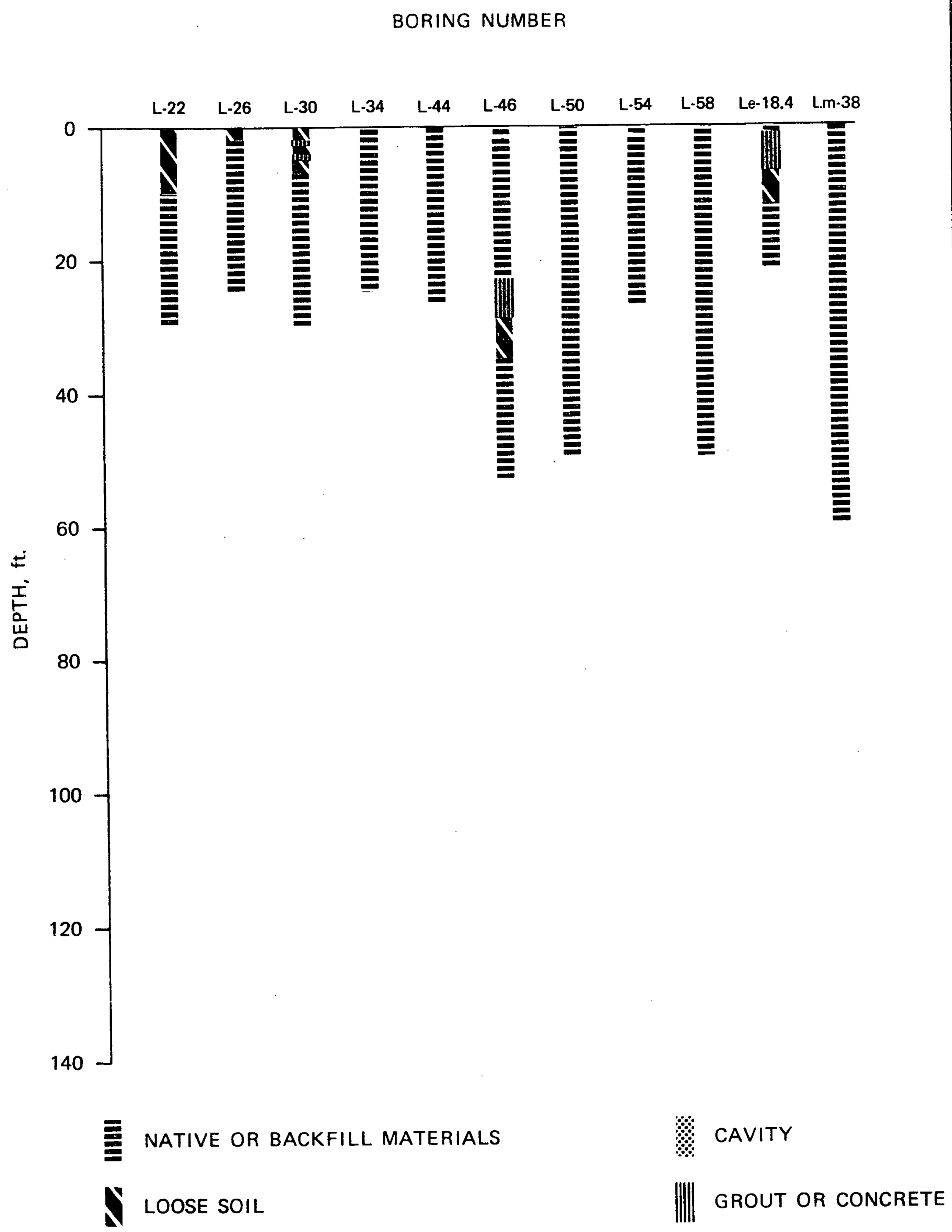
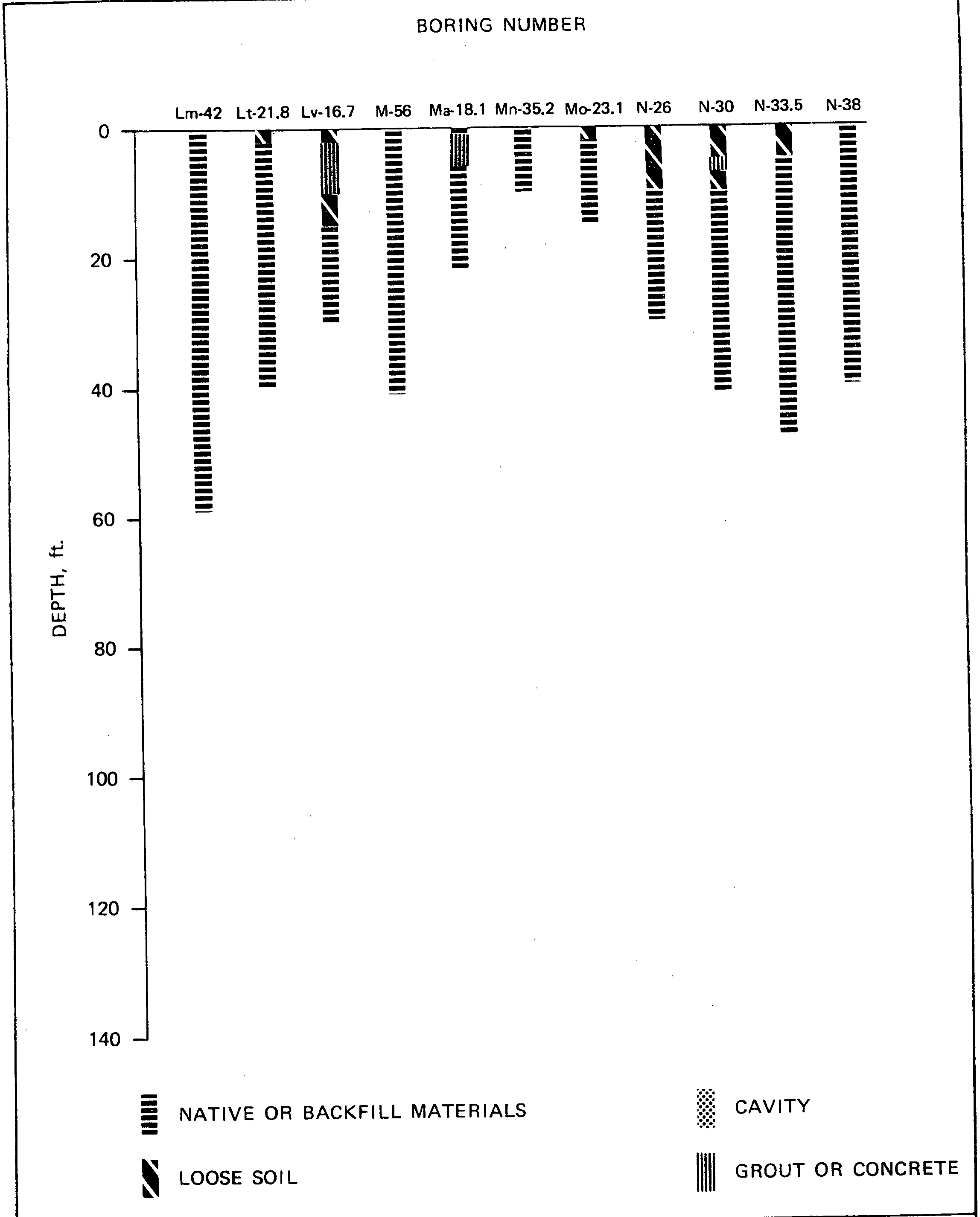


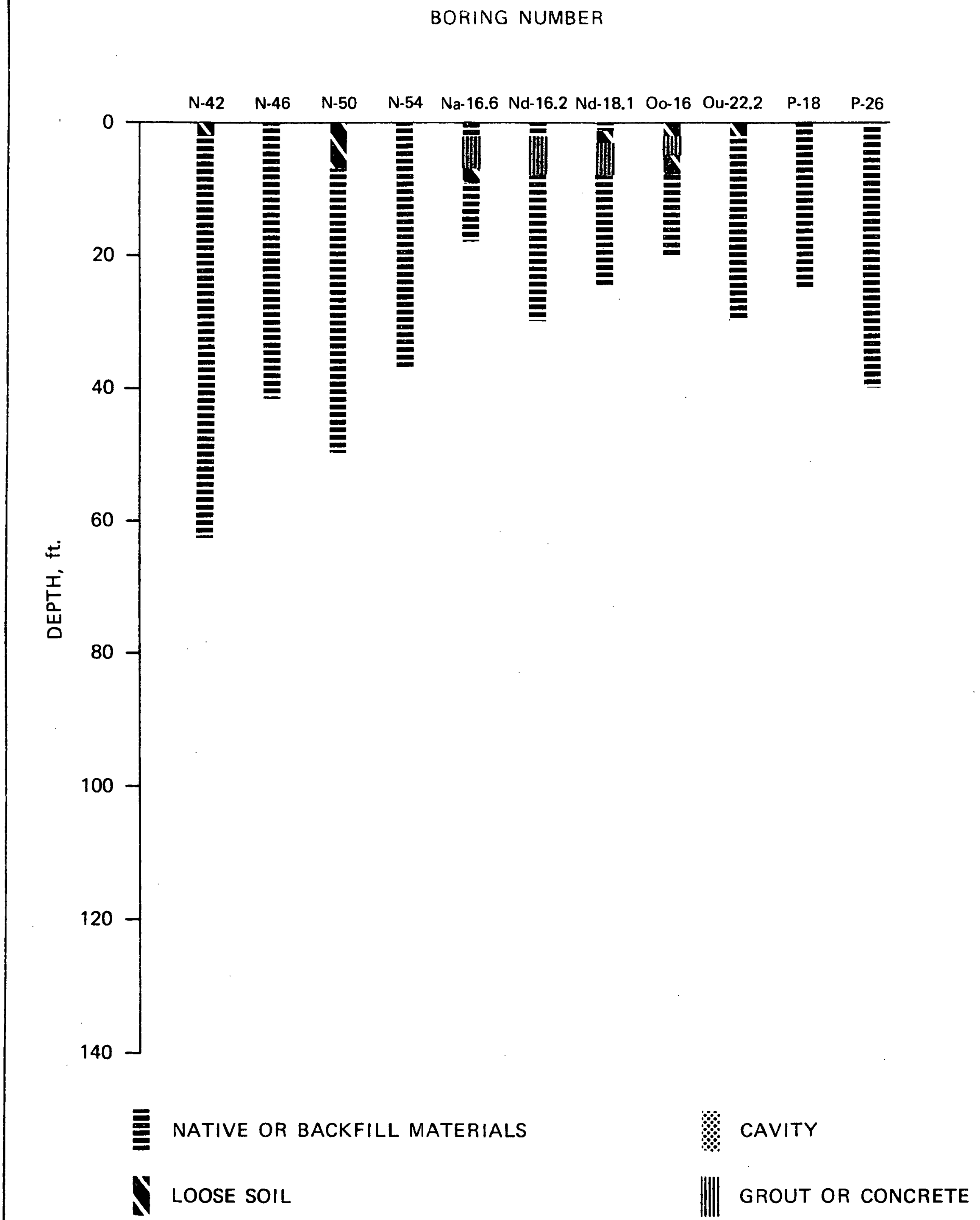
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6o

WOODWARD-CLYDE CONSULTANTS



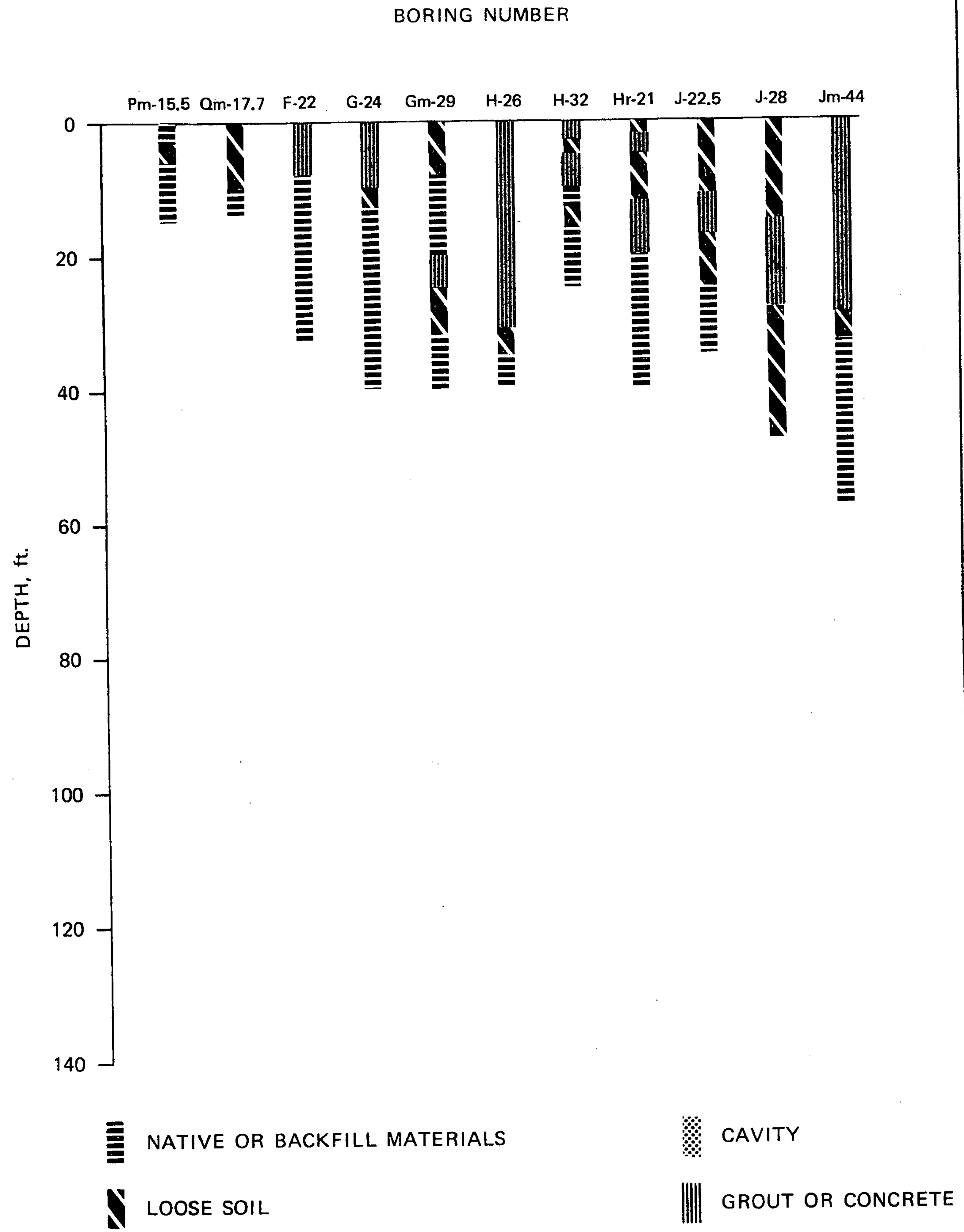
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6p

WOODWARD-CLYDE CONSULTANTS



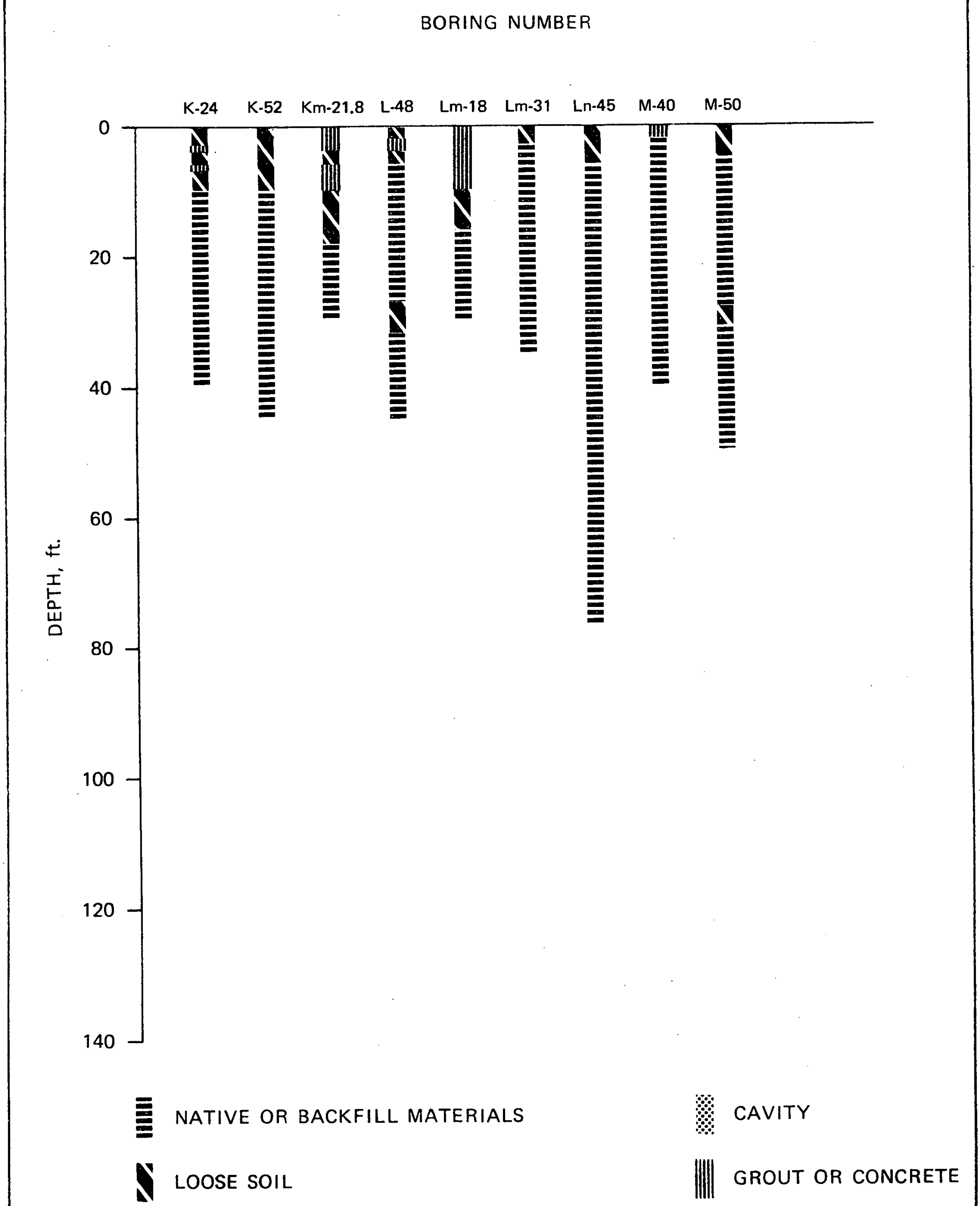
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6q

WOODWARD—CLYDE CONSULTANTS



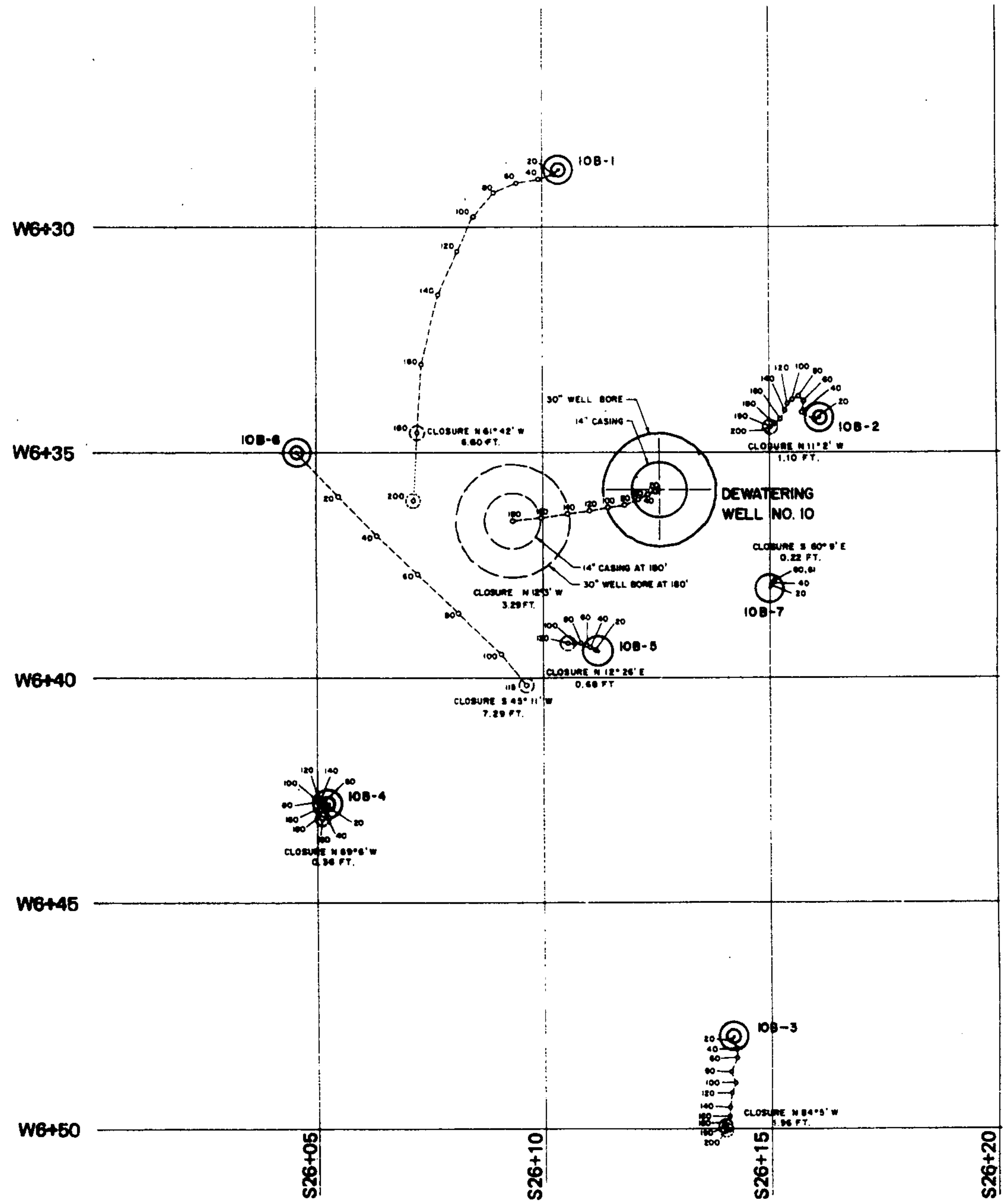
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6r

WOODWARD–CLYDE CONSULTANTS



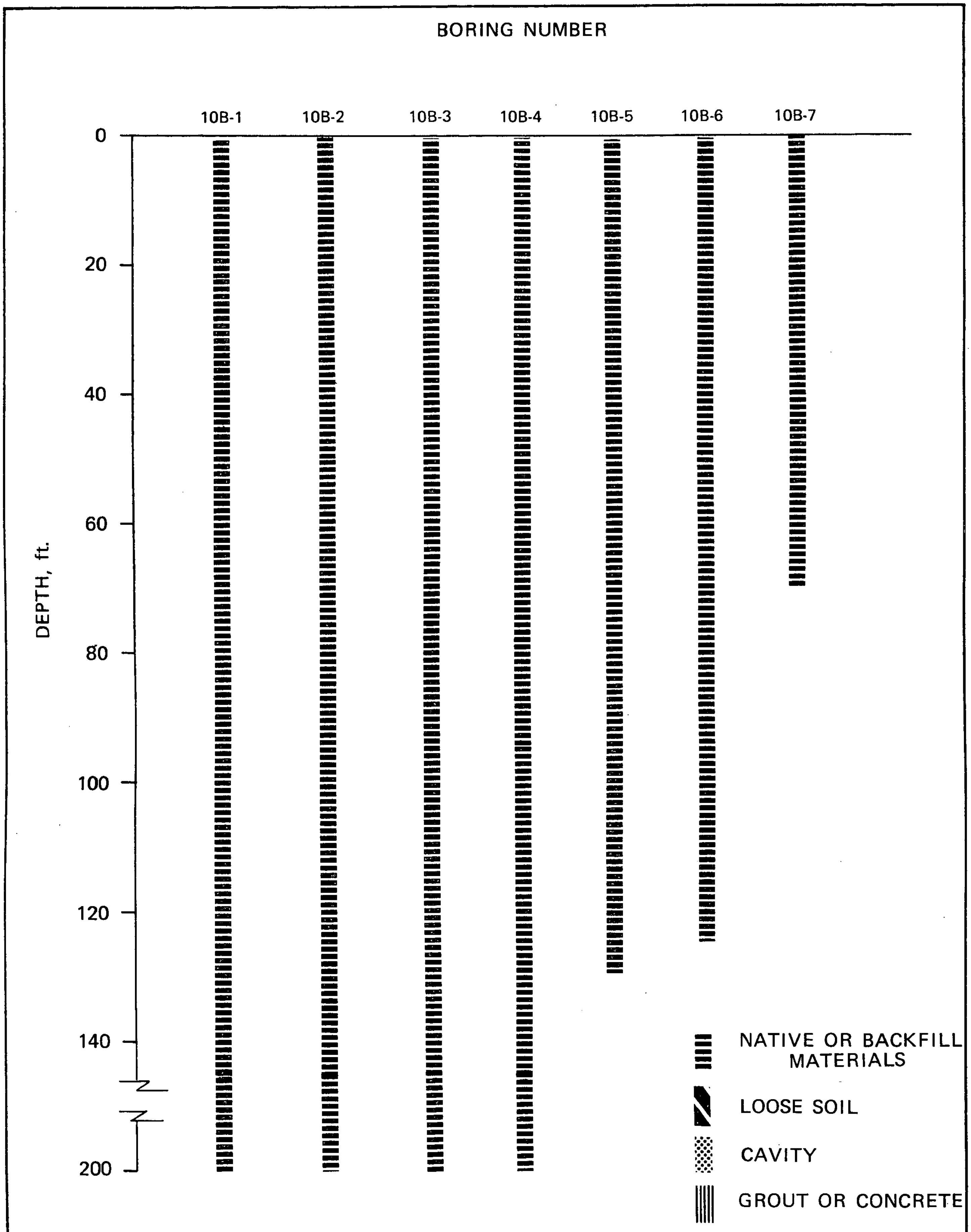
Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 8	Fig.
Project No.	411301	SHALLOW EXPLORATION/GROUTING BORINGS	C-6s

WOODWARD–CLYDE CONSULTANTS



Project:	SONGS 2 & 3	DEWATERING WELL NO. 10	Fig.
Project No.	411301	LOCATION OF DRILL HOLES	C-7a

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	GRAPHIC LOGS, WELL NO. 10	Fig.
Project No.	411301	DEEP EXPLORATION BORINGS	C-7b

WOODWARD—CLYDE CONSULTANTS

APPENDIX D

Laboratory Testing

APPENDIX D
LABORATORY TESTING

D-1 INTRODUCTION

A number of tests have been conducted in the laboratory to: (a) define the grain size distribution of the San Mateo sand in the vicinity of the dewatering wells; (b) evaluate the adequacy of the filter material; and, (c) study the characteristics of simulated cavity-infill material. The results of these tests are summarized in this appendix.

D-2 GRAIN SIZE DISTRIBUTION TESTS

A number of borings were drilled around the dewatering wells to explore the subsurface soil conditions. Samples of soil were obtained at selected intervals as described in Appendix C. Mechanical analysis tests were conducted on selected samples from borings drilled at Wells 3 through 8 to evaluate the grain size distribution. Figures D-1 through D-6 summarize the results of tests conducted on materials obtained at each of the wells. Figures D-7 through D-9 summarize the grain size distribution data for the cavity-infill materials from Wells 6, 7, and 8, respectively. Insufficient data were available to make such summaries for the cavity-infill materials at Wells 3 and 5 and at Well 4 only a small amount of loose sand was noted below the grout placed in the excavation. Figures D-10 and D-11 show summaries of results for all materials tested and for all cavity-infill material tested, respectively. It should be noted that summaries of results for all tests at a particular location, e.g., Figure D-10, include the results from all tests including those for loose soils. In all, the number of grain size distribution tests conducted are as follows:

Well No.	No. of Tests in Cavity-Infill Soil	Total No. of Tests
3	--	57
4	-- *	57
5	--	61
6	22	119
7	65	324
8	28	135
Total Tests	115	753

* Shallow area created by caving during construction excavation.

The grain size distribution tests show that the San Mateo sand is a homogeneous material that generally classifies as SW-SM. Occasional lenses of siltstone were found. The cavity-infill material appears to be slightly more coarse-grained than the surrounding San Mateo sand. This indicates that some of the fine grained component of the sand may have been washed away when the cavity-infill material was deposited.

D-3 TESTS TO EVALUATE THE ADEQUACY OF FILTER MATERIALS

During the construction of the dewatering wells, five gradation tests were performed on the filter gravels. The results of these tests have been summarized in Figure D-12, together with the gradation of the native San Mateo sand, the range of filter material specified for the project, and limits of acceptable filter for the San Mateo sand based on contemporary filter design criteria. As indicated on Figure D-12, two of the five gravel samples tested lay outside the specified range, but were within the limits of acceptable filters for the San Mateo sand. To further evaluate the adequacy of the filter gravel, additional testing was completed. In these tests, San Mateo sand (loose, compacted, and intact-carved) was placed above typical filter material and water was pumped through the sand at gradients varying from 5 to 500. The first group of tests was run in a specially fabricated cylindrical apparatus (3.25-in. diameter and 6-in. long) in which loose filter material was overlain by loose San Mateo sand. The base of the cylinder consisted of a No. 20 sieve over a plastic slab drilled with 1/4-in. holes. Water was introduced into the apparatus from the top through a 1/4-in. Foster fitting and collected at the base after filtering through a No. 30 sieve first and then a No. 200 sieve. The material from which the filter was graded was a gravel meeting the gradation range of Class 2 permeable material, Caltrans Standard Specifications, Section 68-1.025. This material was selectively graded for use in the tests as follows:

Test 1: Fines passing the No. 200 sieve were removed from the filter gravel.

Test 2: Materials retained on the 3/8-in. sieve and passing the No. 10 sieve were removed from the filter gravel.

Test 3: Filter gravel consisted of material retained on the No. 4 sieve.

The test procedure was to increase the water pressure from 5 to 50 psi to complete the test in 10 minutes. In Test 3, the pressure was increased to 90 psi and left overnight (16 hours).

The observations from these tests conducted at high gradients (50 psi is a gradient of about 500) indicate only nominal loss of filter material and San Mateo sand. Even though the filter and the sand were placed loosely, no collapse of the sand or soil transport through the filter was visible.

The second group of tests was run in a triaxial cell on specimens of San Mateo sand (4-in. diameter and 5-1/4 to 5-1/2 in. long) carved from intact block samples. The general procedure of these tests was to first saturate the sand with slow water penetration from bottom to top of the specimen. Then, the specimen was subjected to water flow from top to bottom in gradually increasing gradients up to gradients of 25 to 120. The filter at the base of the specimen was varied as follows:

- A No. 20 sieve
- Gravel filter (Class 2 Permeable Material, Section 68-1.025 Caltrans Standard Specifications)
- Filter graded from the above gravel filter consisting of material passing the 3/4-in. sieve and retained on the No. 8 sieve.

In each case, no significant soil transport through the filter was noted. Some colloidal material came out at first but the flow cleared as the test progressed. The rate of flow did not change appreciably.

The gravel filter material utilized in running the laboratory tests to evaluate the adequacy of the filter material was somewhat more coarse-grained than the gradation range presented by the five tests on the gravel pack used in the dewatering wells (see Figure D-12). Furthermore, in some of the tests, the material was selectively graded to obtain a filter which was significantly more porous than the gravel pack around the wells and extended outside the coarse limits calculated from empirical procedures (Figure D-12). Yet, the laboratory tests show that even at relatively high gradients, no significant sand transported through the filters used. This indicates that a wide range of gradation is acceptable for filtering the San Mateo sand, and that the gravel pack materials used around the dewatering wells are adequate.

D-4 PERMEABILITY OF CAVITY INFILL SAND

A series of tests was run to evaluate the permeability of loose San Mateo sand as it might exist in the disturbed zones adjacent to the dewatering wells. The aim of these tests was to evaluate the density, void ratio, and permeability of simulated cavity-infill material. The tests were run on samples of native San Mateo sand and on San Mateo sand samples with some of the finer soil portions removed (by sieving) to simulate the effects of segregation.

A total of ten tests were conducted. Eight tests were run using the specially constructed constant head permeameter shown in Figure D-13; the other two tests used the falling head method and were run in a triaxial testing chamber. Because of the high permeability of the San Mateo sand, large flow volumes are required to obtain accurate measurements of head loss through the sample. But large flow rates also increase the inlet/outlet head loss, thus introducing an error in the measurement of the head loss across the sample. This error is considered to be significant in the triaxial chamber; however, the large constant head permeameter was designed to minimize these losses and values determined using this apparatus are considered more reliable than those determined in the triaxial chamber.

The results of the permeability tests are presented in Table D-1. The results of these tests are plotted graphically on Figure D-14 as permeability versus the percentage of material (fines) lost due to the process of sieving the soil to simulate segregation. It seems reasonable that as much as 10 to 20% of the finer cavity-infill material may have been removed by pumping considering that this allows for some bulking to occur (due to the density changing from 120 pcf to less than 100 pcf), and it represents the very fine sand and silt fraction (i.e., minus No. 100 sieve soil) which is the most susceptible to removal. This is further evidenced in comparing Figures D-10 and D-11 showing a trend of less fines for the cavity-infill material (Figure D-11) than for the native San Mateo sand (Figure D-10). Based on this argument, the interpreted permeability of the cavity-infill sand is 0.1 cm/sec.

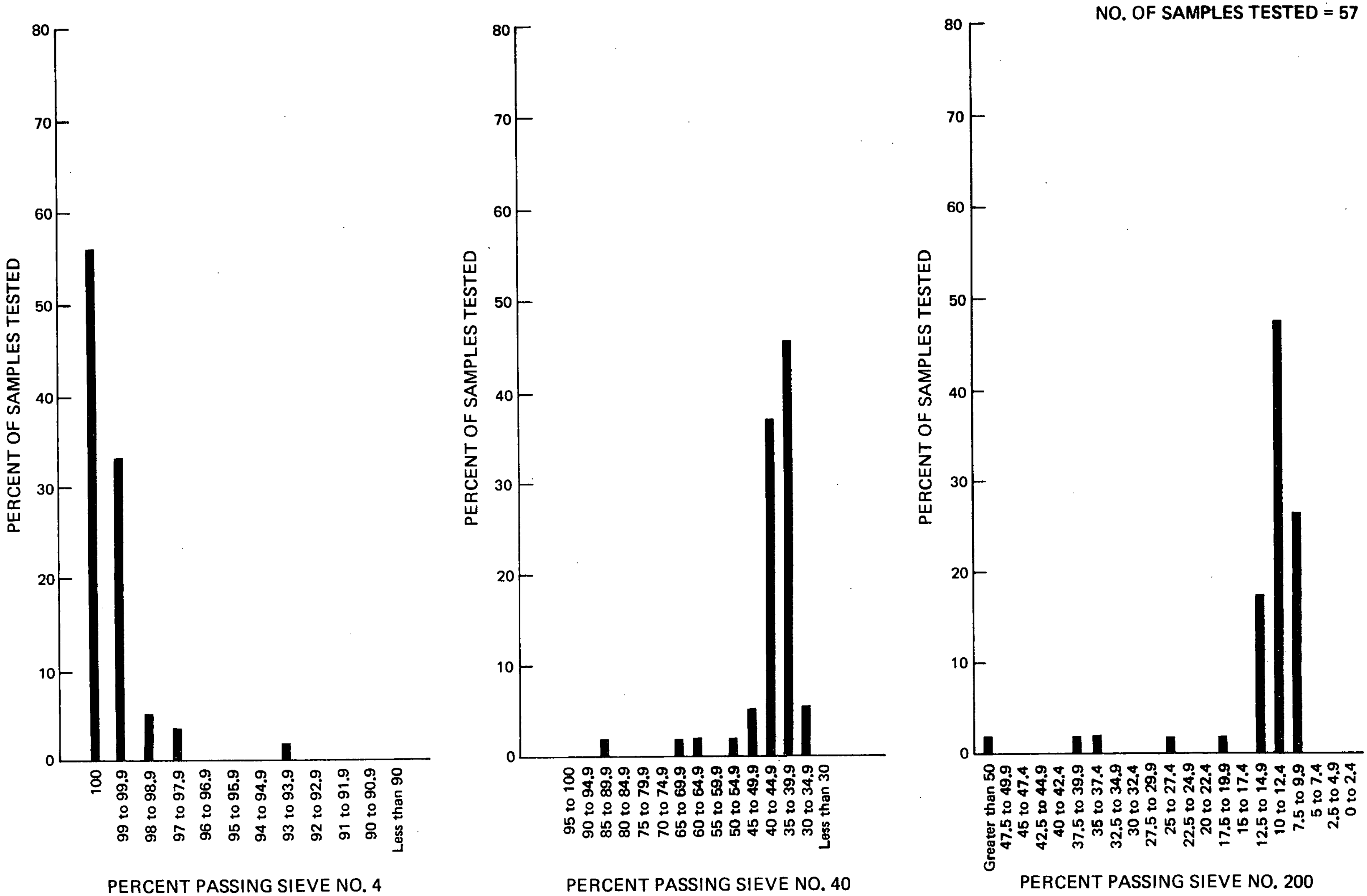
TABLE D-1

PERMEABILITY OF LOOSE SAN MATEO SAND
SUMMARY OF TEST RESULTS

Test No.	Dry Density (pcf)	Void Ratio	Permeability (cm/sec)	Remarks
1	86.9	0.91	0.011	Sample poured into test chamber through water; some layering.
2	91.7	0.81	0.0096	Sample poured dry then saturated by slow upward flow of water.
3	86.8	0.91	0.020	Sample poured through water around a 1-1/4-in. diameter rod; rod removed and sample allowed to settle; small amounts of fines vacuumed from top of sample.
3A	89.2	0.86	0.030	Test repeated on sample No. 3 after removing approximately 1/4-in. of fine material from the top of the sample. There was a considerable amount of air accumulated in the sample.
4*	100.3	0.65	0.076	Plus No. 200 sieve portion of sample only; sample poured through water; densified by rodding.
5*	91.3	0.82	0.028	Plus No. 200 sieve portion of sample only; sample poured through water.
6	91.9	0.81	0.259	Plus No. 20 sieve portion of sample only; sample poured through water.
7	92.1	0.80	0.164	Plus No. 60 sieve portion of sample only; sample poured into test chamber through water.

Test No.	Dry Density (pcf)	Void Ratio	Permeability (cm/sec)	Remarks
8	94.1	0.76	0.096	Plus No. 100 sieve portion of sample only; sample poured through water.
9	95.3	0.74	0.062	Plus No. 200 sieve portion of sample only; sample poured through water.

* Tests 4 and 5 were performed in a triaxial test chamber.



Project: **SONGS 2 & 3** Project No. **411301**	**DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 3**	Fig. D-1

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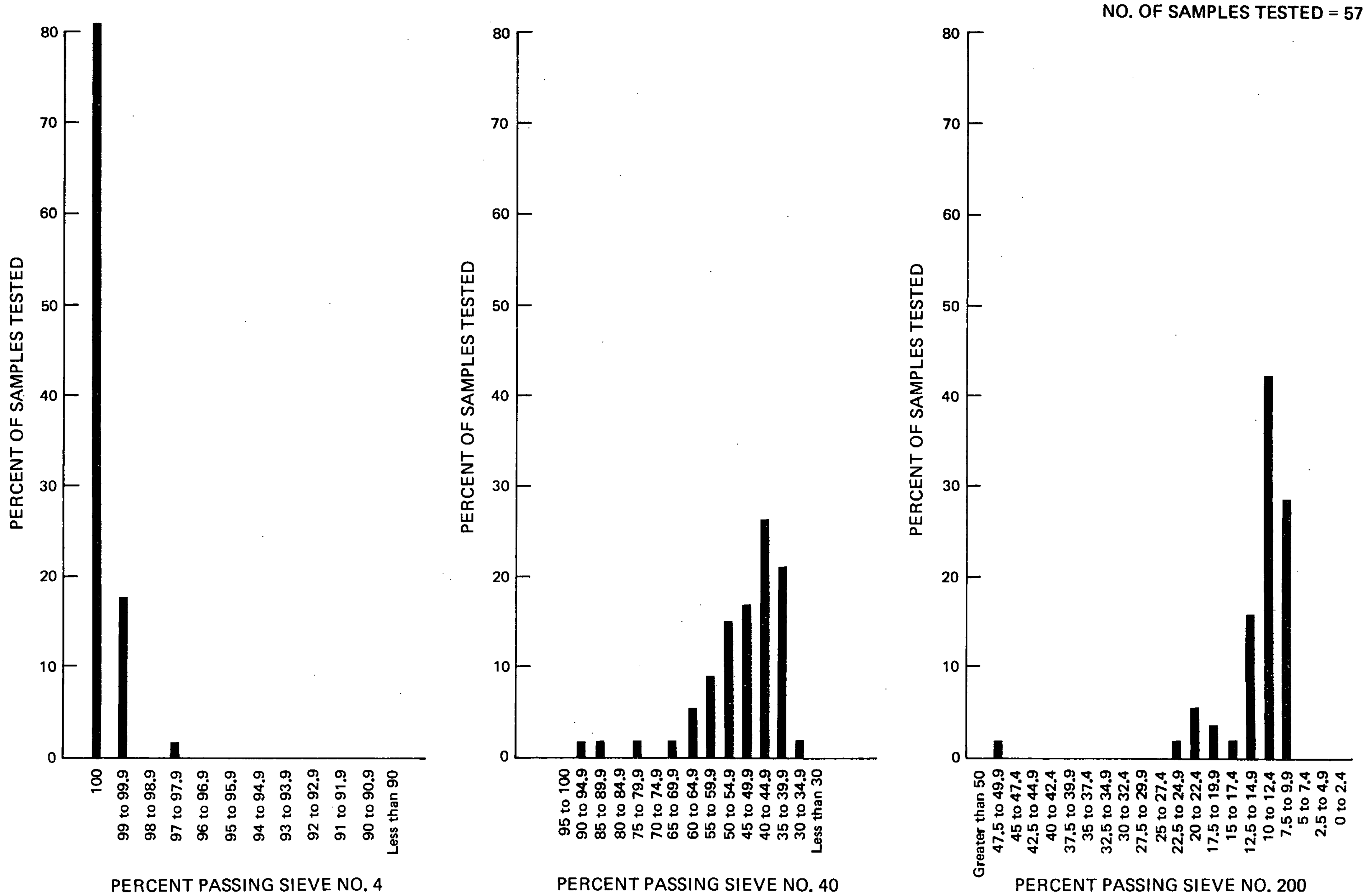
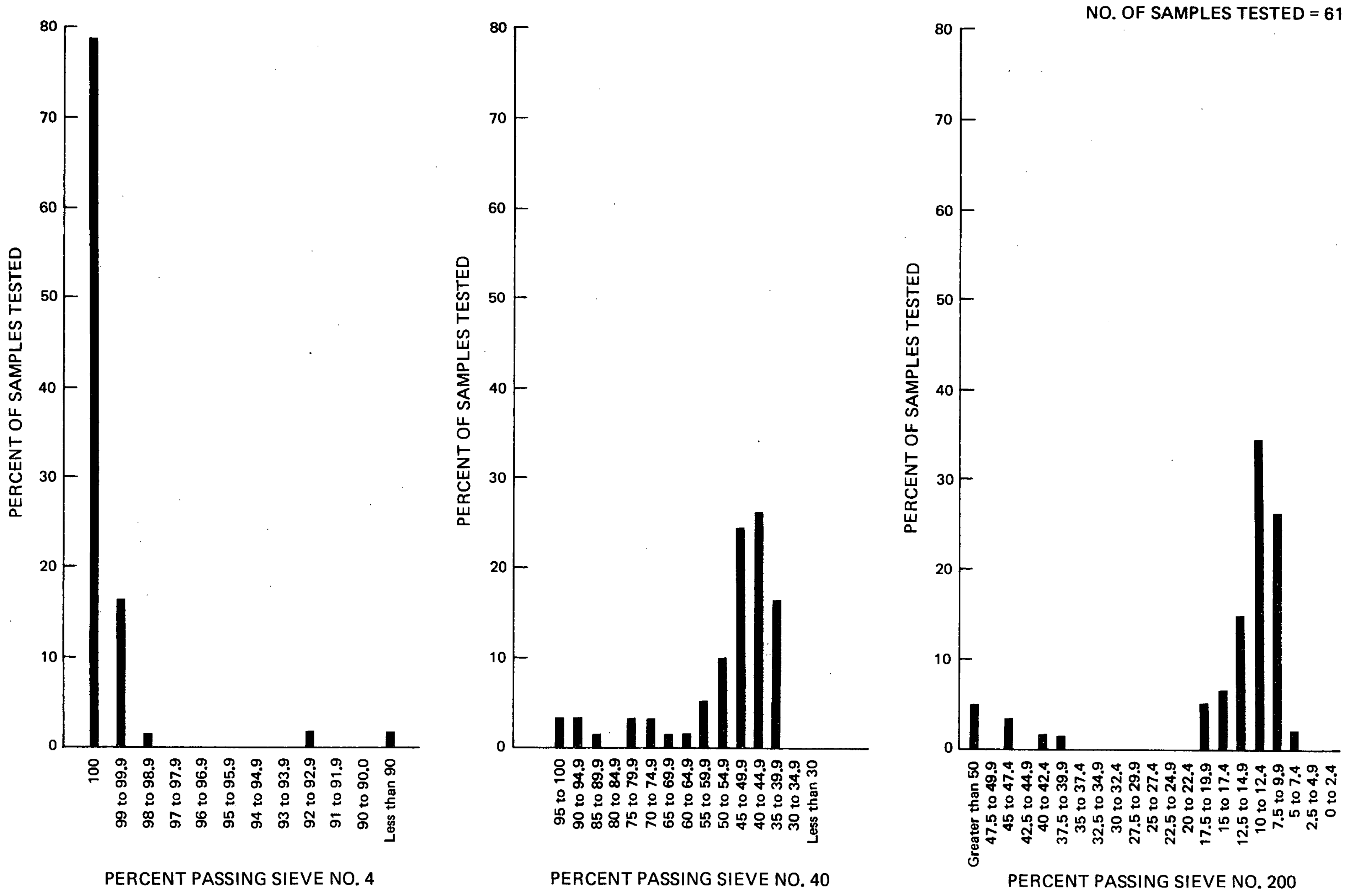


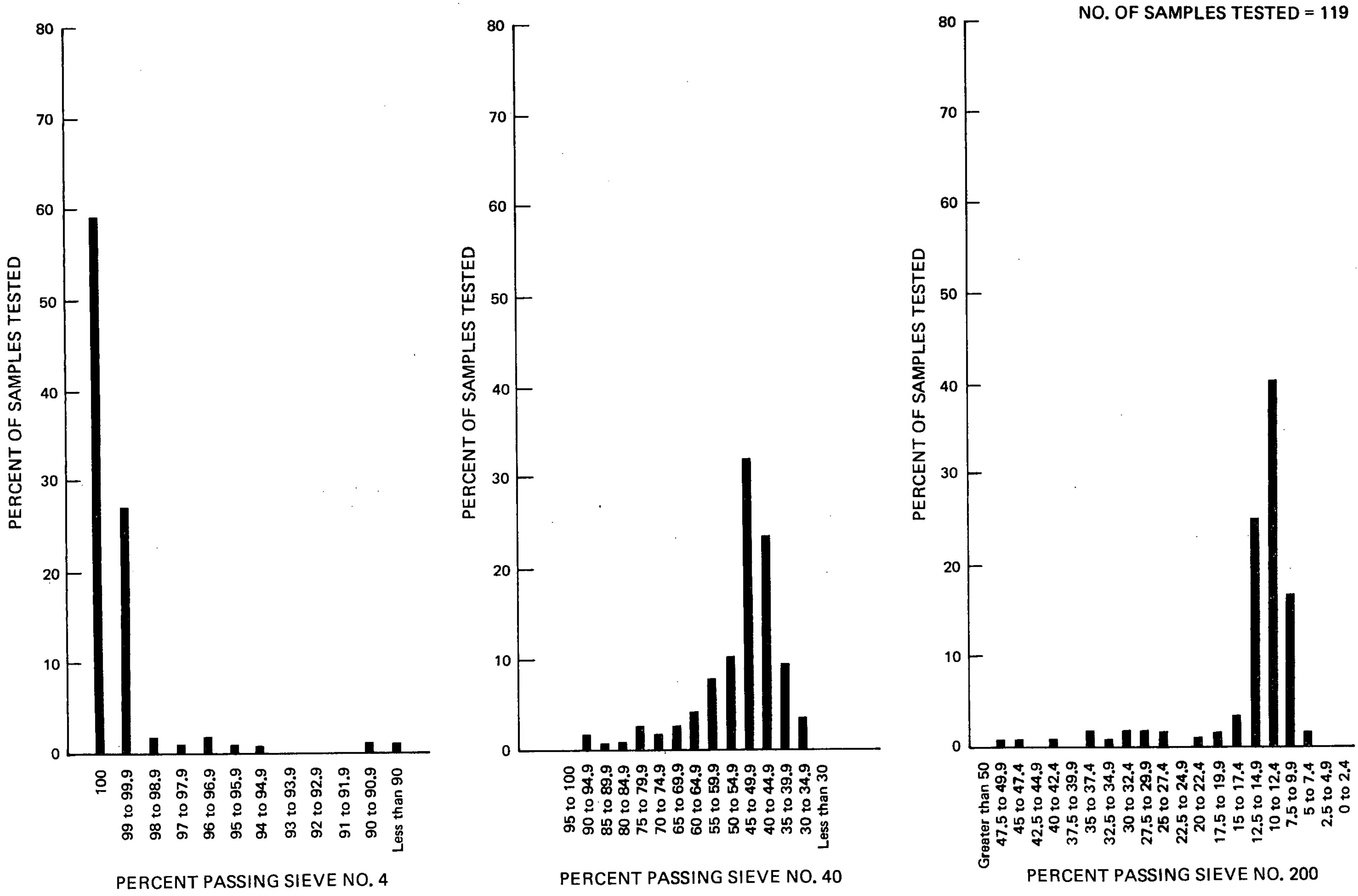
Project: **SONGS 2 & 3** Project No. **41130I**	**DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 4**	Fig. D-2

WOODWARD-CLYDE CONSULTANTS



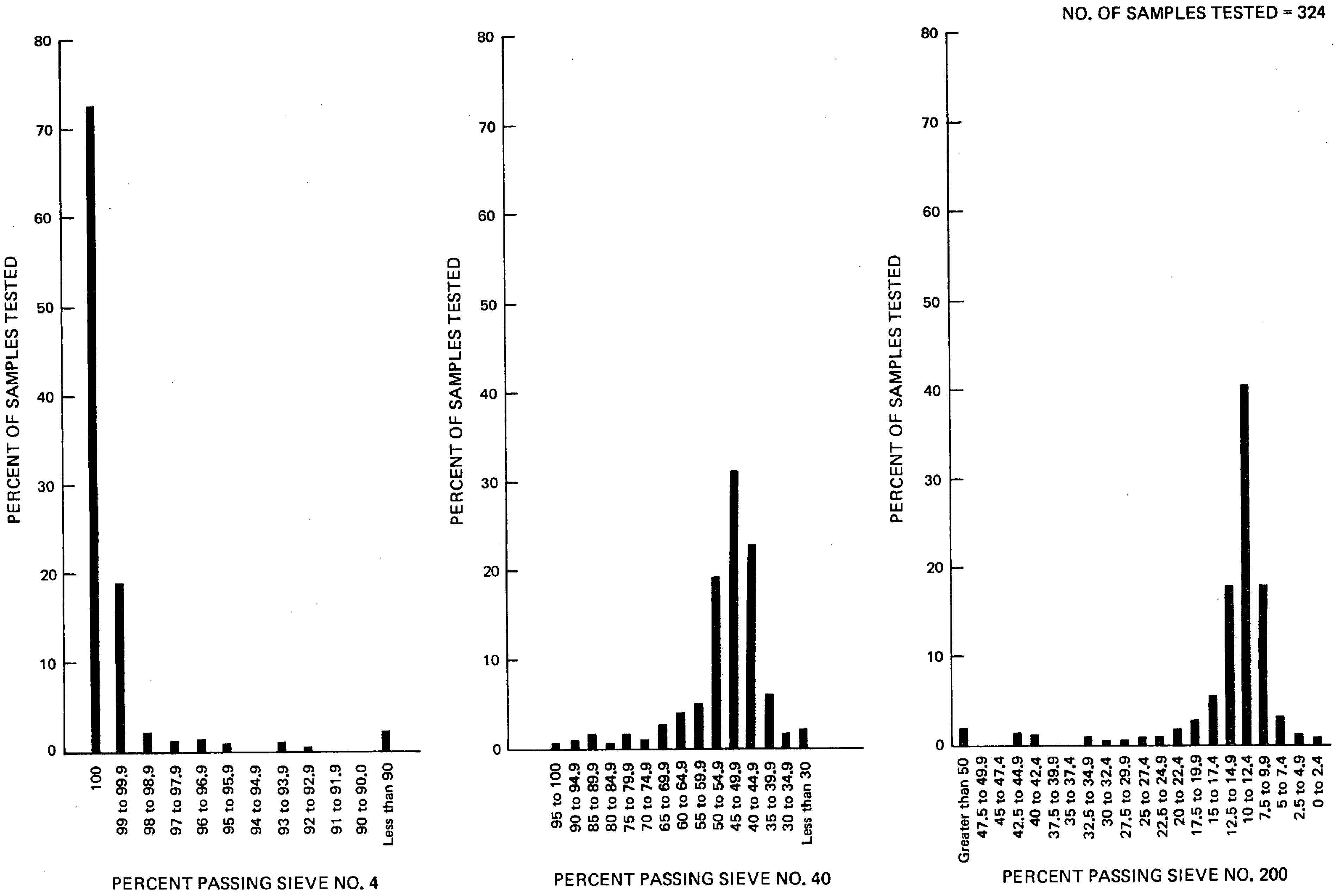
Project: **SONGS 2 & 3** Project No. **41130I**	**DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 5**	Fig. **D-3**

WOODWARD-CLYDE CONSULTANTS



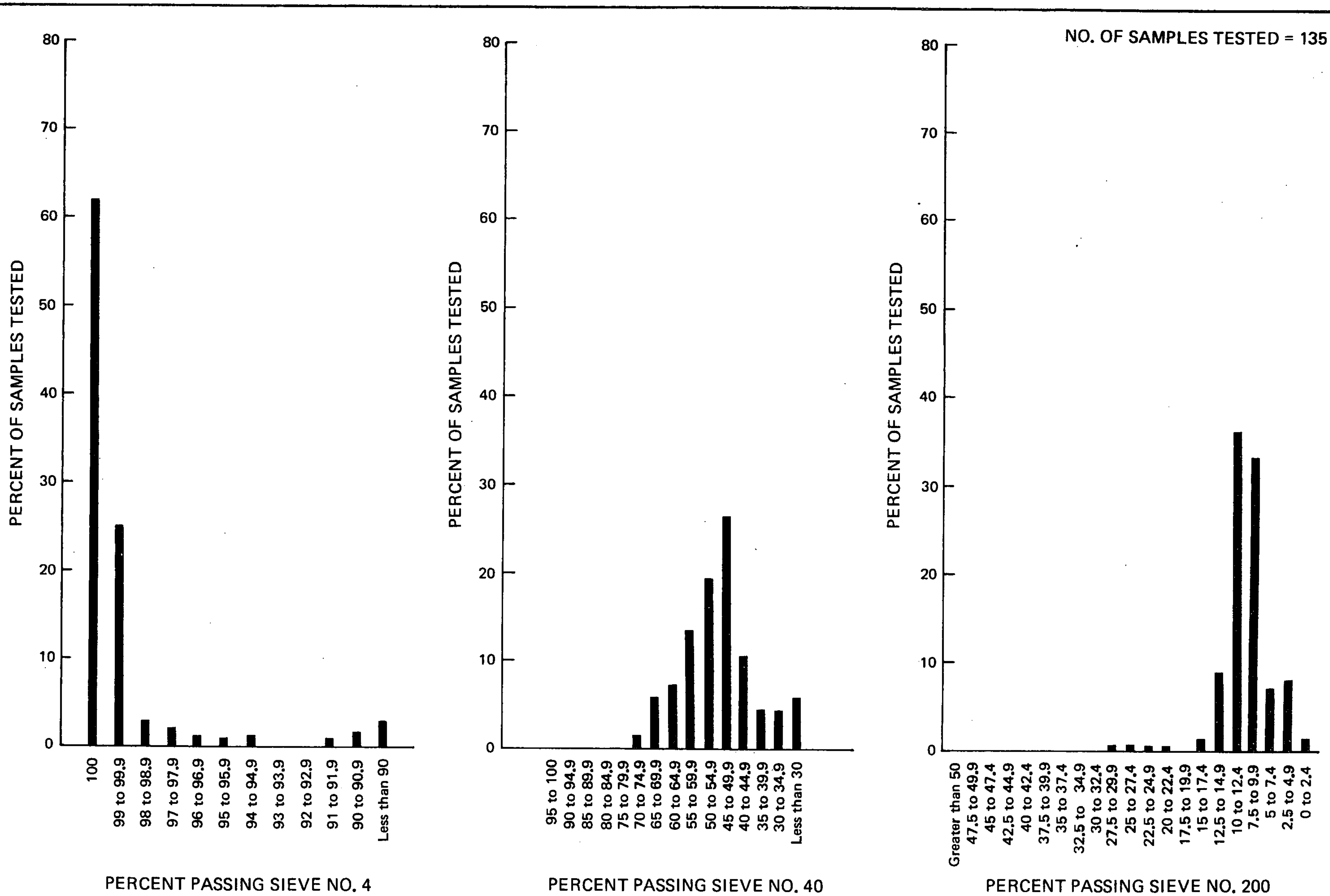
Project: SONGS 2 & 3 Project No. 411301	DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 6	Fig. D-4

WOODWARD-CLYDE CONSULTANTS

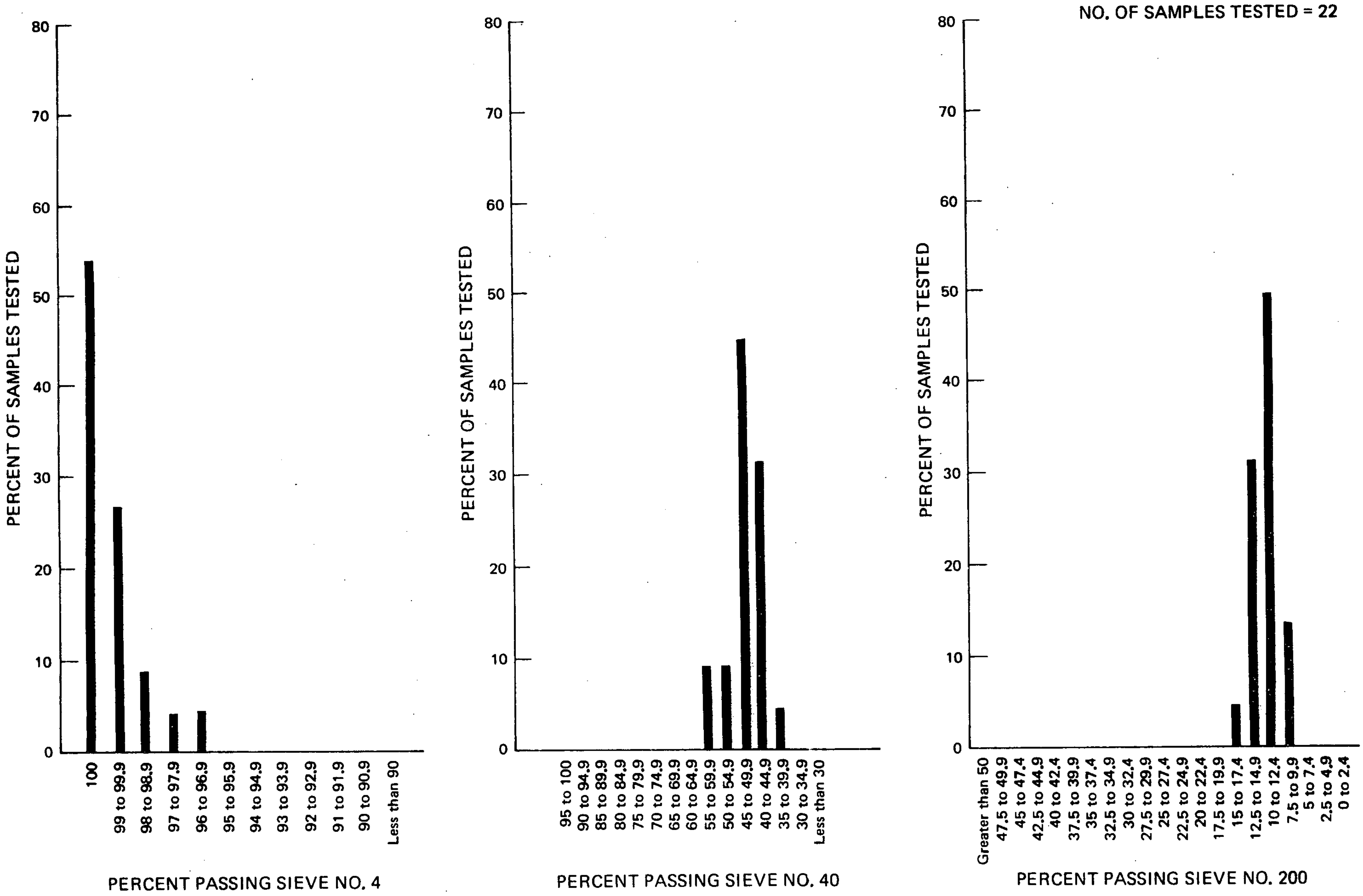


Project: SONGS 2 & 3 Project No. 41130I	DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 7	Fig. D-5

WOODWARD-CLYDE CONSULTANTS

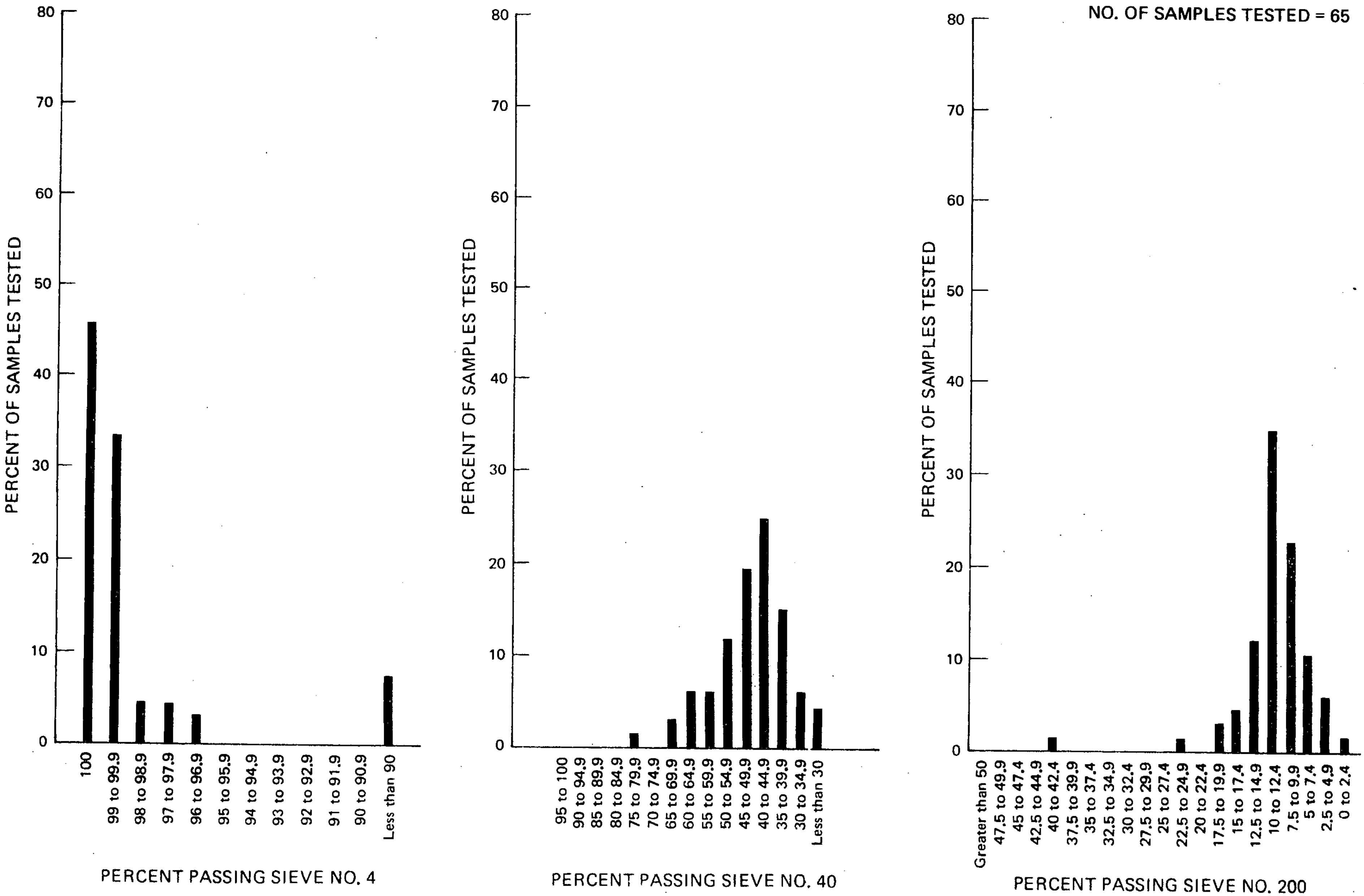


Project: **SONGS 2 & 3** Project No. **41130I**	**DISTRIBUTION OF GRADATION FOR MATERIAL AT WELL NO. 8**	Fig. **D-6**



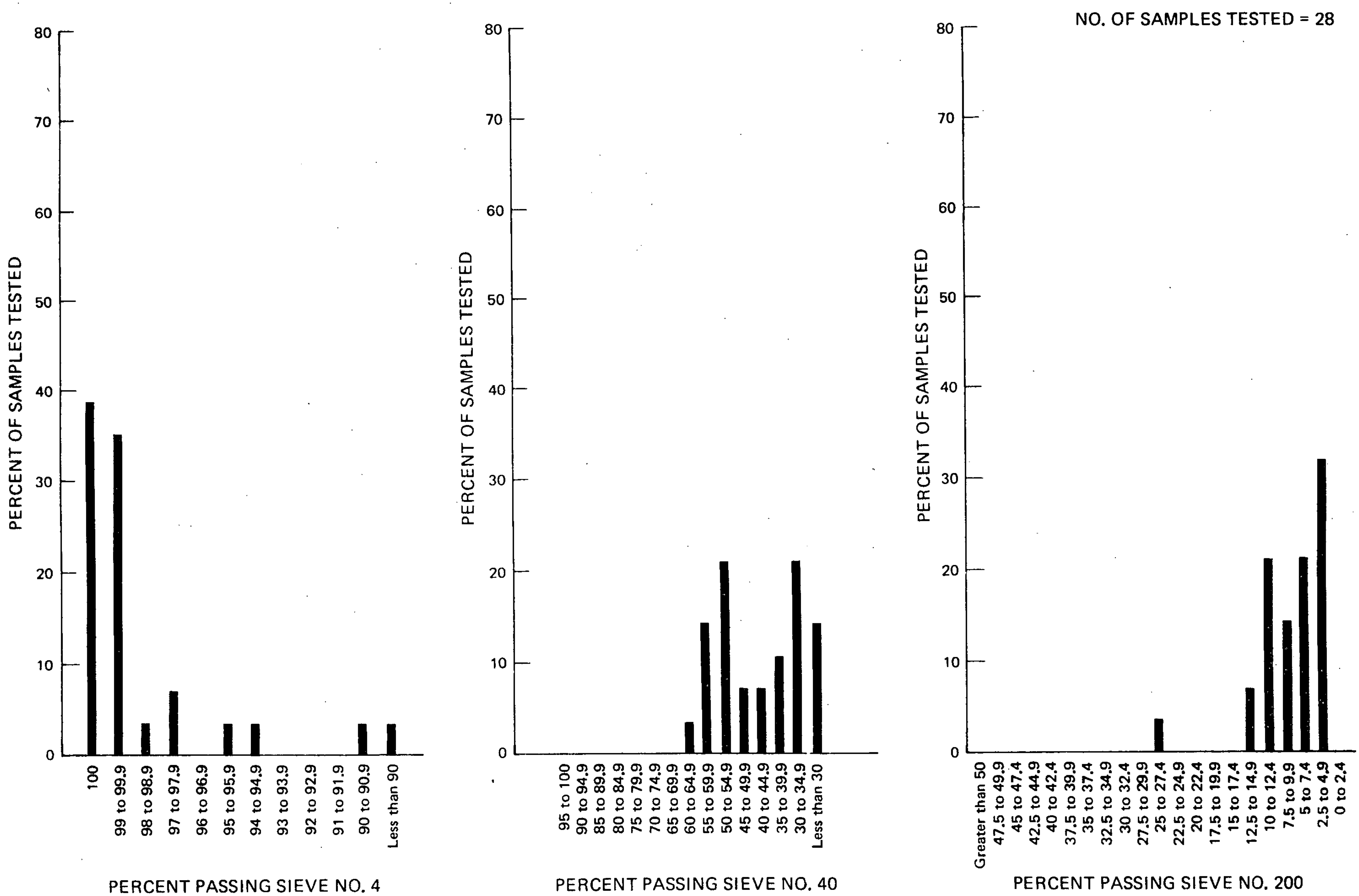
Project: **SONGS 2 & 3** Project No. **411301**	**DISTRIBUTION OF GRADATION FOR CAVITY INFILL MATERIAL AT WELL NO. 6**	Fig. D-7

WOODWARD-CLYDE CONSULTANTS

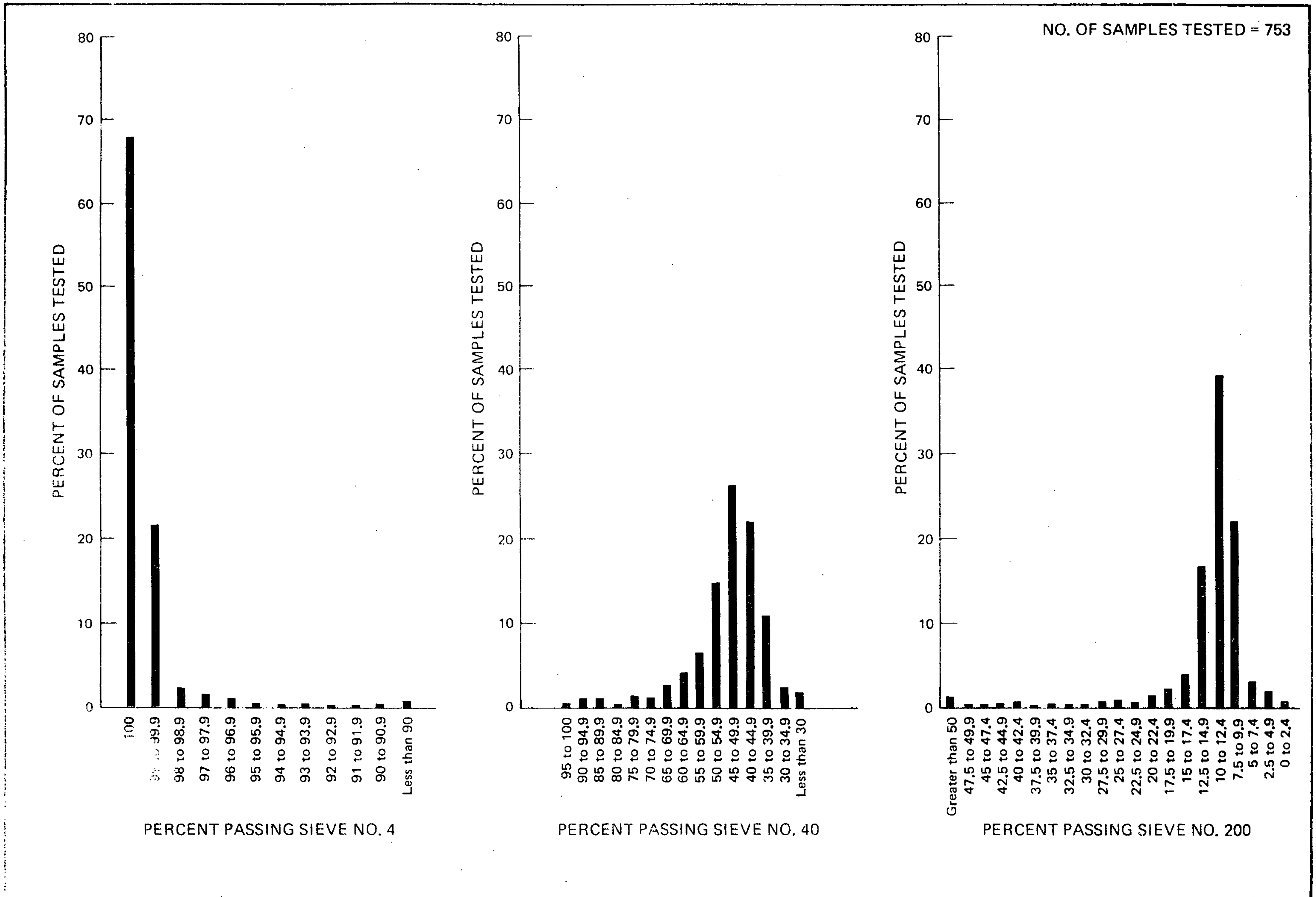


Project: **SONGS 2 & 3** Project No. **411301**	**DISTRIBUTION OF GRADATION FOR CAVITY INFILL MATERIAL AT WELL NO. 7**	Fig. D-8

WOODWARD - CLYDE CONSULTANTS



Project: **SONGS 2 & 3** Project No. **411301**	**DISTRIBUTION OF GRADATION FOR CAVITY INFILL MATERIAL AT WELL NO. 8**	Fig. D-9



Project: **SONGS 2 & 3**
Project No **411301**

DISTRIBUTION OF GRADATION FOR ALL MATERIAL

Fig. D-10

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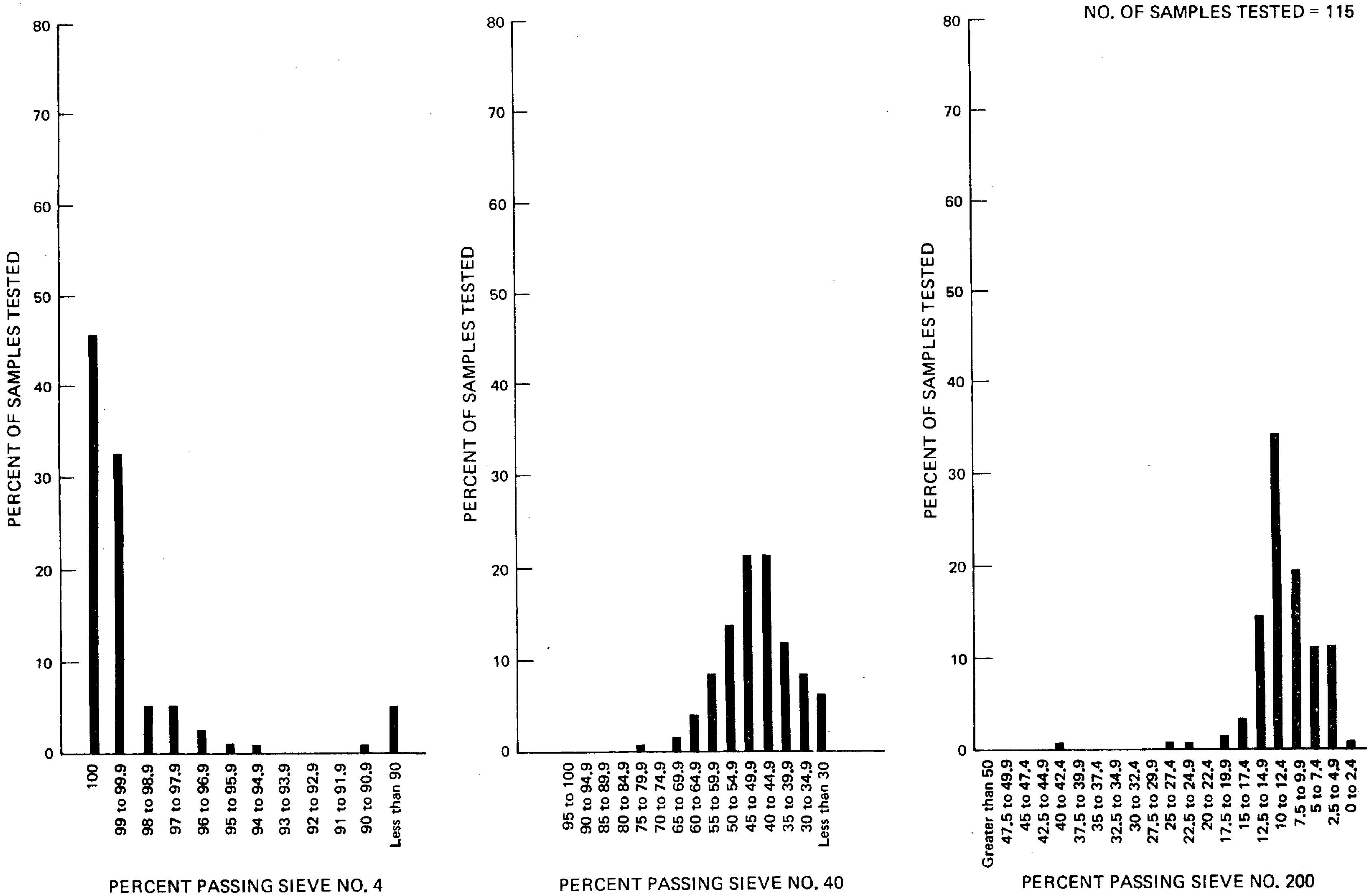
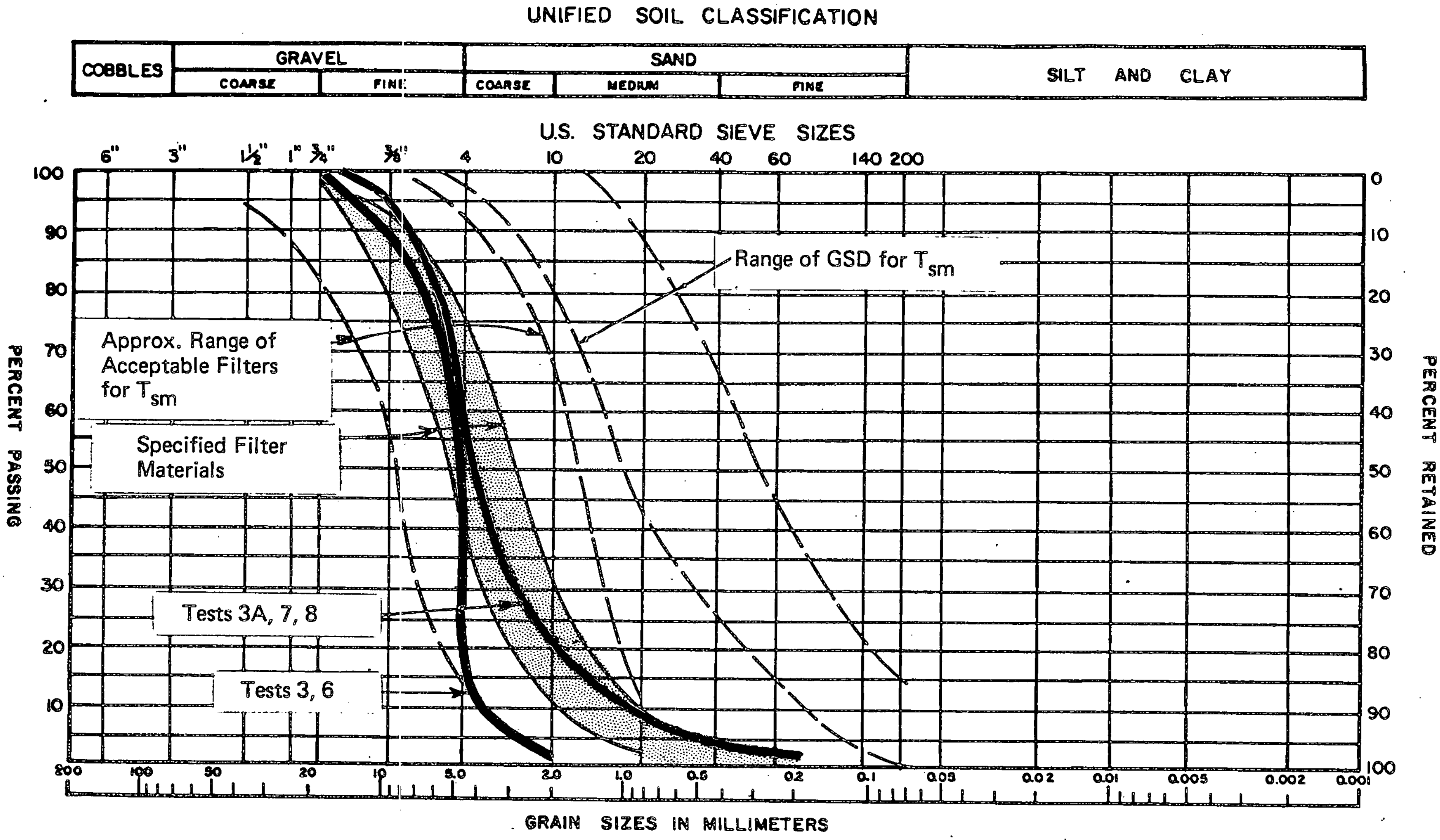


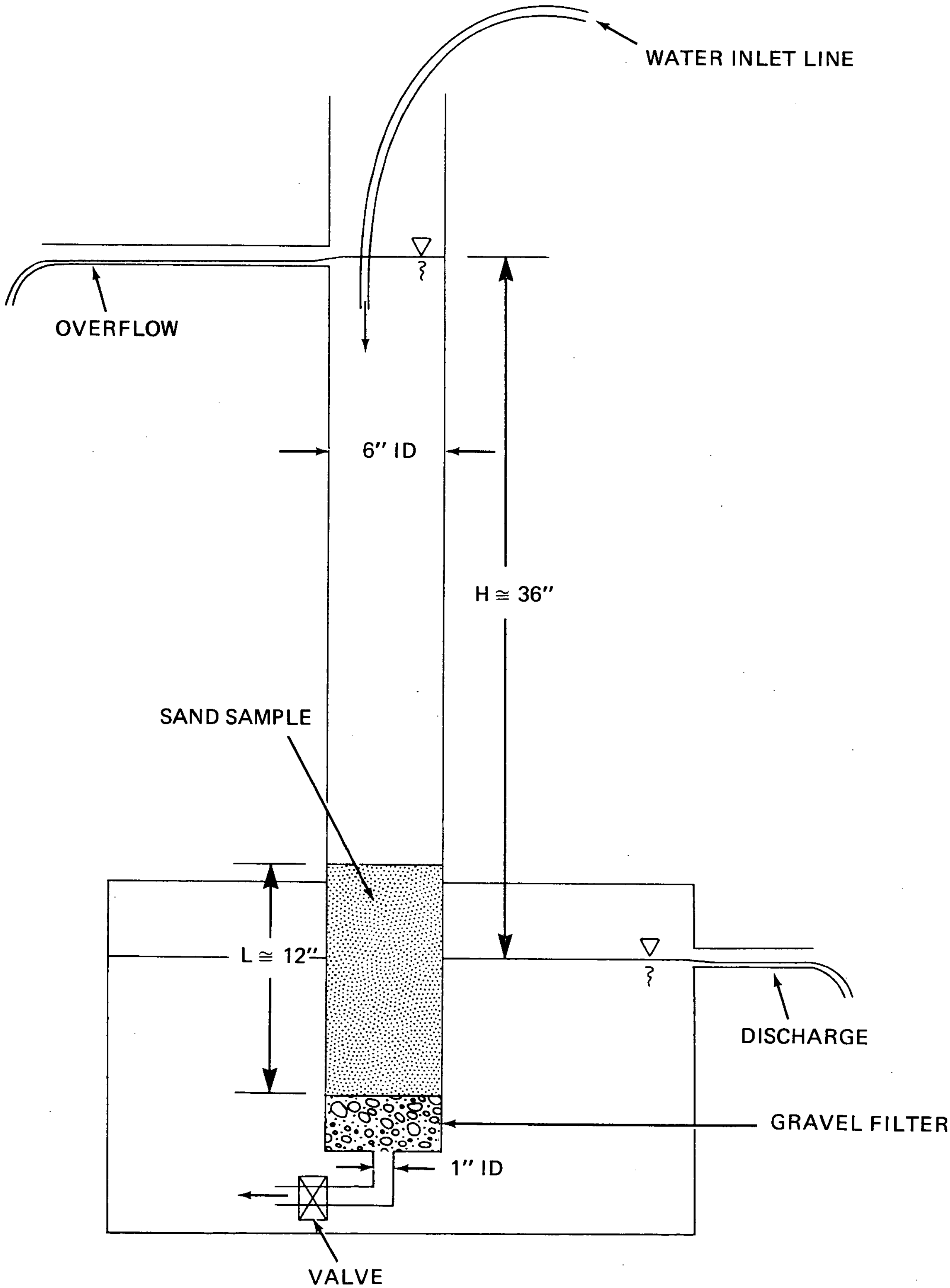
Project: **SONGS 2 & 3** Project No. **411301**	**DISTRIBUTION OF GRADATION FOR ALL CAVITY INFILL MATERIAL**	Fig. D-11



NOTE: Tests 3, 3A, 6, 7, and 8 were run on samples of the gravel filter material taken during dewatering well construction.

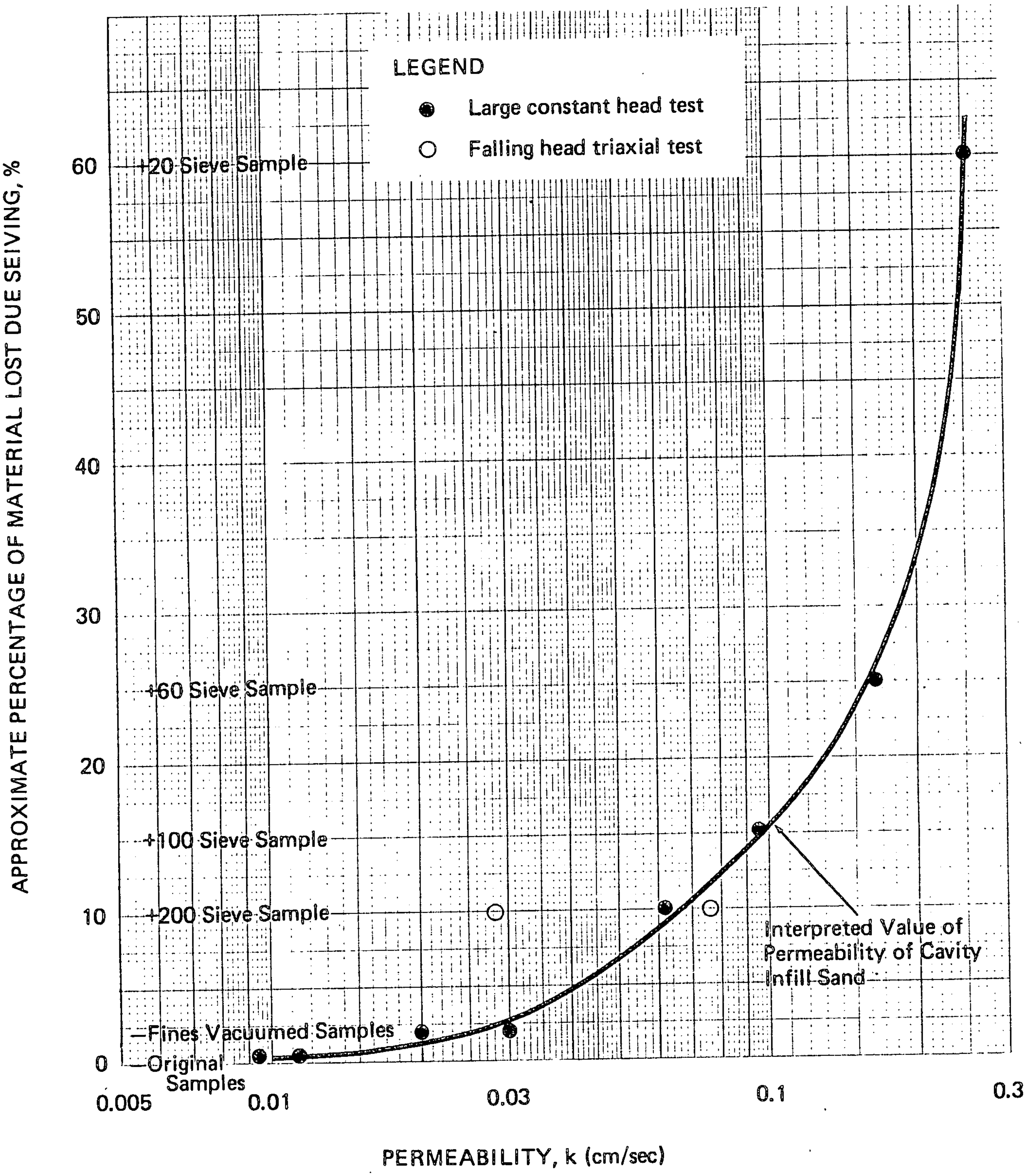
Project:	SONGS 2 & 3	GRADATIONS OF SAN MATEO (T_{sm}) AND FILTER MATERIALS	Fig. D-12
Project No.	411301		

WOODWARD-CLYDE CONSULTANTS



Project:	SONGS 2 & 3	CONSTANT HEAD APPARATUS FOR SOIL PERMEABILITY ESTIMATION	Fig. D-13
Project No.	411301		

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	SUMMARY OF PERMEABILITY TEST RESULTS FOR SIMULATED CAVITY INFILL SAND	Fig. D-14
Project No.	411301		

WOODWARD – CLYDE CONSULTANTS

APPENDIX E

Crosshole Seismic Surveys

APPENDIX E
CROSSHOLE SEISMIC SURVEYS

E-1 INTRODUCTION

Cavities have been detected and defined at dewatering Wells 3, 5, 6, 7, and 8 (Figure E-1) by exploration drilling. These cavities were formed by internal piping during the use of the dewatering wells. The cavities, when they exist, are adjacent to the dewatering wells and are filled with loose sand.

The crosshole seismic surveys were undertaken as a part of the exploration/demobilization program for Wells 4 and 5, as described in the Woodward-Clyde Consultants' Report on the Exploration/Demobilization of Wells 4 and 5, San Onofre Nuclear Generating Station, dated July 1979. A technique was desired which could improve the capabilities of the exploratory drilling program for cavity detection and location. The previously established use of similar methods and theoretical considerations led to the use of the crosshole seismic method as a candidate method with the understanding that while it might produce spurious cavity indications it must never fail to detect a significant cavity. Tests at the known cavity at Well 3 indicated that the method was applicable for the conditions existing at San Onofre.

The purpose of the crosshole seismic surveys was to provide closure information on the possible presence of cavities. Because qualitative information is obtained on the extent of a cavity between exploration borings, the crosshole measurements provide data for the planning of additional exploration borings should any of the borings or the crosshole measurements indicate the possible presence of a cavity.

E-2 SEISMIC PRINCIPLES AS APPLIED TO THE DETECTION OF CAVITIES

Although seismic methods have been used for cavity detection, their success has been mixed and dependent on the site conditions, instruments and method used. The establishment of the crosshole technique for cavity detection requires that seismic principles be taken into account using the specific site conditions and equipment type. Furthermore, the method must be calibrated and tested at a known cavity, as later described.

Conclusions can be made about the relative effects upon a waveform of the San Mateo sand and the loose cavity infill. These conclusions are applicable only when the same hammer source is used in materials with similar properties. Calculations show that the poroelastic properties of the cavity-infill sand are such that it should, for the source frequencies used, attenuate a P-wave rather efficiently and attenuate a S-wave relatively poorly. However, a cavity which is large compared to the crosshole distance should strongly attenuate both waves. The poroelastic properties of the undisturbed native sand are such that it should not, for the source frequencies used, greatly attenuate either the P-wave or the S-wave. These effects are illustrated in Figure E-2 for the case of a cavity situated between two bore holes acting as source and receiver holes. Theoretically, the presence of an infilled cavity results in an greater-than-normal attenuation of the seismic wave, particularly the P-wave, when material properties alone are considered. Additional attenuation results when the wave crosses the native sand/cavity boundaries.

The relative properties of the native sand and the cavity-infill sand are such that the waves will tend to travel fastest around, rather than through, the cavities. The resulting diffraction of the waves will cause wave attenuation as shown in Figure E-3. This figure also shows that diffraction attenuation will be enhanced by the effects of stress relief near the edge of the cavity. Diffraction attenuation is expected to be relatively more severe for the P-wave than the S-wave because the wavelengths of the P-wave are the shorter of the two waves.

Thus, waves traveling through or around a cavity, particularly P-waves, will be attenuated compared to waves traveling only through native sand. Moreover, a large cavity should strongly affect both waves. Factors which could result in the same effects will be conservative, in that they will only indicate cavity where there is no cavity. These factors will be reviewed in the discussion on calibration at a known cavity (Section E-4).

E-3 CROSSHOLE SEISMIC MEASUREMENTS

The crosshole seismic method is a standard geophysical technique which has, in this case, been modified to provide closure information between exploration borings to detect sand-filled cavities. The modification consists of additional data-processing and interpretive techniques.

The principle of operation is illustrated in Figure E-4. A source of seismic energy (the hammer) is placed in one bore hole, and several detectors (geophones) are lowered to the same elevation in adjacent bore holes. The hammer can produce upward and downward blows which generate seismic energy composed of dilational waves (P-waves) and vertically polarized shear waves (S-waves). A recorder at the ground surface records the seismic signal received by the geophones. A typical waveform record contains traces such as those shown on Figure E-5. The P-wave arrives first and has a relatively high frequency (1 KHz), while the slower-traveling S-wave arrives later and has a lower frequency (100-200 Hz). The records represent multiple hammer blows which are added together to improve the signal to noise ratio. Hammer blows in the upward and downward directions result in opposite polarities in the S-wave motion, which can be used to distinguish between the S-wave record and background noise.

Field procedures consist of obtaining measurements across the bore holes such that the well is surrounded by transects for most of its depth. Several set-ups of the hammer and three geophones in alternating bore holes provide redundancy through reversed and multiple travel paths. An important aspect of the measurement process is the standardization of the individual measurements. For example, amplifier gains are held constant for each set of data. This feature allows one to make comparative analyses of the waveform characteristics as a function of depth for a given transect.

The data are analyzed by comparing the waveform characteristics at each depth with the characteristics at other depths for each set of measurements and source-receiver configuration. The most direct means of analysis is a visual comparison of the waveform traces after they have been compiled. A quantitative means for comparison was developed for the conditions and equipment at this site using normalized P-wave and S-wave amplitudes derived by expressing the amplitude of a wave as a fraction of the largest wave amplitude for that set of measurements and source-receiver configuration. A small fraction, such as 0.1 or 0.2, indicates that the seismic energy has undergone a relatively large amount of attenuation. These values are plotted for both the P-wave and S-wave and the product of their values. Additional items of interest, which are also plotted, are the crosshole distance and the closest approach of the well to the transect. All data are summarized in the Woodward-Clyde Consultants' July 1979 report.

The analyses were found to produce suitable criteria for cavity detection for these cavities under the existing site conditions. Velocity and spectral analyses were also made but were found to be less useful than the approach discussed above.

E-4 CALIBRATION OF DETECTION CRITERIA AT A KNOWN CAVITY AT WELL 3

The calibration of the cavity-detection technique requires that a known cavity be analyzed under the same conditions as the cavities to be found. A cavity was detected at Well 3, as shown in Figure E-6. The cavity at Well 3 was identified and measured using 31 exploration borings and limited sonar-caliper measurements (see Appendix C). The bore holes, cavity and the crosshole transects used in the calibration are shown on Figure E-7. The transects are color coded to show what the results of the crosshole survey should be. The borings used for the survey are C, E, Q, T, U and V. Well 3 was found to exhibit seismic characteristics identical to those of the other wells tested, with the exception of the cavity region.

There are certain practical aspects which must be assessed for their possible effects on the seismic signatures being used to define the possible existence of cavities. These items are:

- variations in native soil
- water-filled cavity
- air entrainment
- casing coupling
- timing errors
- equipment calibration
- distance effects
- site seismic ground noise

A detailed discussion of these effects and their consideration during the calibration process is presented in Appendix B of the aforementioned Wells 4 and 5 exploration/demobilization report. It was found that some of these effects could be accepted as leading to conservative indication of cavity where no cavity was present. In other cases, the field procedures were set to minimize the effects on the measurements.

A direct examination of the records can be used to interpret the results of the crosshole surveys. A cavity will cause phase changes, waveform distortion and amplitude reduction. A quantitative measure is, however, desirable in that it minimizes interpretive bias. The amplitude reduction is the most prominent effect noted and can generally be measured to about 10% accuracy. The normalized trace amplitude method is used to produce plots of the amplitude versus depth for each data set. Sample waveform sets will be discussed and their normalized amplitude plots will then be used to develop the calibrated values which are believed to be indicative of cavity.

Samples of non-cavity transects for Well 3 include U-T and U-E. Figure E-8 shows the waveform set in the U-T transect. The traces exhibit minor P-wave and S-wave variation. Particular attention is paid to the P-waves which at shallow depths (30-60 ft) show amplitude values similar to those at depth. Figure E-9 shows the waveform set in the U-E transect. Here again, the amplitudes are fairly consistent with moderate reduction at 35 to 40 ft, yet still quite evident P-wave. It should be noted that at these depths, the cavity is nearby and may be causing the amplitude reduction in what might be termed a graze situation. The V-Q transect waveforms in Figure E-10 also show such a P-wave amplitude reduction in an otherwise unaffected group of waveforms at depths near 95 ft. This feature is noted on some of the other transects and may in fact be due to a small disturbed zone or cavity adjacent to the well at these depths. Again, the shallow waveforms show minor amplitude reduction. These, and the remaining transects, show that amplitude variations may normally drop to as much as 20 to 30% of the largest values in each set, yet still be considered native sand indications.

Samples of transects which cross the cavity include Q-E and Q-U. The Q-U transect shown in Figure E-11 again shows a P-wave amplitude reduction at the 95-ft region, but also shows a strong reduction of both P-wave and S-wave amplitudes at depths of 40 to 50 ft, where the cavity must be crossed. In Figure E-12 the Q-E transect shows virtual absence of any seismic energy above 55 ft. A similar situation occurs in the V-T transect shown in Figure E-13, where the P-wave is virtually absent above 60 ft, although noise having a similar appearance does occur. These and the remaining transects show that amplitudes less than 10 to 20% of the largest values in each set are associated with cavity or are spurious. A very small amplitude value approaching or equal to zero is strongly indicative of such a situation. A severe amplitude reduction on reversed transects is the best indicator since spurious reductions are less likely to occur on several repeats of the same transect. Also, the reduction of amplitude in both P-waves and S-waves is strong evidence for a cavity.

Consideration of the above factors suggests that a cavity indication should be based on the reduction of amplitudes to below 20% of the largest normal amplitudes and should be seen in both directions of travel for a given transect. This may apply to both the S-wave and P-wave, although the latter condition is more evident. This effect can be accentuated by multiplication of the normalized amplitude values so that a PxS value is derived. A fraction such as 0.1 or 0.2 can be used to indicate the amount of amplitude reduction. Using this method, empirically comparing the Well 3 crosshole data with the data developed on cavity configuration at Well 3 (Appendix C), the following criteria are developed:

1. LOG OF BORING

Observation	Interpretation
Loose sand encountered, or void encountered (based on SPT, samples, changes in drilling rate and/or feed pressure)	Cavity

2. PRODUCT OF NORMALIZED P AND S AMPLITUDES

Observation	Interpretation
PxS = 0 in both directions	Possible Cavity
PxS = 0 in one direction and $\leq$ 0.2 in the other direction	Possible Cavity
PxS < 0.1 in both directions	Possible Graze
PxS $\leq$ 0.1 in one direction and $\leq$ 0.2 in the other direction	Possible Graze
PxS = 0.2 in both directions	Native Soil
PxS > 0.2 in either direction	Native Soil

A graze is a disturbance which results in a strong amplitude reduction, but not necessarily strong enough to imply that a sizable cavity may exist between the borings. This is also considered to minimize the chance that an odd-shaped cavity or less amplitude picking accuracy might otherwise lead to missing a cavity indication. A significant cavity would, however, be associated with the total or almost total absence of P-wave energy in both directions of travel.

Using the above criteria, the data at Well 3 are summarized in Table E-1 and show excellent correlation with the known cavity as shown in Figure E-7. These criteria apply only to the specific conditions at the San Onofre site.

E-5 CROSSHOLE DATA AND INTERPRETATION AT WELLS 4, 5, AND 10

E-5.1 Introduction

This section provides an overview of the data for Wells 4 and 5 and results of crosshole surveys at Wells 4, 5, and 10. The full development of the results and the data for Wells 4 and 5 are provided in the exploration/demobilization report for Wells 4 and 5. A review of results at Well 10 is provided here for completeness since this well is not located near any critical structures. The data quality of the crosshole measurements at these wells is generally as good or better than at Well 3.

E-5.2 Well 4

Figure E-14 shows Well 4 and the eight bore holes used for exploration drilling and the crosshole survey. The coverage at Well 4 is adequate near the surface and excellent below 80 feet. Some of the coverage and interpretations are illustrated in Figure E-15 for the region around 40 ft and in Figure E-16 for the region around 180 feet. These depths were selected because they are the only depths that show any indication of cavity. The results of all transects are summarized in Table E-2.

The area around the well to a depth of 40 ft was inspected by direct observation during reopening operations, and was subsequently backfilled with sand and concrete. Therefore, the only crosshole data of interest is that below 40 ft.

As shown in Figure E-15, the 5-7, 7-5 transect has an indication of possible cavity at 40 ft. Interpretations of possible cavity detection are not present immediately below this depth and the disturbing conditions described above occur above this depth. Because of these factors, this cavity indication is interpreted as being due to these disturbances and is not considered indicative of cavity.

Figure E-16 shows the possible graze indications at depths of 175 to 180 ft for transects 2-5, 5-2 and 2-1, 1-2. These transects are away from the area of the well and a transect showing a native soil indication is present between them and the well. The possible graze therefore appears to be due to causes other than a cavity. The most likely explanation is the distance effect in conjunction with possibly poor coupling between the casing and the surrounding soil in Boring 2 at this depth. These transects show pronounced attenuation proportional to the crosshole distance which at these depths is more than twice that near the surface where the largest wave amplitudes occur.

Based on the above observations and the fact that many of the best quality waveforms occur near the surface, the crosshole indication is that no significant cavities are present between the borings at Well 4. This conclusion is further confirmed by the fact that shear wave velocities and wave forms in all Well 4 transects were essentially unaffected.

E-5.3 Well 5

Figure E-17 shows Well 5 and the four bore holes used for the exploration drilling and the crosshole survey. All borings showed native undisturbed sands. The coverage at Well 5 is good to excellent. Crosshole interpretation is not necessary above a depth of 60 ft since this area was extensively drilled and pressure grouted. The coverage and interpretations at 100 ft are shown in Figure E-18. Native soil conditions are indicated in these and all other transects, as summarized in Table E-3. This conclusion is further confirmed by the fact that the shear wave velocities and wave forms in all Well 5 transects were essentially unaffected.

E-5.4 Well 10

Figure E-19 shows Well 10 and seven exploratory borings. The first four borings were used in the crosshole survey. The coverage is good, although restricted to only one reversed measurement across each transect. Subsequent borings were drilled after the crosshole survey indicated possible cavity conditions. All borings showed native undisturbed sands. Also, the well is a large distance from any Seismic Category I structures. Because of this and the nature of these crosshole survey results, no further work was done.

Table E-4 is a summary of the crosshole results at Well 10. Figure E-20 shows the coverage and interpretation at 50 feet. At this depth, the 4-1, 1-4 transects and 2-3, 3-2 transects show possible cavity while the remainder show possible graze. The other extensive graze indication is at 150 to 165 feet between 1-2, 2-1 and 4-1, 1-4 as shown in Figure E-21. These interpretations showed that the possible cavity at 45 to 50 feet, if it existed, would trend west of the well or in a north-south direction. Boring 5 eliminates the former possibility while Borings 6 and 7 make the latter possibility unlikely for a sizeable cavity. The concept of a significant cavity as used in this report does not arise here because no Seismic Category I structures are involved. The possible graze at 150 to 165 ft is also not significant in this respect and, in fact, would indicate that only a rather small cavity, if any, could be involved. Such a cavity could only exist on the immediate west side of the well since the remaining transects show native sand conditions. The two transects which indicate a graze are, in fact, so close to the well that they may actually be interacting with the well itself, thereby giving a conservative indication.

The results of the crosshole seismic survey at Well 10 have indicated that small cavities may be present but are not significant.

TABLE E-1

SUMMARY OF PxS TRACE AMPLITUDE INTERPRETATION FOR WELL 3

	Depth Interval Fitting Criteria				Depth Interval Fitting Criteria			
Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Reverse Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Interpretation
V-T	30-55'	--	60-65'	T-V	--	50	--	Possible cavity at 30-50'.
V-Q	--	--	95-130'	Q-V	--	90-95'	80-85' 100-105'	Possible graze near 95'.
V-U	--	--	--	U-V U-V	-- --	-- --	-- --	Native soil at all depths.
U-T	--	--	130-140' 170'	T-U	--	--	--	Native soil at all depths.
U-Q	30-45'	50-55' 90'	80' 95-100'	Q-U	--	45	40', 50'	Possible cavity at 30-55'.
	45-50' 30-50'	-- --	-- --	Q-U	32-59'	--	--	
Q-C	-- --	-- --	-- --	None				Native soil to depth of Hole C.*
Q-T	--	50-59'	40-45'	T-Q	--	--	--	Native soil at all depths.
U-E	--	--	--	None				Native soil to depth of Hole E.*
U-C	30-55'	--	--	None				Possible cavity at 30-55'.*
Q-E	32-59' 30-59'	-- --	-- --	None				Possible cavity at 30-60'.*

* No reverse leg for strict application of criteria.

TABLE E-2

SUMMARY OF PxS TRACE AMPLITUDE INTERPRETATION FOR WELL 4

Transect	Depth Interval Fitting Criteria: PxS=0	0<PxS<0.1	0.1<PxS<0.2	Reverse Transect	Depth Interval Fitting Criteria: PxS=0	0<PxS<0.1	0.1<PxS<0.2	Interpretation
5-2	--	105-115' 175'	95-100' 125', 185'	2-5 2-5	-- --	180' --	45', 130' 150' --	Possible graze at 175 to 180'.
5-1	--	--	--	None				Native at all depths.*
6-4	--	--	--	None				Native at all depths.*
6-3	--	--	--	None				Native at all depths.*
6-5	--	--	55', 90-100' 115', 175'	5-6	--	--	45' 105-115'	Native at all depths.
5-8	--	--	--	8-5	--	--	--	Native to depth of Hole 8.
5-7	41'	--	--	7-5	41'	--	--	Possible cavity at 41'; see Section E-5.
8-7	--	--	--	7-8	41-46'	--	--	Native to depth of Hole 8.
2-4	-- --	-- --	135-190' --	None				Native at all depths.*
2-3	--	--	--	3-2	--	--	--	Native at all depths.
2-1	-- -- --	175-190' -- --	80-100' 155' 180-195' --	1-2	--	--	95-115', 125' 135-160', 170' 175'	Possible graze at 175'.

Table E-2
Page 2

	Depth Interval Fitting Criteria				Depth Interval Fitting Criteria			
Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Reverse Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Interpretation
3-4	--	--	--	None				Native at all depths.*
3-1	--	95', 105'	80', 90' 100'	1-3	--	--	--	Native at all depths.
1-4	--	--	--	None				Native at all depths.*
2-6	--	--	40'	None				Native at all depths.*

* No reverse leg for strict application of criteria

TABLE E-3

SUMMARY OF PxS TRACE AMPLITUDE INTERPRETATION FOR WELL 5

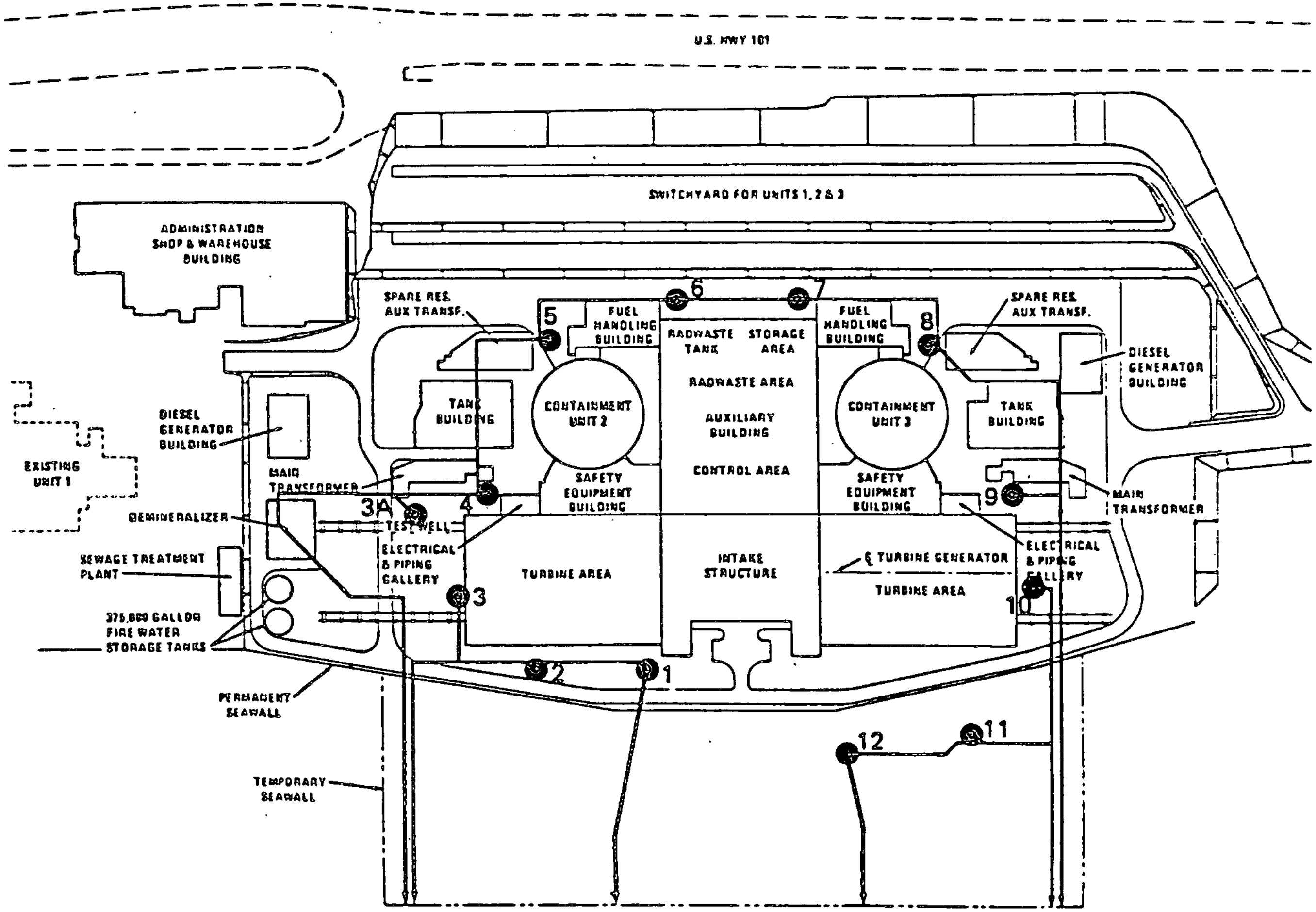
	Depth Interval Fitting Criteria				Depth Interval Fitting Criteria			
Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Reverse Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Interpretation
2-1	--	--	60', 85' 175'	1-2	--	--	--	Native at all depths.
2-3	--	--	60', 70-80' 135', 140'	3-2	--	--	--	Native to depth of Hole 3.
2-4	--	--	120'	4-2	--	--	160', 170'	Native at all depths.
3-1	--	--	130-140'	1-3	--	--	--	Native to depth of Hole 3.
3-4	--	--	60', 130-140'	4-3	--	--	150'	Native to depth of Hole 3.
1-4	--	--	--	4-1	--	--	--	Native at all depths.

TABLE E-4

SUMMARY OF PxS TRACE AMPLITUDE INTERPRETATION FOR WELL 10

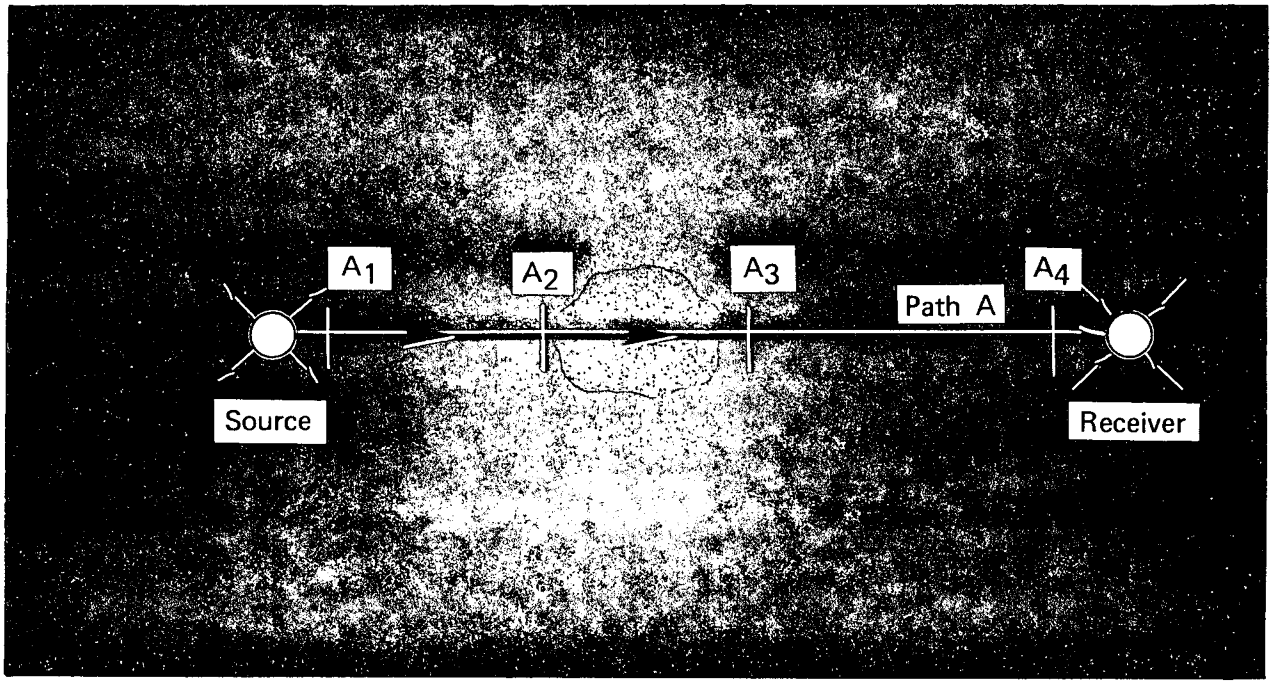
	Depth Interval Fitting Criteria				Depth Interval Fitting Criteria			
Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Reverse Transect	PxS=0	0<PxS<0.1	0.1<PxS<0.2	Interpretation
4-1	45-50'	55-65' 85-95' 155-160'	30-40', 70-80' 115-155', 170'	1-4	45-55'	40' 60-85' 170'	30-35' 90-165'	Possible cavity at 45-55'; possible graze at 55-95' and 155-165'.
4-3	--	50-70' 85', 115'	45', 100' 75-80', 110' 125-135', 185'	3-4	--	35-70' 135'	75-130' 140-170'	Possible graze at 45-70' and 135'.
2-3	--	40-50' 185-195'	55-60' 170-180'	3-2	40-50'	35', 55' 145-165'	60', 140' 170'	Possible cavity at 40-50'; possible graze at 55'.
1-2	--	35-40' 55-75' 150-170'	45-50', 80-95' 145', 175'	2-1	--	45-55' 105', 120' 135-160'	60-100' 110-115' 125-130' 165-175'	Possible graze at 45-75' and 145-170'.

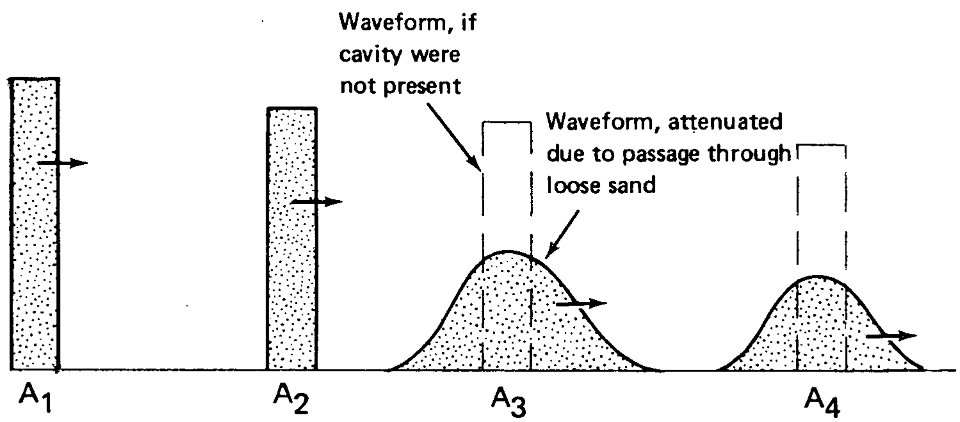
SAN ONOFRE NUCLEAR GENERATING STATION UNITS 2 & 3
PLOT PLAN



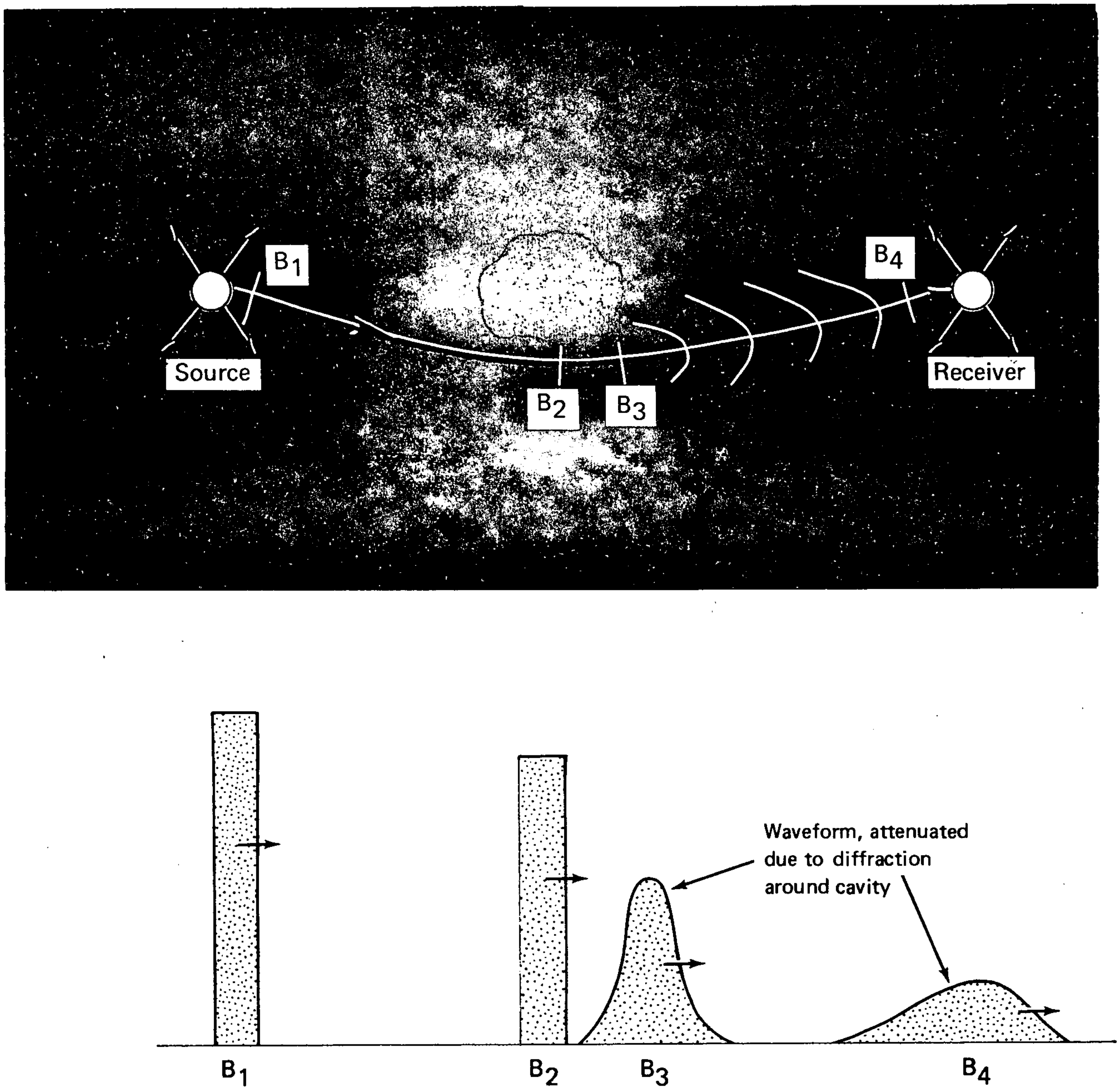
Project:	SONGS 2 & 3	PLOT PLAN SHOWING LOCATION OF DEWATERING WELLS	Fig. E-1
Project No.	411301		

WOODWARD-CLYDE CONSULTANTS





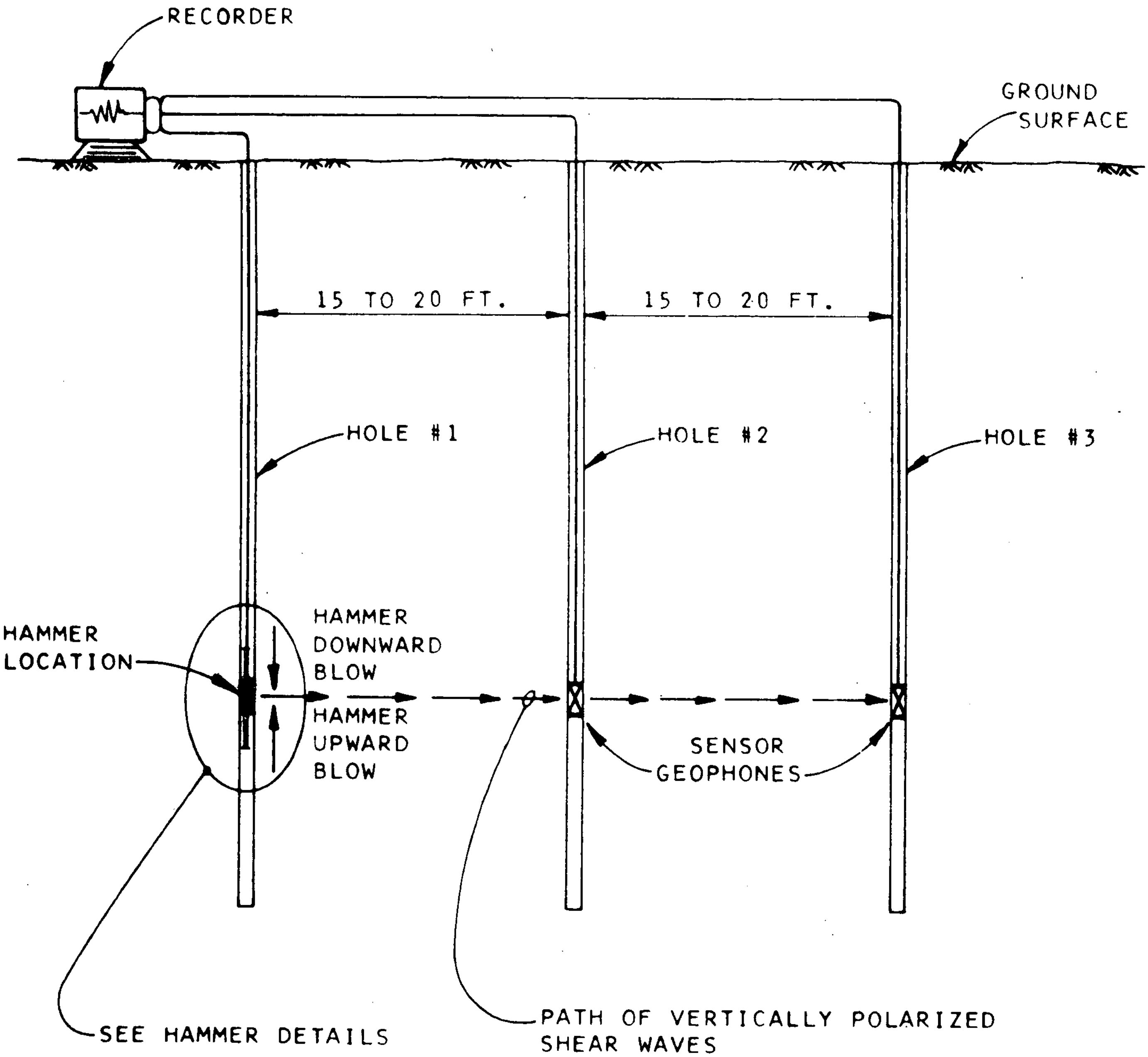
Project: **SONGS 2 & 3** Project No. **411301**	**WAVE PROPAGATION THROUGH CAVITY FILLED WITH LOOSE SAND**	Fig. **E-2**



Project: **SONGS 2 & 3**
Project No. **411301**

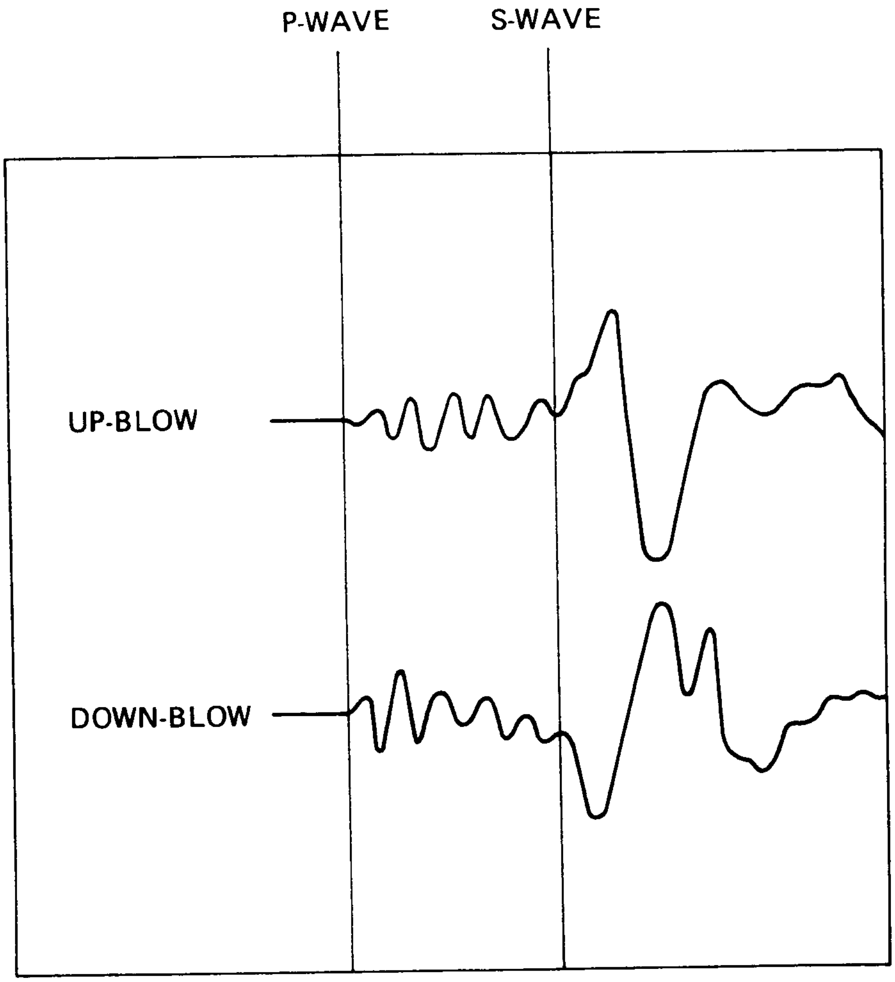
WAVE PROPAGATION AROUND CAVITY

Fig. **E-3**



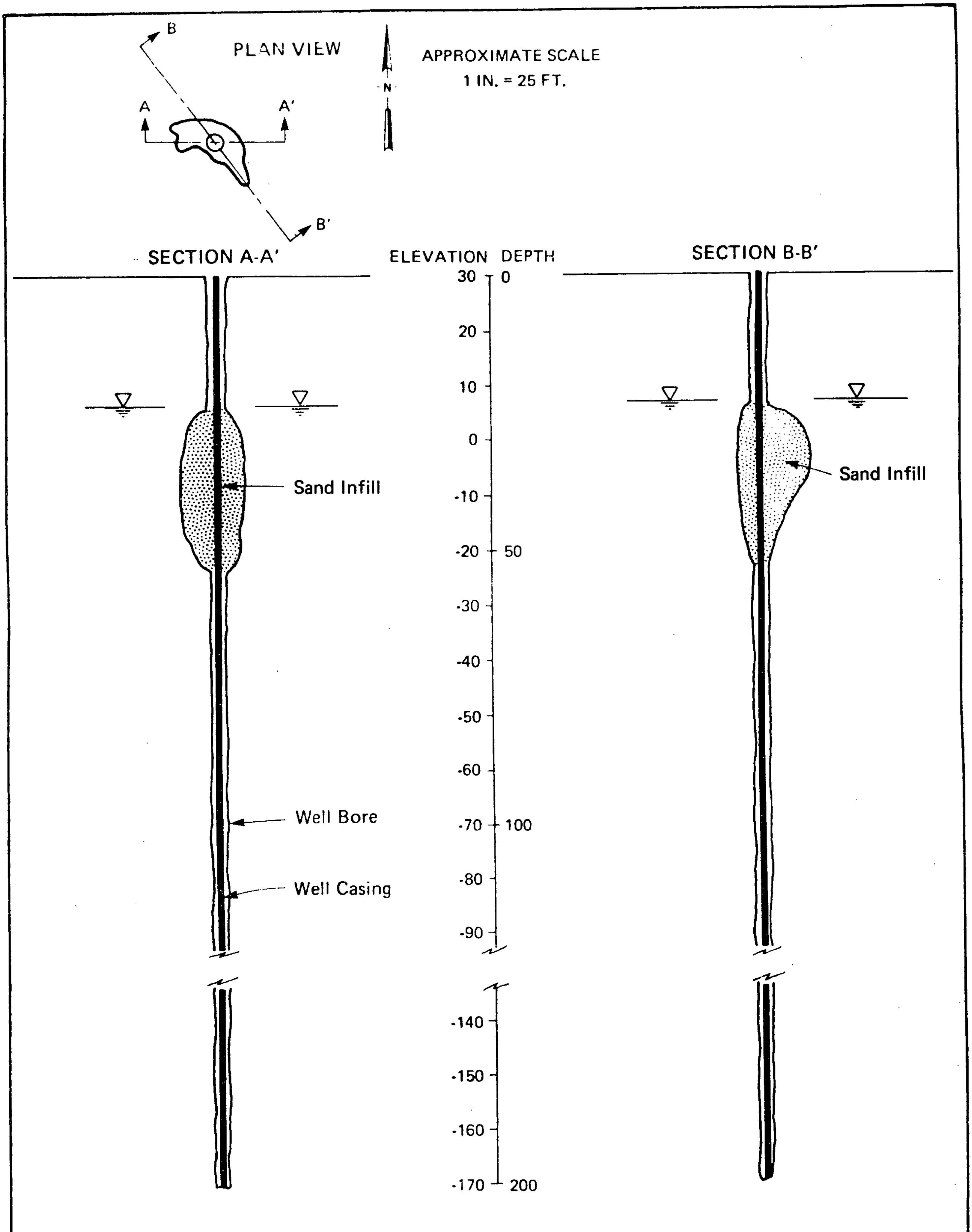
Project: SONGS 2 & 3	ARRANGEMENT OF INSTRUMENTS FOR CROSSHOLE SURVEY	Fig.
Project No. 411301		E-4

WOODWARD—CLYDE CONSULTANTS



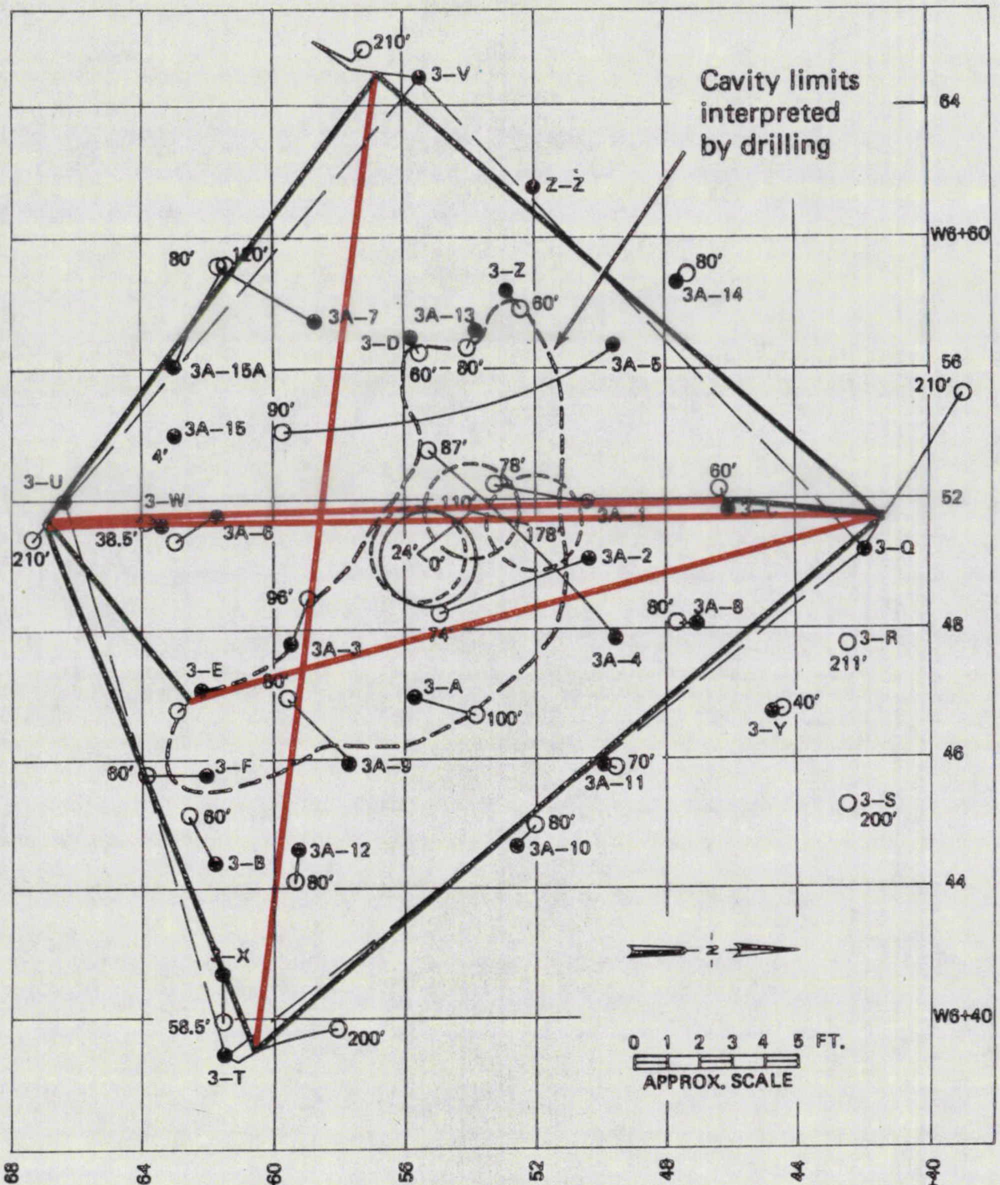
Project:	SONGS 2 & 3	WAVEFORM RECORDS	Fig.
Project No.	411301	OF SAMPLE PAIR OF TRACES	E-5

WOODWARD—CLYDE CONSULTANTS



Project: SONGS 2 & 3 Project No 411301	PLAN AND SECTION VIEWS OF WELL NO. 3	Fig. E-6

WOODWARD – CLYDE CONSULTANTS



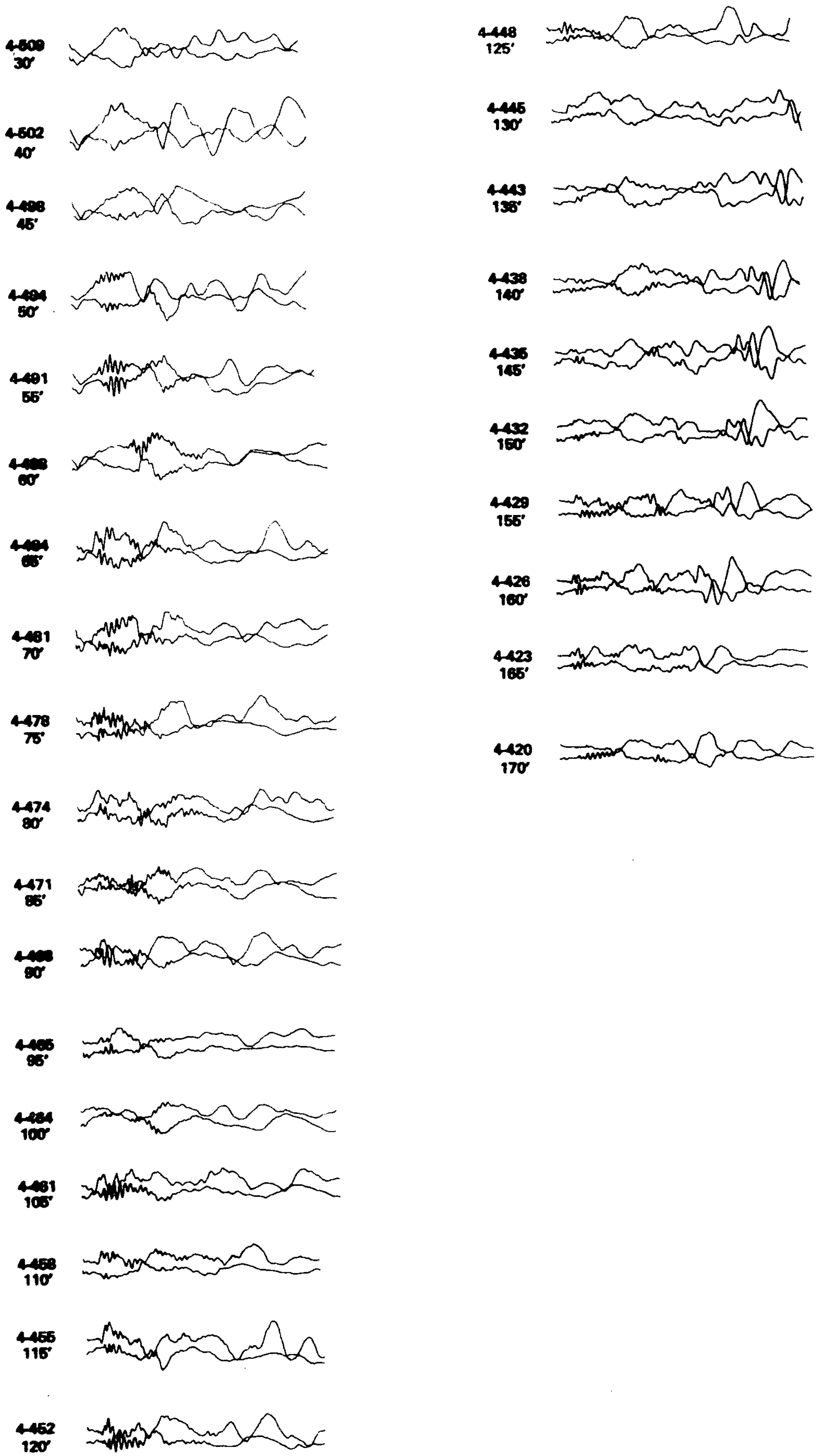
TYPICAL CROSSHOLE TRANSECTS 30-60 FT.

Across possible cavity

Across native soil

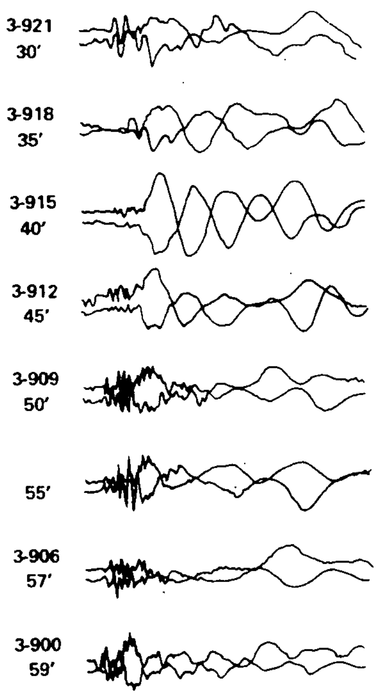
Project:	SONGS 2 & 3	DEWATERING WELL NO. 3 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 30 TO 60 FT. DEPTHS	Fig. E-7
Project No.	41130I		

WOODWARD–CLYDE CONSULTANTS



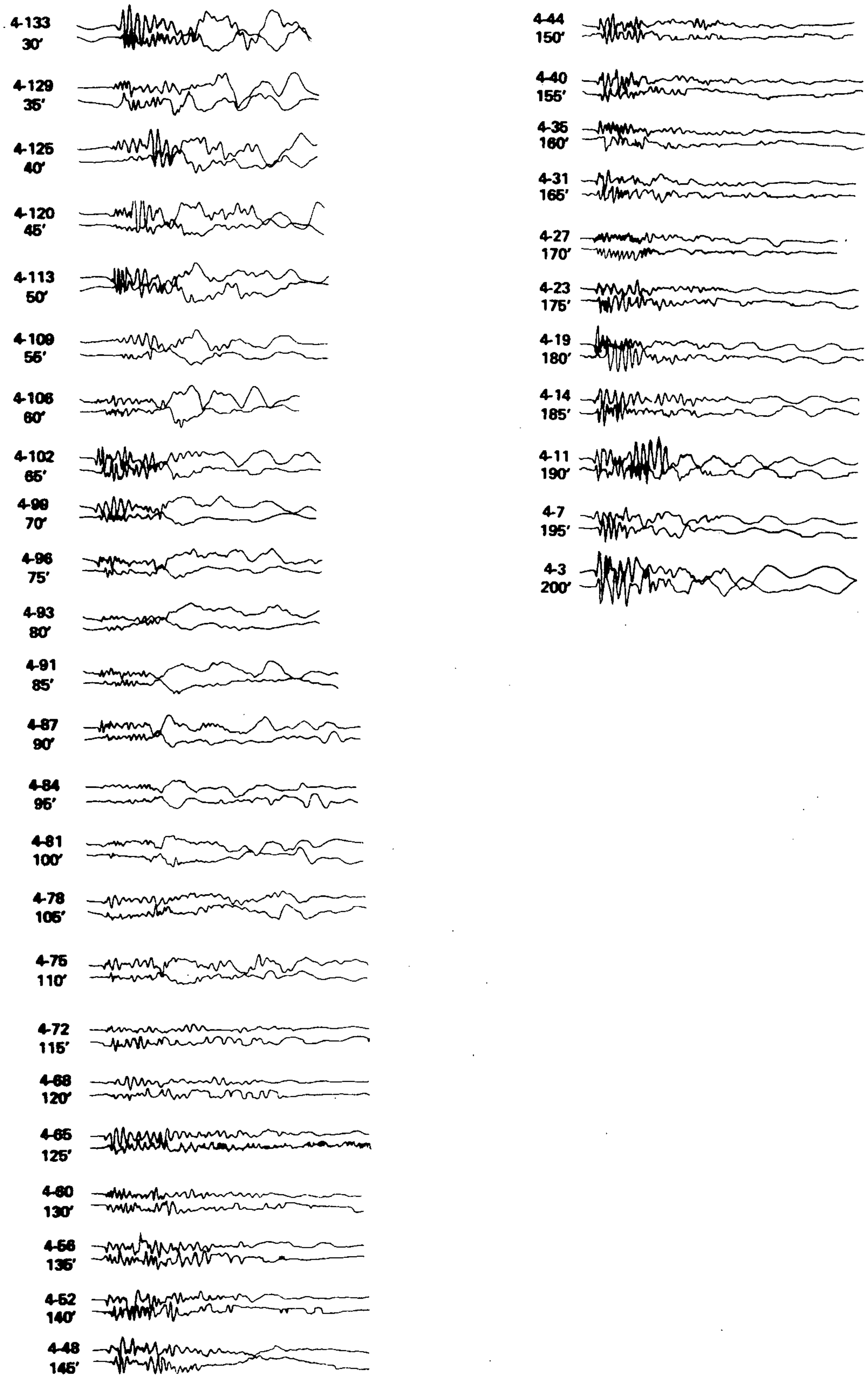
Project: SONGS 2 & 3 Project No. 411301	WELL NO. 3 U → T WAVEFORM TRACE	Fig. E-8

WOODWARD–CLYDE CONSULTANTS



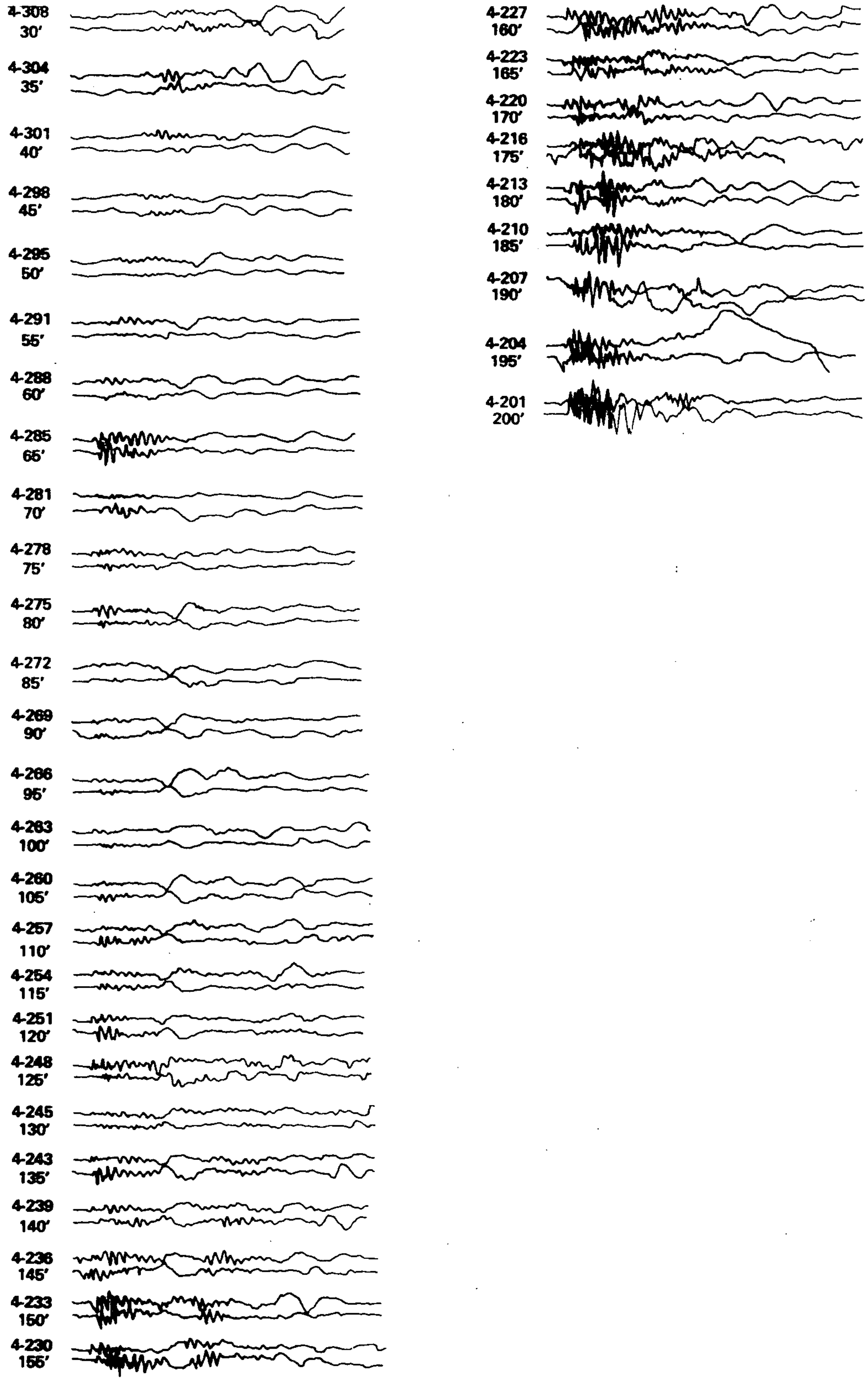
Project:	SONGS 2 & 3	WELL NO. 3 U → E WAVEFORM TRACE	Fig.
Project No.	411301		E-9

WOODWARD–CLYDE CONSULTANTS



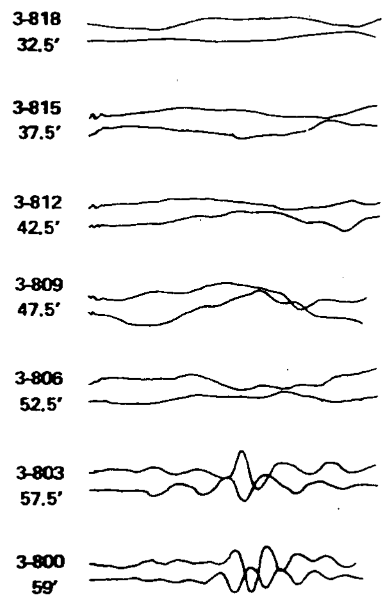
Project:	SONGS 2 & 3	WELL NO. 3 V → Q WAVEFORM TRACE	Fig.
Project No.	411301		E-10

WOODWARD – CLYDE CONSULTANTS



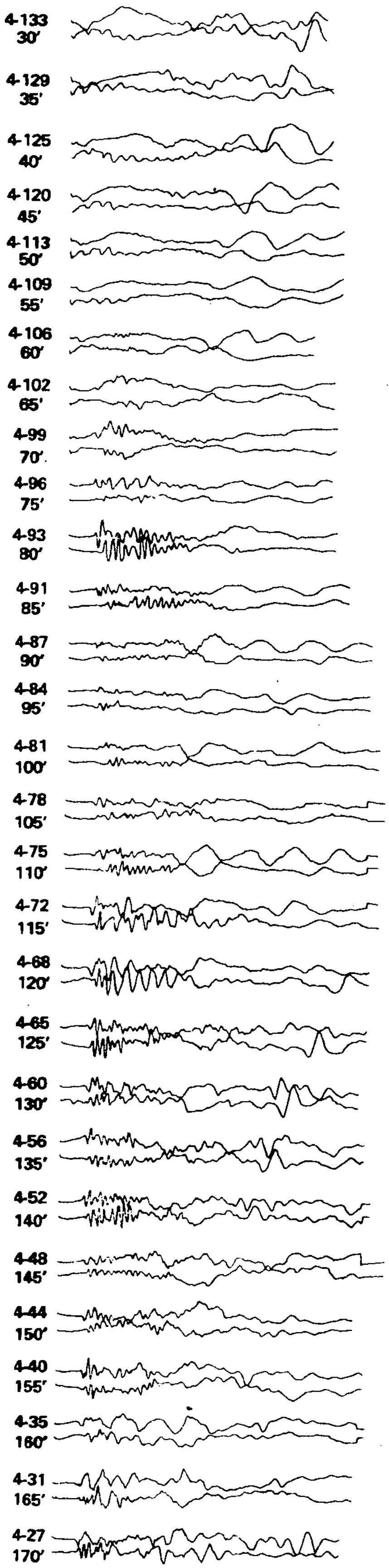
Project:	SONGS 2 & 3	WELL NO. 3 Q → U WAVEFORM TRACE	Fig.
Project No.	411301		E-11

WOODWARD – CLYDE CONSULTANTS



Project:	SONGS 2 & 3	WELL NO. 3 Q → E WAVEFORM TRACE	Fig.
Project No.	411301		E-12

WOODWARD—CLYDE CONSULTANTS



Project:	SONGS 2 & 3	WELL NO. 3 V→T WAVEFORM TRACE	Fig.
Project No.	411301		E-13

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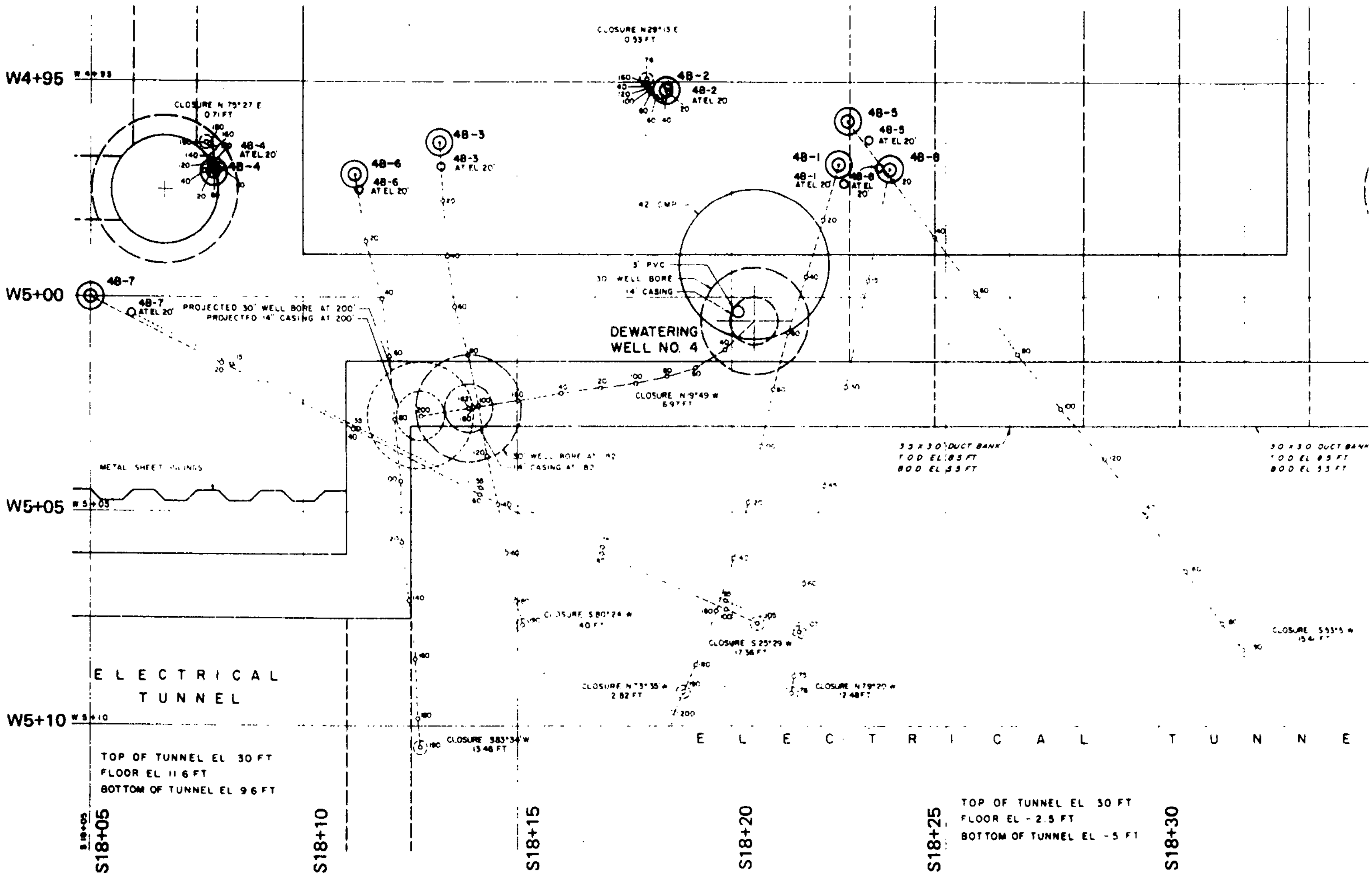
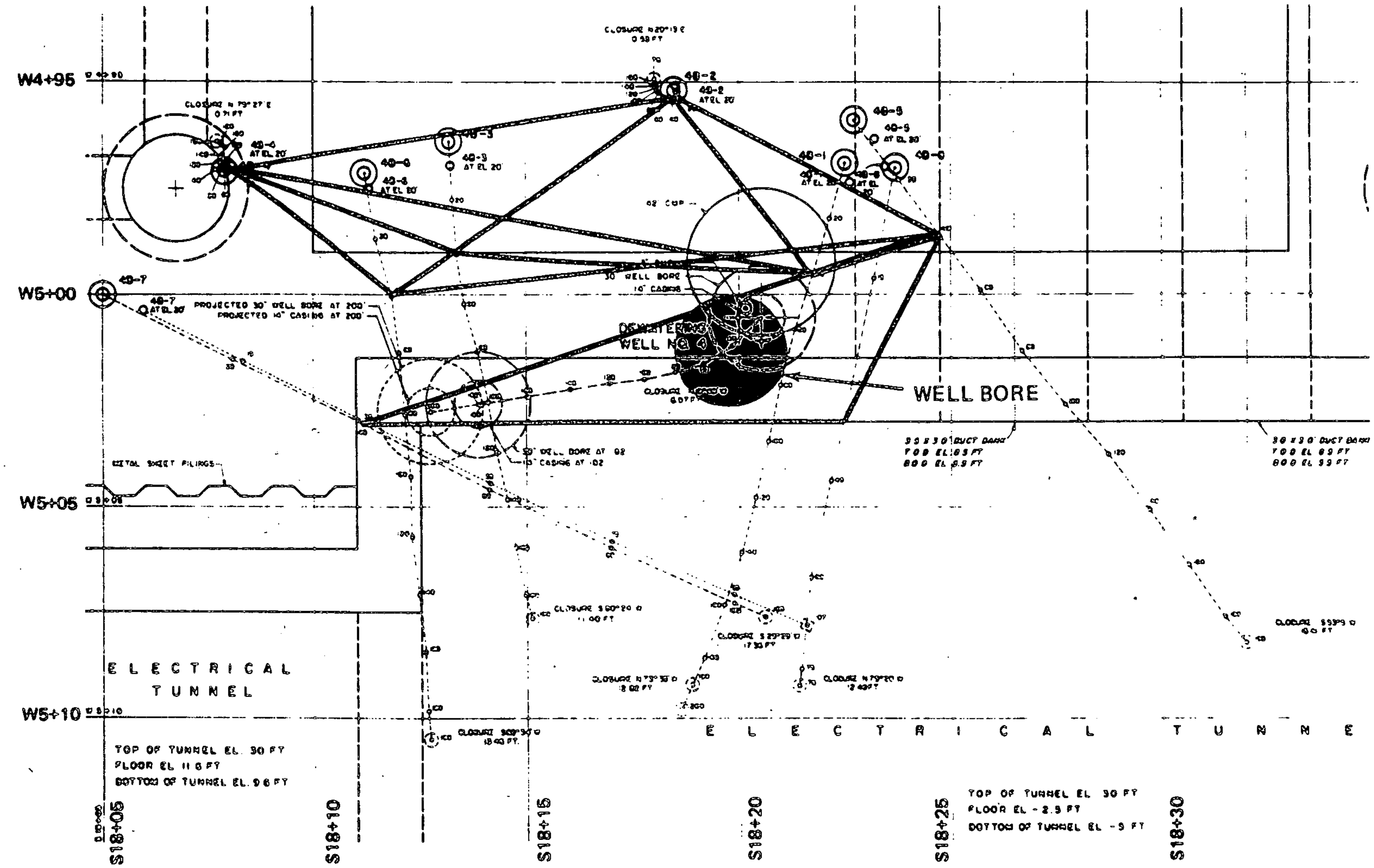


Project:	SONGS 2 & 3	DEWATERING WELL NO. 4 LOCATION OF DRILL HOLES	Fig.
Project No.	411301		E-14

WOODWARD-CLYDE CONSULTANTS



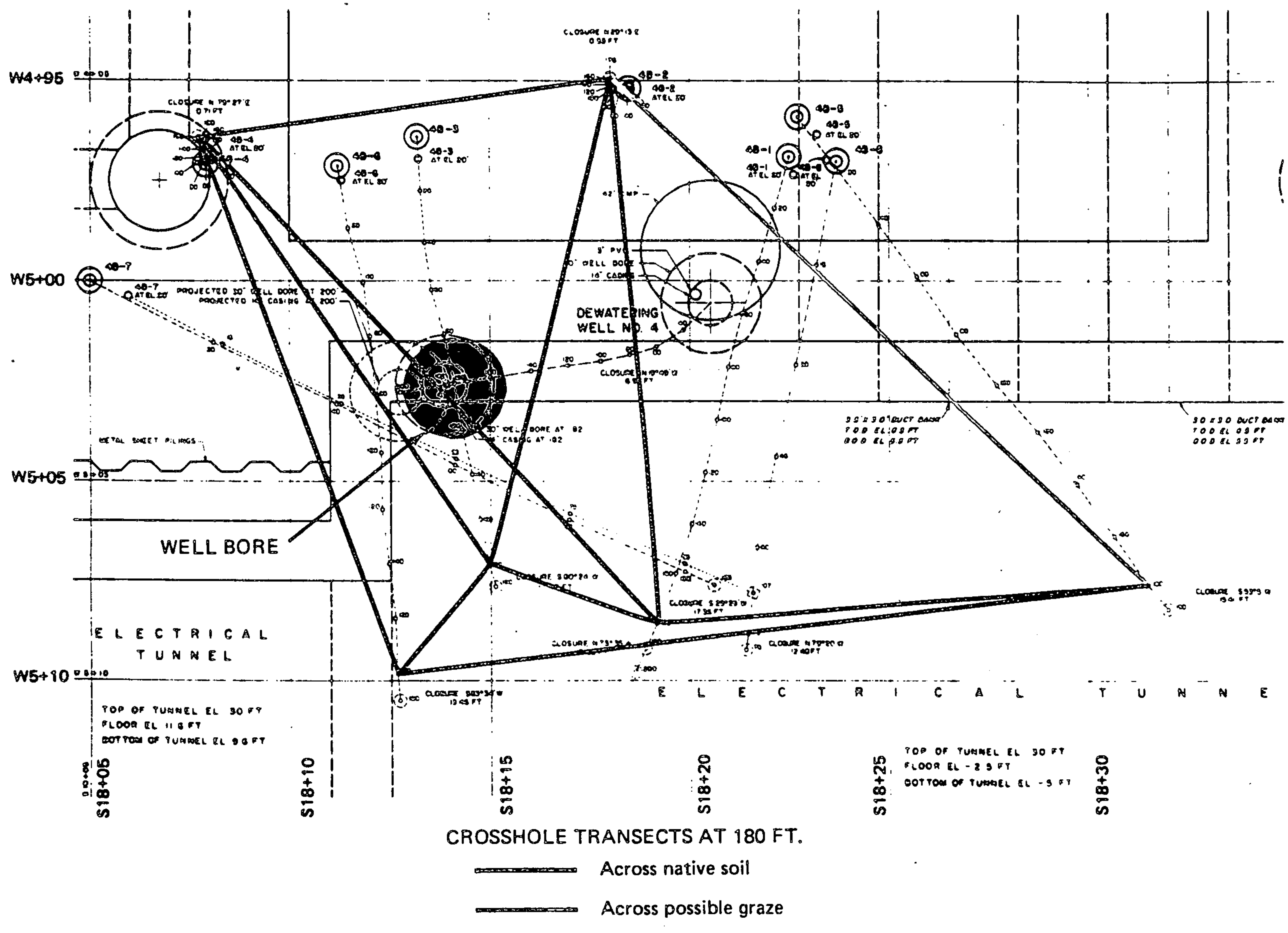
CROSSHOLE TRANSECTS AT 40 FT.

Across possible cavity

Across native soil

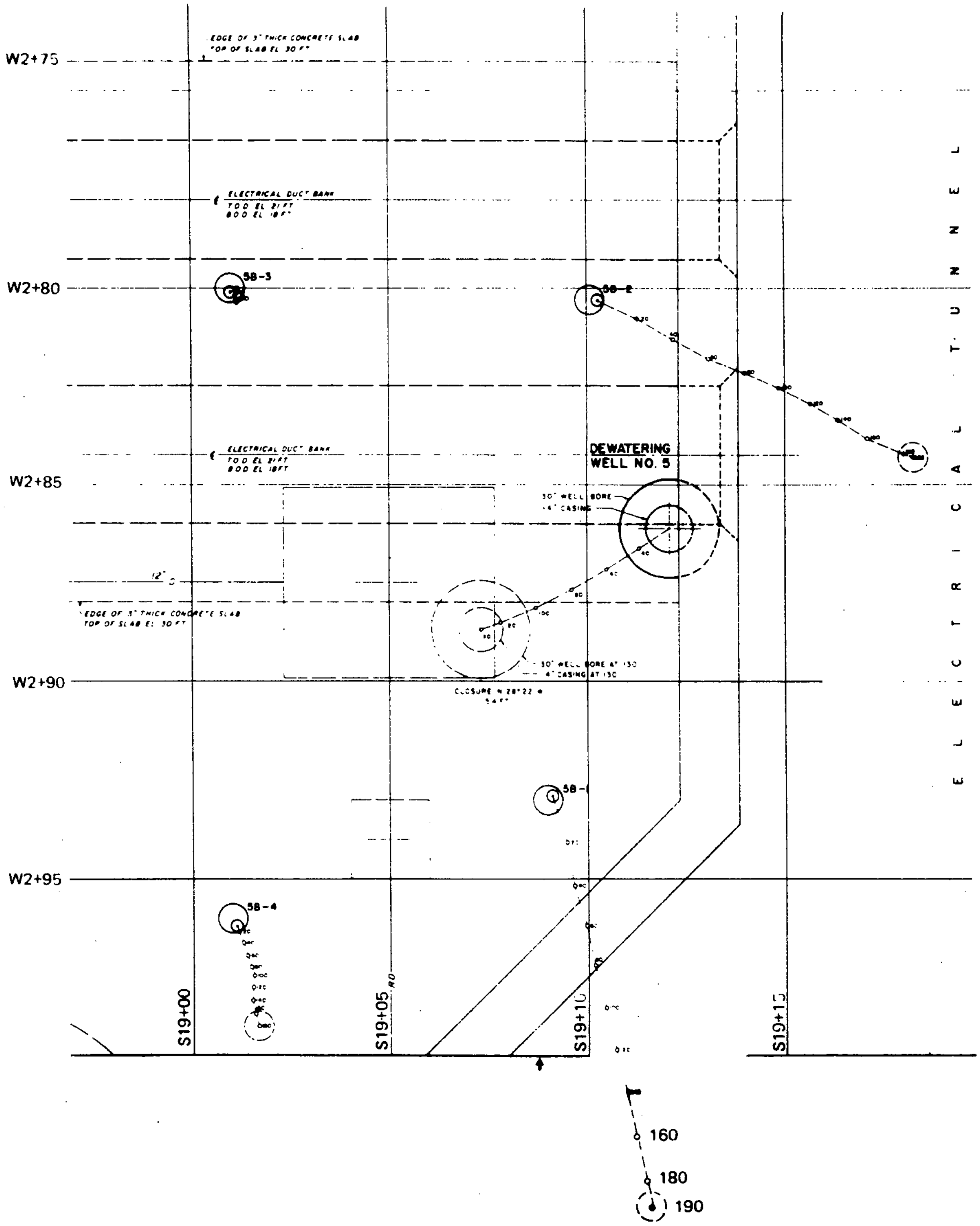
Project:	SONGS 2 & 3	DEWATERING WELL NO. 4 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 40 FT. DEPTH	Fig. E-15
Project No.	411301		

WOODWARD-CLYDE CONSULTANTS



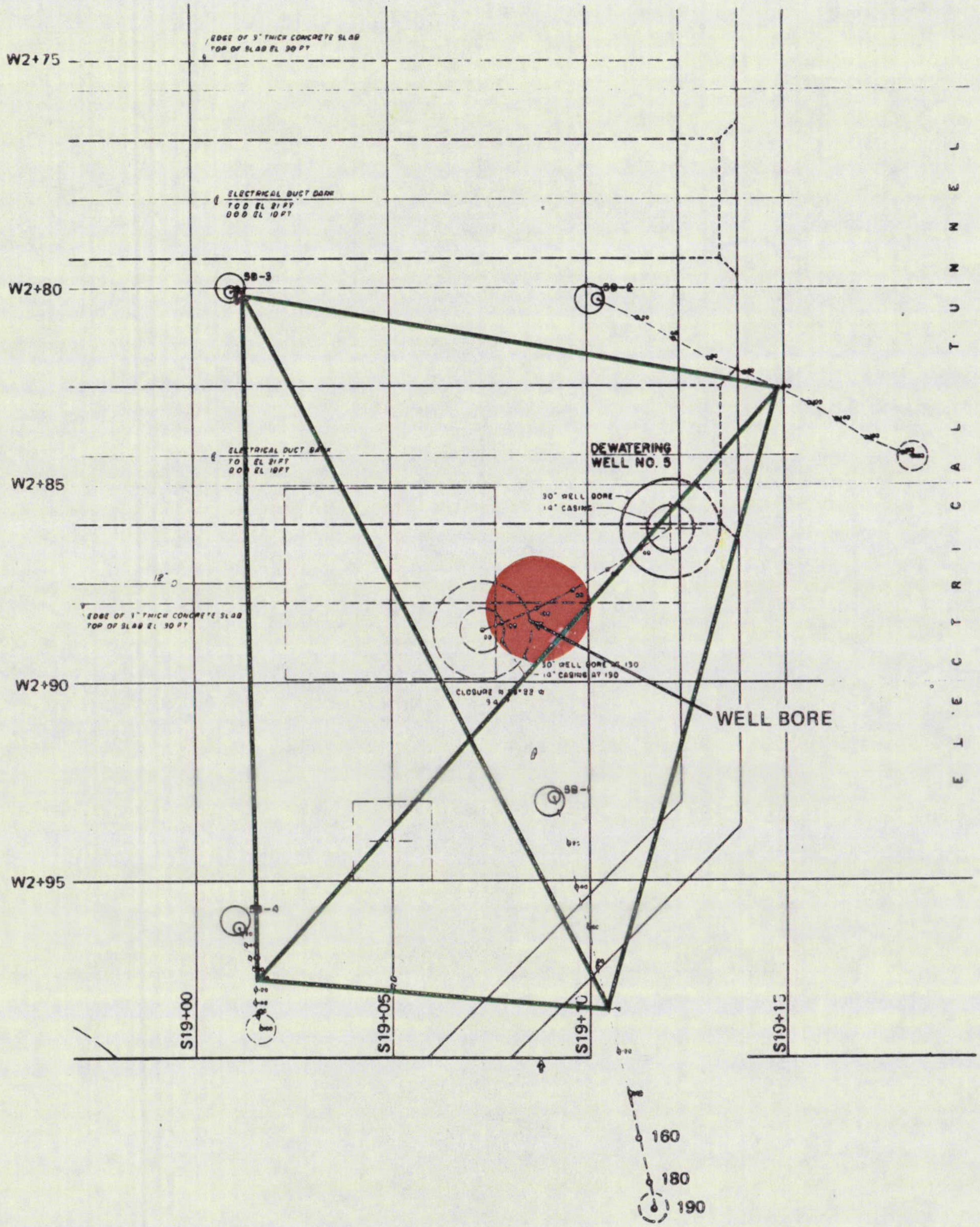
Project:	SONGS 2 & 3	DEWATERING WELL NO. 4 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 180 FT. DEPTH	Fig. E-16
Project No.	411301		

WOODWARD-CLYDE CONSULTANTS



Project:	SONGS 2 & 3	DEWATERING WELL NO. 5	Fig.
Project No.	411301	LOCATION OF DRILL HOLES	E-17

WOODWARD—CLYDE CONSULTANTS



CROSSHOLE TRANSECTS AT 100 FT.

Across native soil

Project:	SONGS 2 & 3	DEWATERING WELL NO. 5 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 100 FT. DEPTH	Fig.
Project No.	41130I		E-18

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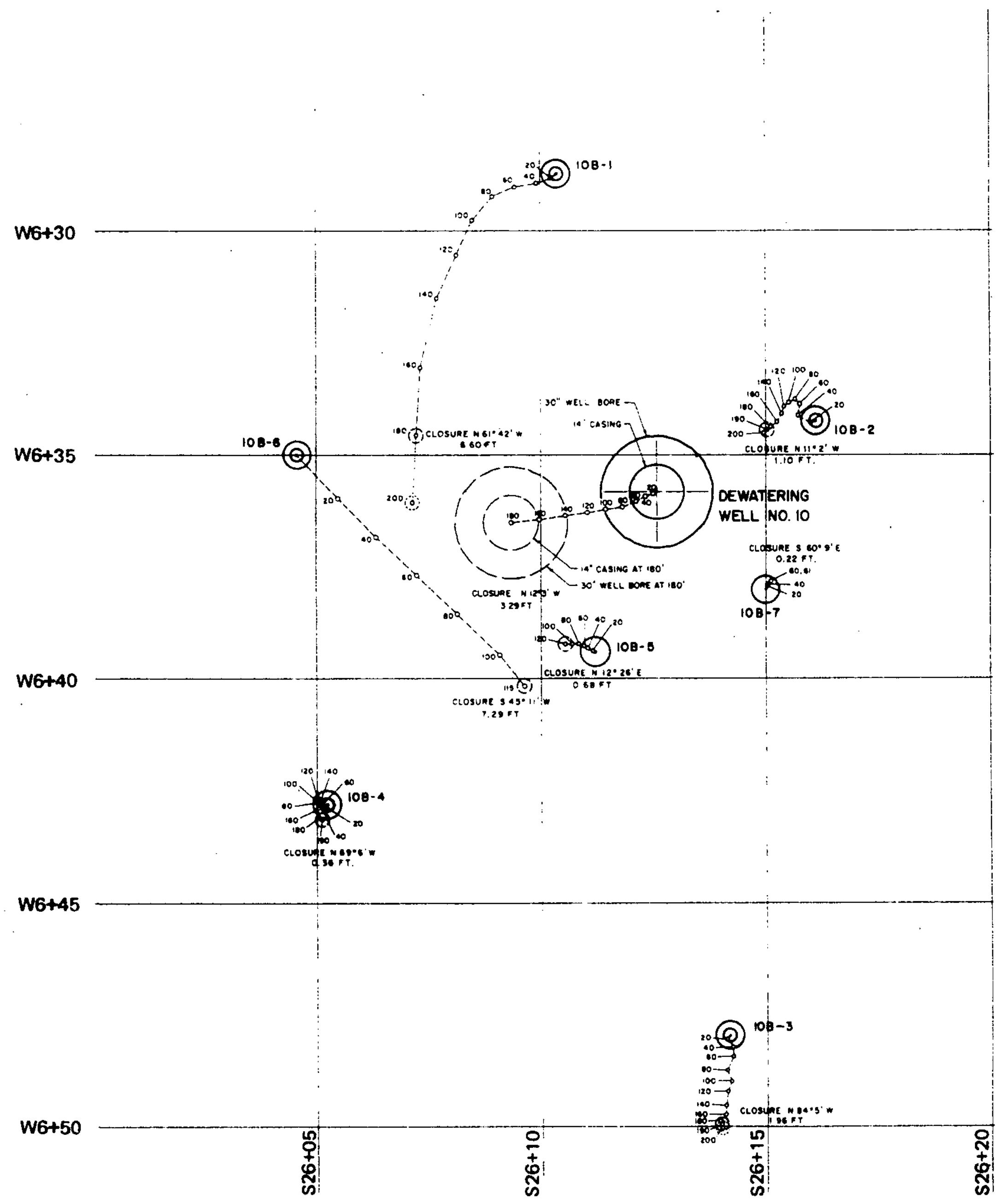

Project:	SONGS 2 & 3	DEWATERING WELL NO. 10	Fig.
Project No.	411301	LOCATION OF DRILL HOLES	E-19

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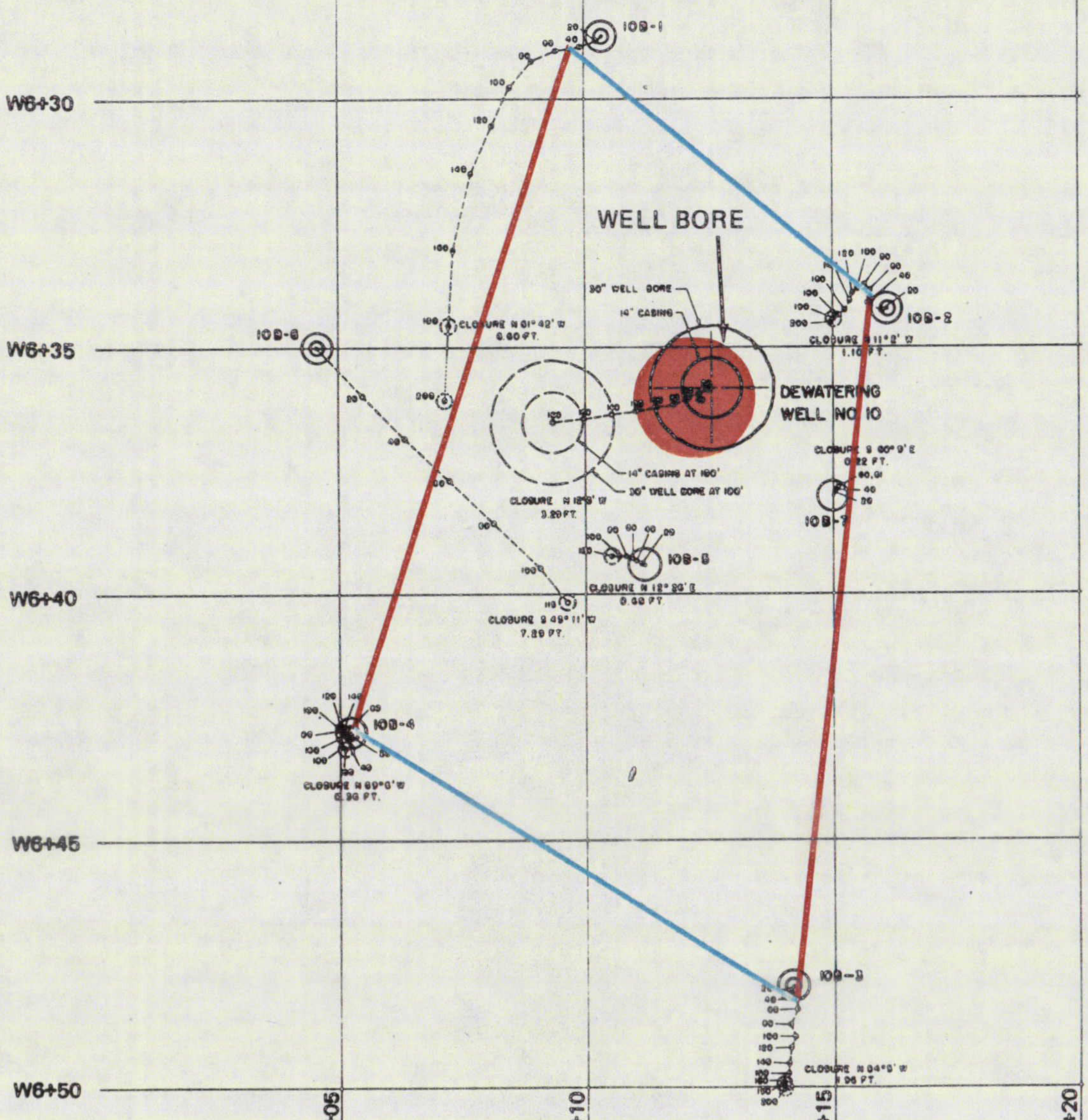

CROSSHOLE TRANSECTS AT 50 FT.

Across possible cavity

Across possible graze

Project: SONGS 2 & 3 Project No. 41130I	DEWATERING WELL NO. 10 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 50 FT. DEPTH	Fig. E-20

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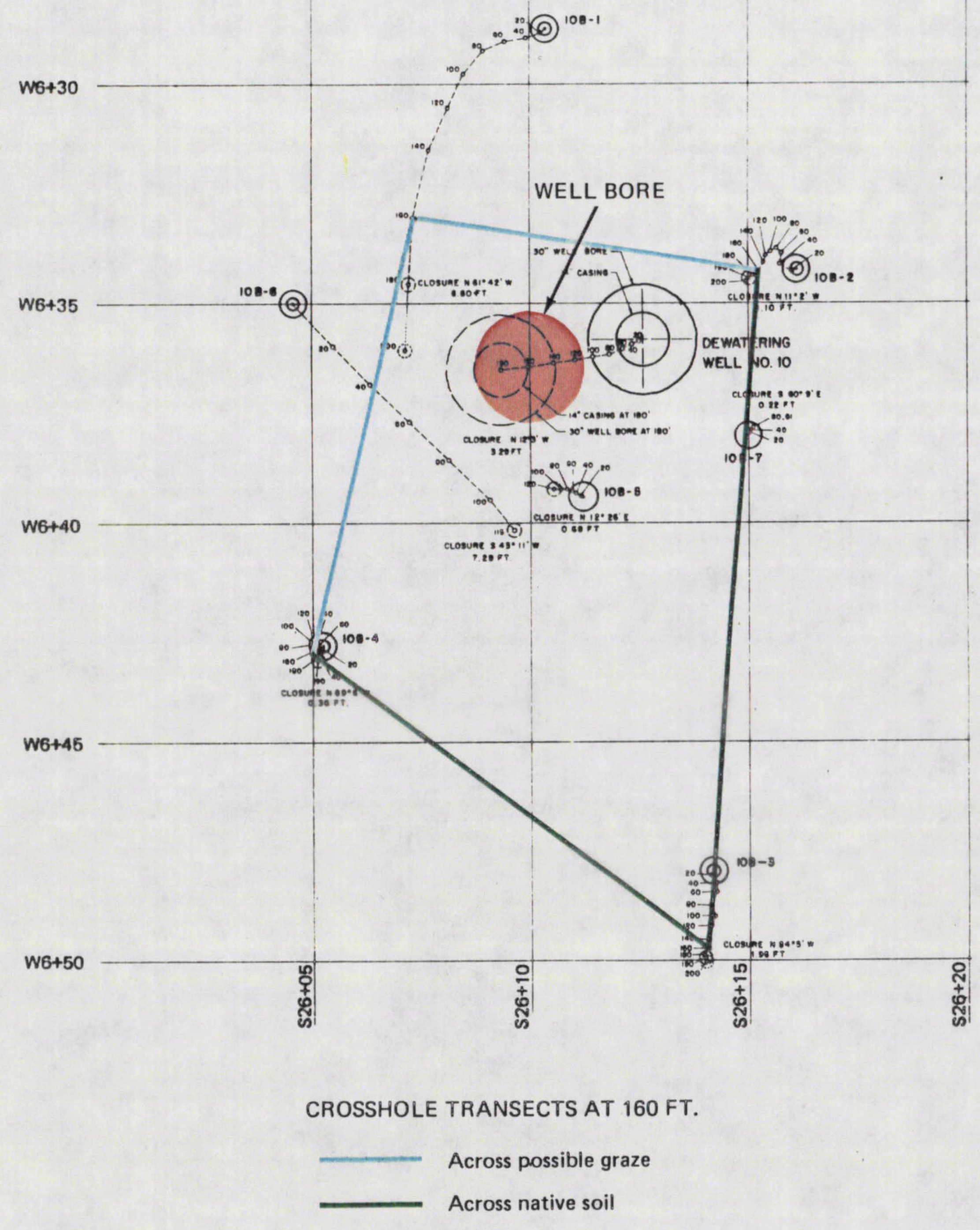

Project:	SONGS 2 & 3	DEWATERING WELL NO. 10 LOCATION OF DRILL HOLES AND INTERPRETED CROSSHOLE TRANSECTS AT 160 FT. DEPTH	Fig.
Project No.	41130I		E-21

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APPENDIX F

Analysis Of Cavity Stability

APPENDIX F
ANALYSIS OF CAVITY STABILITY

F-1 INTRODUCTION

During seismic shaking, excess pore water pressures are generated in the loose saturated sand filling a cavity and in the surrounding native soil. The pore water pressures in both the cavity-infill material and the native soil dissipate with time following a seismic event. Some of the excess pore pressures in the cavity-infill are likely to be transferred to the native soil. These transferred excess pore pressures reduce the strength of the native soil and, if such reduction is significant, the cavity expands. This mechanism has been evaluated by studying the generation and dissipation of pore water pressure in and surrounding a cavity, using finite-element analytical procedures. Details of this study are described in the Woodward-Clyde Consultants' (1978) report. This appendix contains a brief description of the analytical procedures and a summary of the potential for cavity expansion by failure of the cavity wall.

F-2 ANALYSIS OF PORE PRESSURE GENERATION AND DISSIPATION FOR WELL 8

The potential expansion of a cavity due to generation of excess pore water pressure during seismic shaking and the transmission of such pressures to surrounding native soil are evaluated by finite-element procedures. The analysis was made in two steps: (1) an assessment of the dynamic response and stresses induced during DBE, and (2) an estimation of the generation and dissipation of excess pore water pressures. In the study, the conditions at Well 8 adjacent to the Containment Structure at SONGS Unit 3 were modeled. Figure F-1 shows the finite-element model used for the analysis. Typical results showing pore water pressure distribution at the end of the DBE time history are presented in Figure F-2. The analysis employed a plane-strain model, while in fact, the cavity has a small dimension perpendicular to the plane of the model. Thus, the estimates for excess pore pressures generated in the cavity-infill material are very conservative. Volume calculations show the cavity assumed in the model is more than 25 times larger than that of the actual cavity. Based on the results of the response and pore pressure dissipation analyses, such as presented in Figure F-2, contours of equal pore pressure ratios can be developed for various depths and time intervals during and after the earthquake. The maximum extent of the contours at Elev. -10 ft are shown in Figure F-3. Based on a detailed review of the results of analyses as documented in the Woodward-Clyde Consultants' 1978 report, it was concluded that the liquefaction of cavity-infill sand and the reduction of confining pressure on adjacent native soils due to pore pressure dissipation represents a transient condition and the soils stabilize to the pre-earthquake condition within one hour after the earthquake.

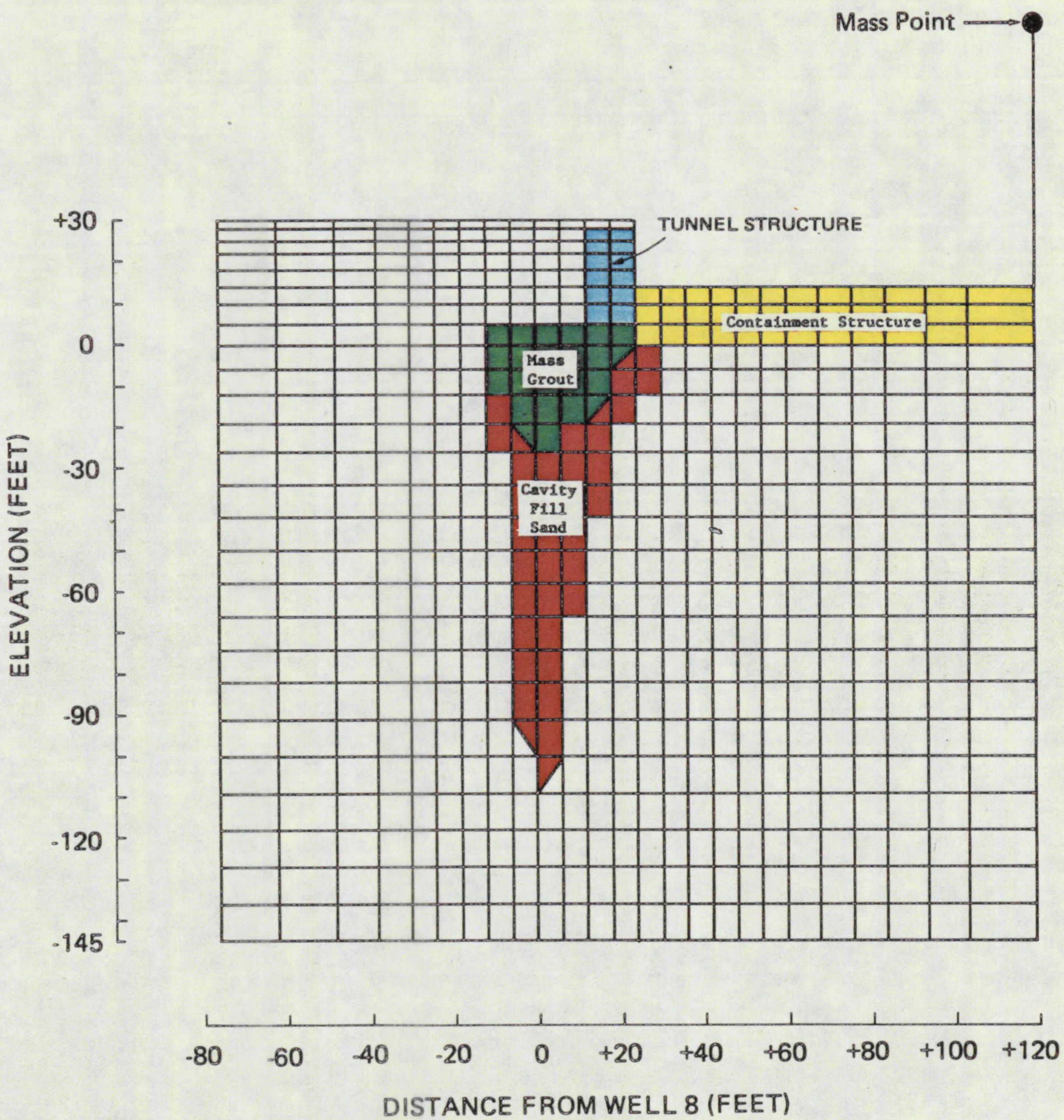
F-3 EXTRAPOLATION OF WELL 8 ANALYSIS RESULTS TO WELLS 6 AND 7

The results of the analyses completed for the Well 8 cavity (Woodward-Clyde Consultants, 1978) were extrapolated to the Well 6 and 7 cavities. Assuming that the upper limit of pore pressure ratio likely to effect the stiffness characteristics is 0.3, the Well 8 results were extrapolated by multiplying the ratio of the relative size of the 0.3 pore pressure ratio contour to the cavity at Well 8 times the size of the cavities at Wells 6 and 7 to obtain the 0.3 pore pressure ratio contours at Wells 6 and 7. Typical results of this extrapolation for the cavities at Wells 6 and 7 at the elevation of the base of the Auxiliary Building are presented in Figure F-4. The interpreted location and size of the cavities at Wells 6 and 7 are based on BPC (1979 a, b, c, d)

F-4 DISCUSSION OF POTENTIAL CAVITY EXPANSION

A mechanism may be postulated for expansion of the cavity wherein the excess pore water pressure developed in the walls of the cavity due to seismic shaking cause the cavity wall material to collapse and simulate cavity-infill soil. In examining this mechanism, it is noted that the native San Mateo sand is very dense (100% relative density) and is characterized by a very efficient grain packing. Further, experience in the field and the results of laboratory tests show that the native soil fails by particulating grain-by-grain. In doing so, the soil bulks and increases in volume by about 20%. Thus, failure of cavity walls causes the soil to particulate and bulk. This bulking is resisted by the existing soil in the cavity and the expansion of the cavity by wall failure is considered to be self-healing.

The dissipation of excess pore water pressure from the cavity-infill material, to the adjacent native soil tends to reduce the stiffness of the native soil. If the affected soil extends directly below a structure, the dynamic response of the structure, the bearing capacity of the soil supporting the structure, and settlements due to structural loads, can be affected. These effects are discussed in Appendix G.



Project:	SONGS 2 & 3	FINITE ELEMENT MESH USED IN ANALYSIS	Fig. F-1
Project No.	411301		

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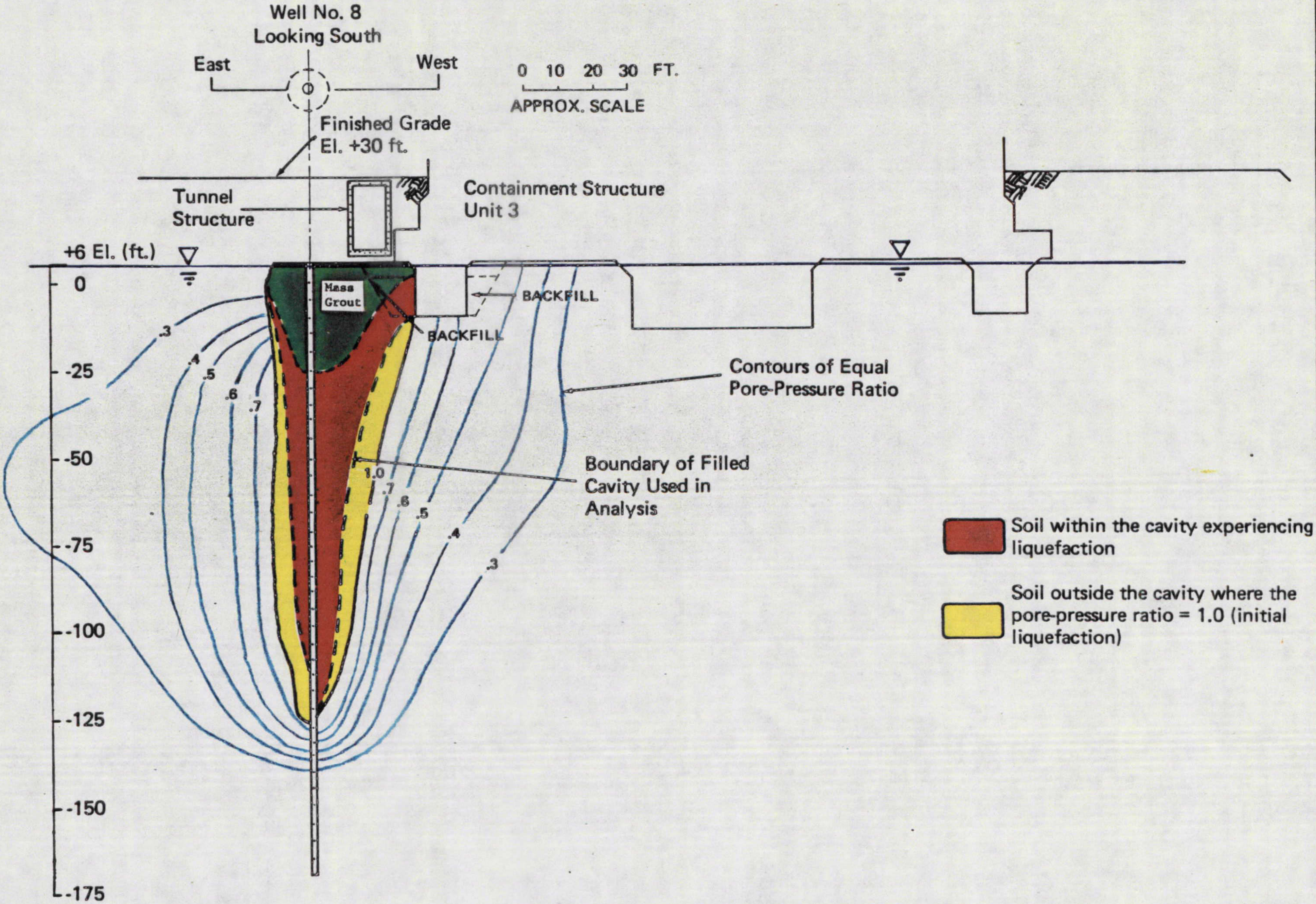

Project:	SONGS 2 & 3	SUMMARY OF RESPONSE/PORE-PRESSURE DISSIPATION ANALYSIS -	Fig.
Project No.	41130I	CROSS SECTION AT TIME = 80 SECS.	F-2

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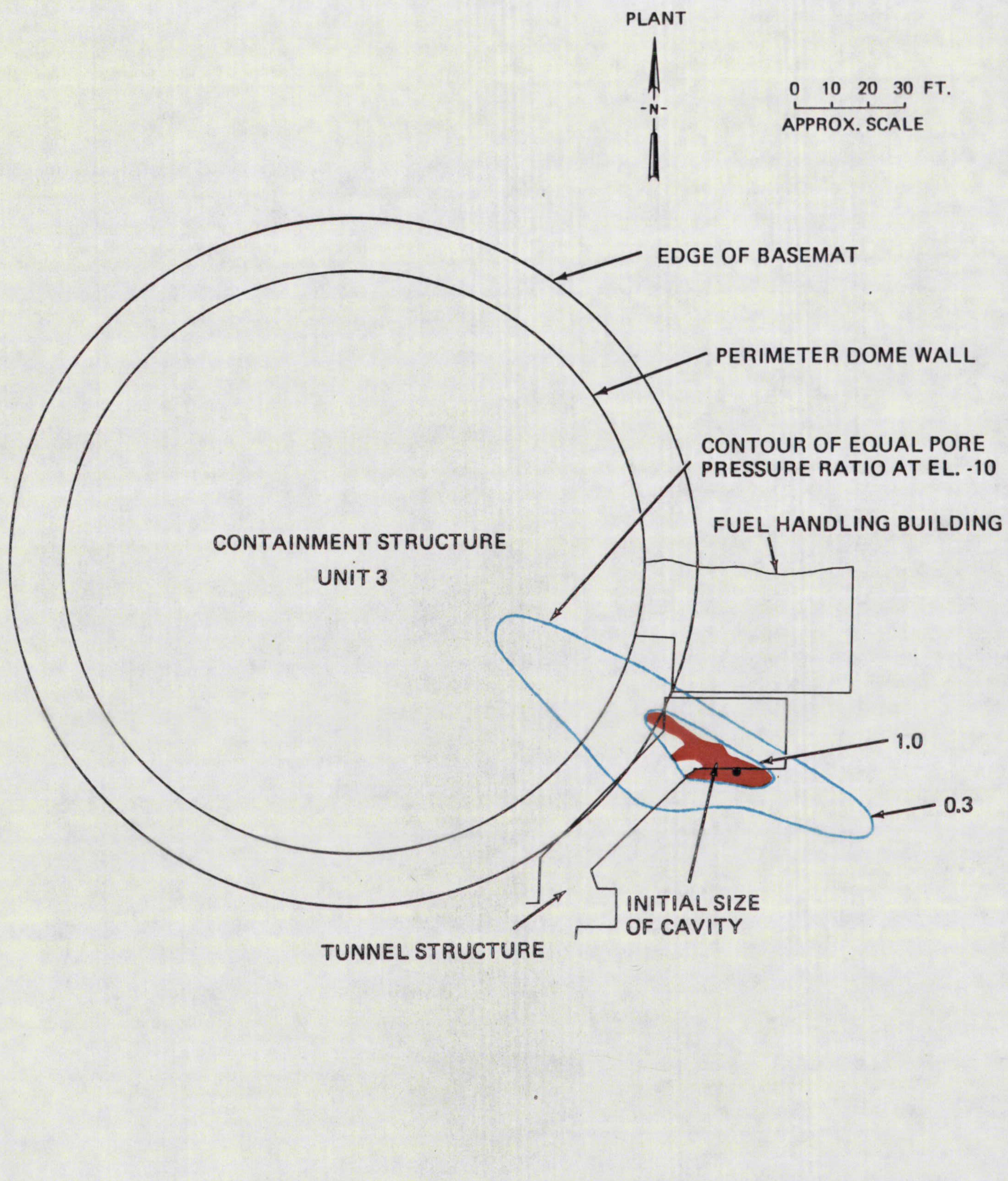

Project:	SONGS 2 & 3	PLAN SECTION OF CAVITY AND PORE PRESSURE RATIOS = 0.3 AND 1.0 AT ELEVATION -10 FEET FOR WELL 8	Fig.
Project No.	41130I		F-3

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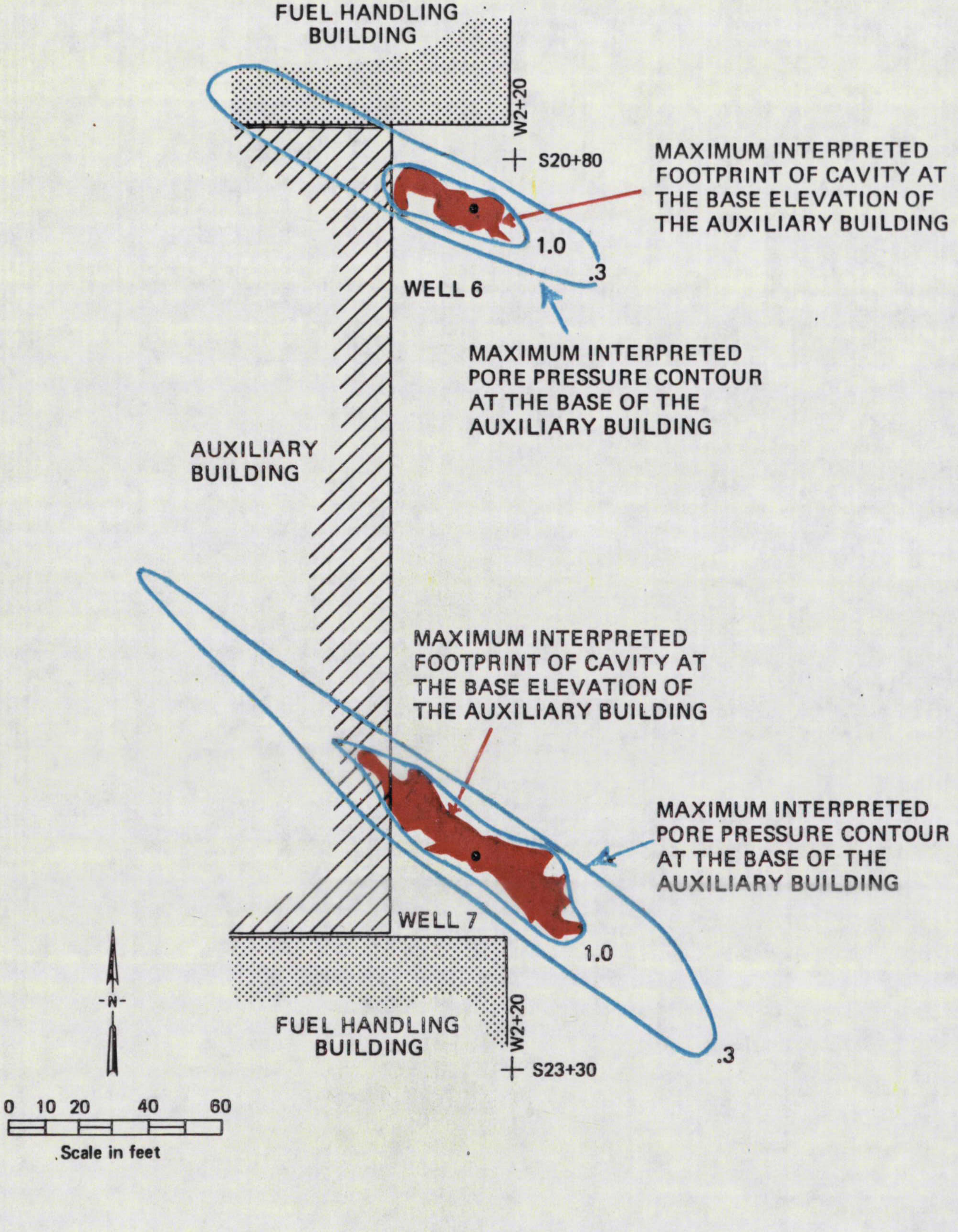

Project:	SONGS 2 & 3	PLAN SECTION OF CAVITY AND PORE PRESSURE RATIOS = 0.3 AND 1.0 AT ELEVATION 0 FEET. FOR WELLS 6 AND 7	Fig. F-4
Project No.	411301		

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APPENDIX G

Effects Of Cavities On Structures

APPENDIX G
EFFECTS OF CAVITIES ON STRUCTURES

G-1 INTRODUCTION

The cavities at Wells 6, 7, and 8 have been carefully defined by drilling exploration as discussed in Appendix C and BPC (1978a, b; 1979a, b, c, d). The footprint of the cavity at Well 8 at the base of the Containment Structure Unit 3 (Elev. -10 ft) is shown in Figure G-1. Footprints of cavities at Wells 6 and 7 at the base of the Auxiliary Building (Elev. +1 ft) are shown in Figure G-2. As shown in Figures G-1 and G-2, the cavity at Well 6 closely approaches the foundations for the north end of the Auxiliary Building and the Unit 2 Fuel Handling Building; the cavity at Well 7 extends nominally beneath the south end of the Auxiliary Building and approaches the Unit 3 Fuel Handling Building; and the cavity at Well 8 extends nominally beneath the Unit 3 Containment Structure and approaches the Unit 3 Fuel Handling Building. Because these are Seismic Category I structures, it is important to understand the effect of the cavities on the performance of the structures in both the static and seismic loading conditions. The effects of the cavities on foundation bearing capacity, settlement and seismic response are evaluated from analytical procedures utilizing conservative parameters to model the cavities.

Details of the analyses for Well 8 and the adjacent Containment Structure and tunnel structure for SONGS Unit 3 are presented in the Woodward-Clyde Consultants' report entitled Analyses Performed on Well 8 at the SONGS Units 2 and 3, San Onofre, California (August 1978). A summary of the general analytical procedures used and a compilation of the results developed for Well 8 and extrapolated to Wells 6 and 7 are presented in this appendix.

G-2 GENERAL APPROACH

The cavity in Well 8 is assessed for its effect on the Unit 3 Containment Structure and Fuel Handling Building while the cavities in both Wells 6 and 7 are considered inasmuch as they effect the Auxiliary Building and Fuel Handling Buildings for Units 2 and 3, respectively. This assessment was facilitated by making conservative assumptions regarding the interrelationships between the geometry and spatial location of the cavity and the body of soil dominating the support of the structure, as described below.

The mass of native San Mateo sand dominating the seismic response of the structures has been demonstrated to be the soil within one radius of the structure as documented in Appendix 3.7C of the FSAR. A reasonable lateral boundary for this volume of soil is assumed to be that enclosed by a plane subtended from the edge of the structure at an angle of 45 degrees. Therefore, the mass of native soil that dominates the seismic response of the structure is assumed to be enclosed in a frustum of a right rectangular cone centered on the structure with top dimensions equal to those of the base of the structure, a height equal to the equivalent radius of the structure, and side surfaces inclined at 45 -grees as shown in Figure G-3. Since the ratio of the structural loading to confining pressure will be higher near the base of the structure compared to deeper in the soil mass, the soil nearer the base will play a more important role in the support of the structure. Therefore, we have chosen to weight the importance of the soil with depth linearly from a factor of I=1 at the base of the structure to zero at a depth of one equivalent radius.

To evaluate the effects of a filled cavity on the overall stiffness of the supporting medium, the ratio of several geometric characteristics of the cavity to those of the dominant supporting soil, as shown in Figure G-3, are studied. Specifically, four characteristic ratios are considered: (1) the ratio of the projected plan area of the cavity within a plane subtended at 45 degrees from the edge of the Containment Building to that of the base area of the structure (a/A from Figure G-3); (2) the ratio of the volume of the cavity to that of the supporting soil extending to one radius below the structure within the 45 degree planar surface; (3) the ratio of the sum of area moments of inertia of the cavity from an axis of rotation through the center of the structure at 10-ft depth intervals to that of the supporting soil extending one radius below the structure; and, (4) the ratio of mass moments of inertia of these same elements. The characteristic ratios (1) and (2) describe maximum effects of the cavity on the static and seismic vertical translation response of the structure relating to the compression and inertia of the soil masses, respectively. Characteristic ratios (3) and (4) describe the maximum effects of the cavity on the static and seismic rotational response of the structure, relating to the bending resistance (rotational compression) and rotational inertia of the soil masses, respectively. By assuming zero stiffness of the soil within the cavity the characteristic ratios equal the effective overall reduction in stiffness of the supporting soil mass.

In the case of the response and pore pressure dissipation analyses the soil within the contour of pore pressure ratio equal to 1.0 (pore pressure = effective confining pressure, or initial liquefaction) the stiffness of the soil was assumed to reduce to zero. For the soil between the 0.3 to 1.0 contours of pore pressure ratio (Appendix F), the stiffness of the soil was assumed to be reduced by the average reduction in effective confinement. Because shear modulus of the native soil is proportional to the confinement to the two-thirds power, the loss of stiffness was calculated by the expression:

$$\text{Stiffness Loss} = 1 - (1 - r_u)^{2/3}$$

Where r_u = pore pressure ratio

The characteristics of the areas between the 0.3 and 1.0 contours of pore pressure ratio are therefore multiplied by the stiffness loss factor and added to the characteristics of the areas within 1.0 contour. To incorporate the effects of pore pressure ratio below 0.3, an additional reduction was included based on an inspection of average pore pressures of soil elements within the soil mass dominating the support of the structure (Figure G-3). The resulting characteristic value for the cavity and adjacent area softened by excess pore pressure is then divided by the total characteristic for the mass of supporting soil to obtain the final characteristic ratio.

G-3 RESULTS OF ANALYSES

For evaluating the effects of cavities on the overall stiffness of the supporting soil, all of the four geometrical characteristics described in the previous section are considered for Well 8 and the Containment Structure. Based on this evaluation (Woodward-Clyde Consultants, 1978), comparisons for areas and area moments are found to provide the maximum effect of cavity on the structure. The other two characteristics, the volume ratio and the mass moment of inertia, indicate a significantly smaller effect. Based on these results, it is appropriate to only consider the area and area moment comparisons for the Auxiliary Building and the Fuel Handling Buildings. For the Auxiliary Building, effects of Wells 6 and 7 are added to obtain the total effect on the stiffness of the supporting soil. Similarly, for the Unit 3 Fuel Handling Building the effects of Wells 7 and 8 are added to obtain the total effect on this structure.

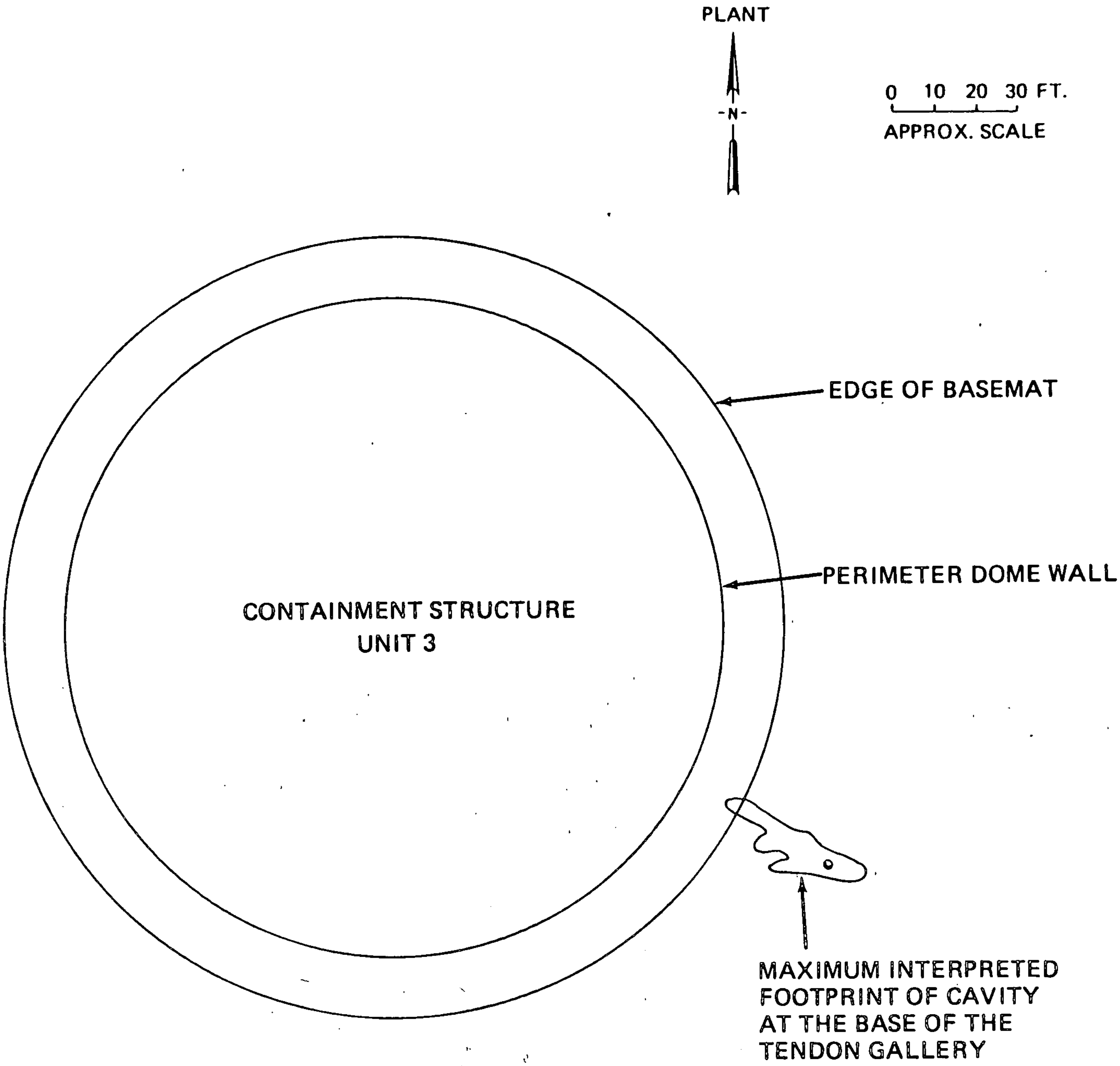
For the Auxiliary Building and the Fuel Handling Buildings, shapes of contours of pore pressure ratio of 1.0 and 0.3 are estimated on the basis of relative dimensions of the cavity and the 1.0 and 0.3 pore pressure ratio contours developed for Well 8 as discussed in Appendix F. The resulting characteristic values for the cavity and adjacent area softened by excess pore pressure is then divided by the total characteristic for the mass of supporting soil to obtain the final characteristic ratio. The calculated characteristic ratios for various structures are summarized in Table G-1.

TABLE G-1

SUMMARY OF MAXIMUM EFFECTS OF CAVITIES ON STRUCTURES

Structure	Well No.	Maximum Decrease of Dynamic Stiffness* (percent)		Maximum Increase in Settlement of Structure (percent)	
		Translation	Rocking	Total Vertical	Differential
Containment Unit 3	8	4	5	4	5
Auxiliary Units 2 and 3	6,7	2	2	2	2
Fuel Handling Unit 2	6	<1	3	<1	3
Fuel Handling Unit 3	7,8	<1	8	<1	8

* Affecting dynamic response of the structure during earthquake shaking.



Project:	SONGS 2 & 3	INTERPRETED PLAN SECTION OF CAVITY AT WELL NO. 8	Fig. G-1
Project No.	411301		

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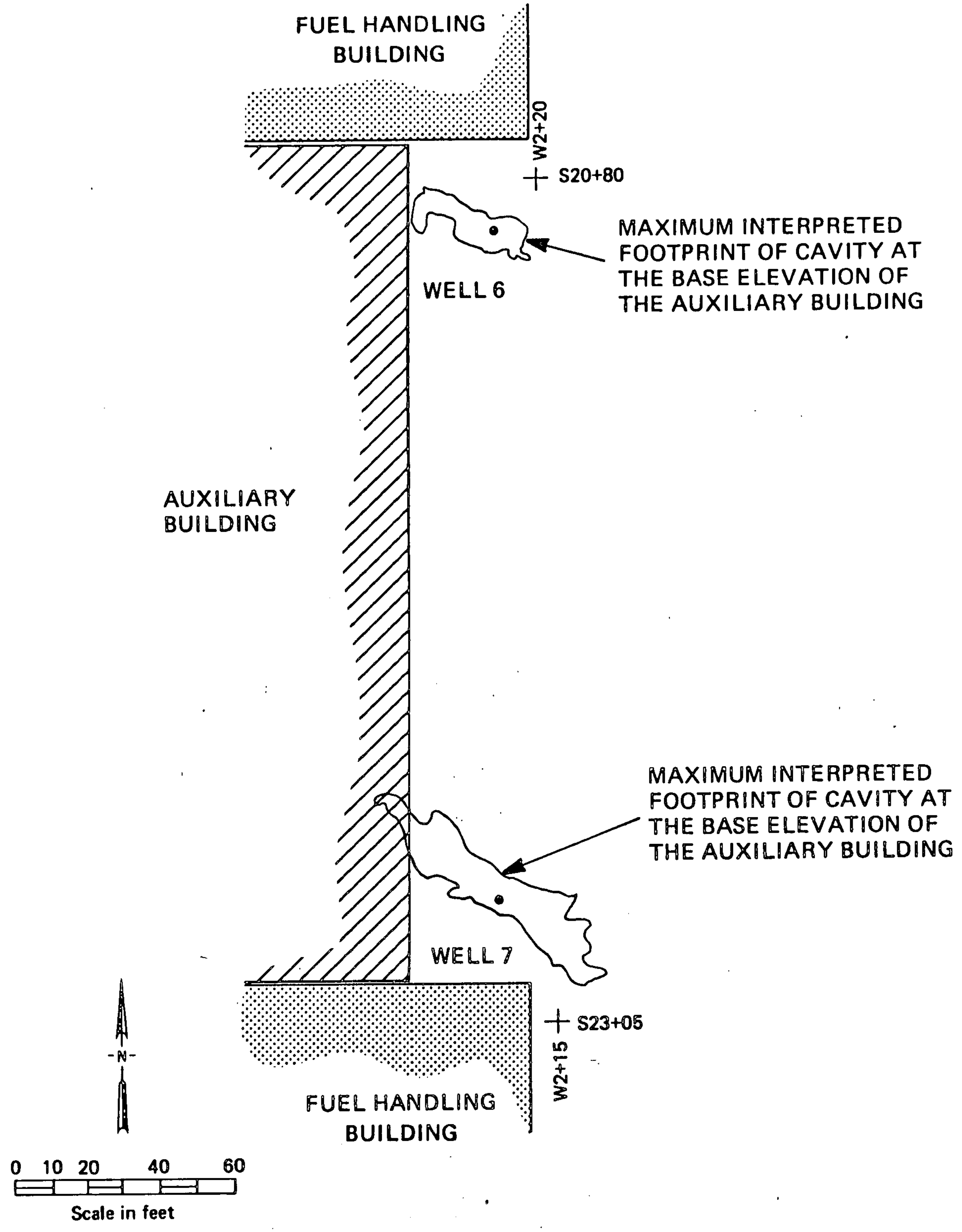

Project:	SONGS 2 & 3	INTERPRETED PLAN SECTION OF CAVITIES AT WELL NOS. 6 AND 7	Fig. G-2
Project No.	411301		

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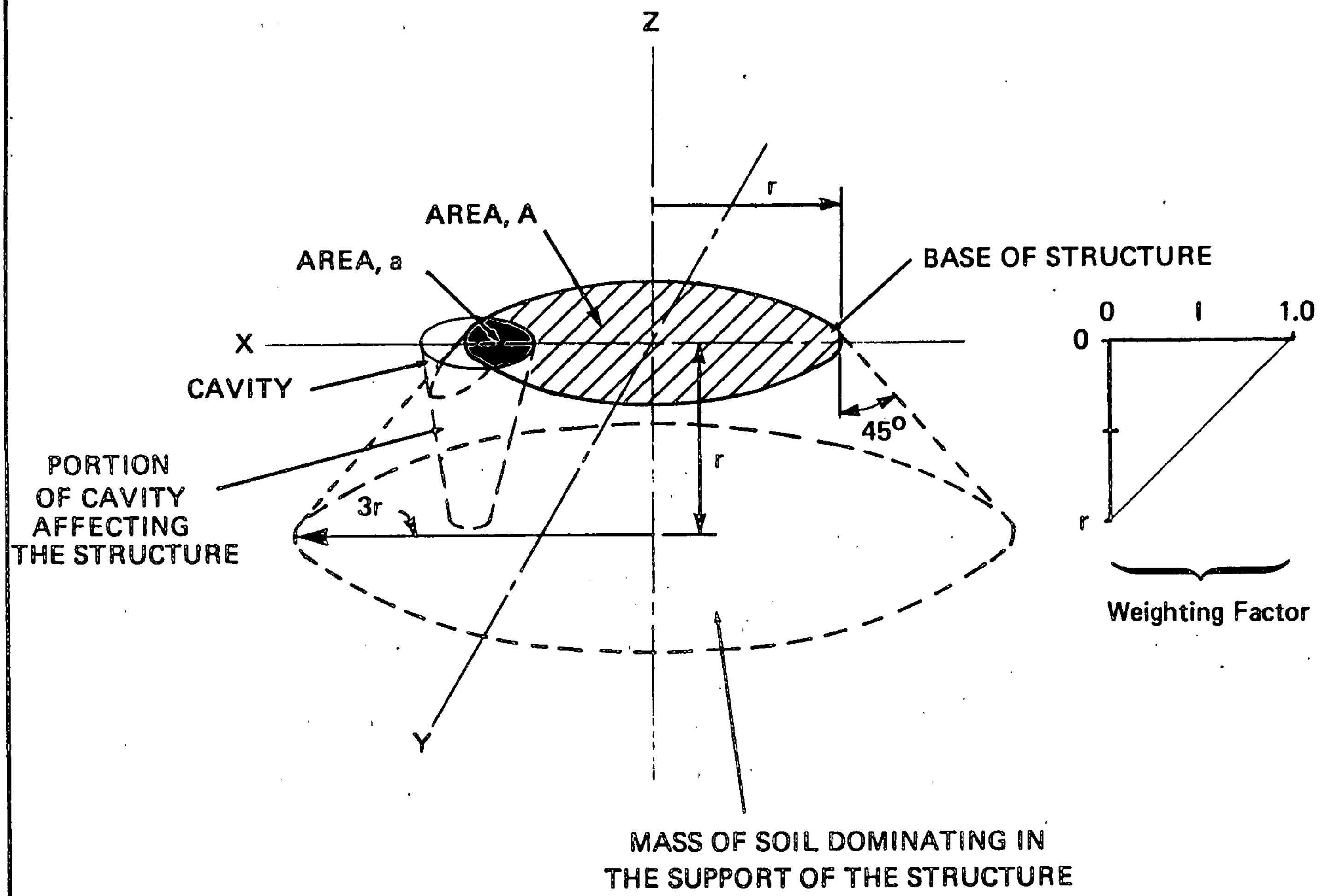

Project:	SONGS 2 & 3	DIAGRAM DESCRIBING THE EFFECT OF THE CAVITY ON THE STRUCTURE	Fig.
Project No.	411301		G-3

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REFERENCES

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