WSRC-TR-92-42-004

JANUARY 1992

REACTOR ENGINEERING DEPARTMENT
REACTOR RESTART DIVISION

INTEGRATED GEOLOGIC ANALYSIS OF THE K-REACTOR AREA (U)

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Aiken, SC 29808

SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

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INTEGRATED GEOLOGIC ANALYSIS OF THE K-REACTOR AREA

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EXECUTIVE SUMMARY

Carbonate material was originally deposited with the sediments of the Santee formation (formerly McBean) in the K-Reactor study area. The carbonate material resulted from growth of oyster banks in the area at the time of deposition. The carbonate material has been removed almost completely from the local sediments by geochemical dissolution. As a result of this dissolution process, soft zones and underconsolidated zones exist in three layers within the Santee formation in the study area.

The thickness, distribution and areal extent of the soft zones and the associated underconsolidated sediments (referred to as complexes) can be determined by examining the data from the more than 500 borings and cone penetrometer tests in the study area. These data indicate that well developed soft zones are rare in the local area. The soft zones that are found are generally 3-5 feet thick and usually associated with 8-10 feet of underconsolidated sands. The soft zone and underconsolidated sediment complexes have maximum areal extents of 200 feet long and 60 feet wide. The complexes occur along well developed northeast to southwest trends, which are associated with the underlying sediments.

The soft zones which are found in the study area are small, thin, limited in areal extent, and poorly interconnected. The limited thickness, extent, and distribution of the zones precludes the development of surface depressions resulting from collapse of the subsurface complexes. There is no evidence to indicate that surface depressions in the K Reactor study area are associated with the subsurface soft zones.

1.0 INTRODUCTION

The following discussion presents a compilation of the geologic information used to evaluate the subsurface conditions in the K Reactor study area. Section 2 is a brief review of work done previously in the area. Special emphasis is placed on summarizing of the original work done by the U.S. Army Corps of Engineers (Corps). Its investigative work formed the basis for the initial grouting program in 1951-1952. The information contained in Corps' reports is critical for evaluation of the occurrence and extent of subsurface soft zones. Section 3 is a summary of the regional geology and specifically addresses the development of the sedimentary section in K Area. A discussion of the depositional environments is presented in Section 3.3. An understanding of these environments provides a general model for interpreting the sedimentary structures in K Area. An interpretation and analysis of how soft zones and underconsolidated sediments form and are interrelated is the final part of the discussion of general geology. The general geology discussion forms the basis for evaluating the site-specific subsurface conditions, which are presented in Section 4. The site specific analysis deals with determining the occurrence, distribution, and extent of subsurface soft zones. Section 5 discusses the relationship of the geology and subsurface soft zones to the development of surface depressions.

2.0 HISTORICAL BACKGROUND

Initial geological work done at the site was performed by the Corps in 1951 and 1952. Their findings are presented in their reports, "Geologic-Engineering Investigations of Savannah River Site, Volumes 1 & 2". This work was the first investigation of the Savannah River Site (SRS), and many of the conclusions and observations made in that report were substantiated by subsequent site explorations. Soft zones were encountered in the subsurface in all areas of the site during the exploratory drilling done by these investigations. Much of the present understanding and concerns associated with soil and foundation stability at SRS is based on the data and conclusions presented in this original study. The conclusions presented in this early report are general in nature and are not necessarily valid for all of the individual facility areas. This early work formed the basis for the initial grouting program (1951-1952), which was designed to increase foundation stability of critical structures.

A large scale grouting program for the K Reactor Area was initiated in 1951 and continued through early 1952. This grouting program is documented in the "Foundations Grouting Operations Savannah River Site" (Corps 1952). That report discusses the field operations and grouting procedures. The Corps kept detailed records on the depths where soft zones and lost circulation were encountered. Subsurface movement of fluids occurred during the grouting operations, as indicated by the occasional venting of water and grout from nearby wells. Records were kept of venting wells and communication between wells and are presented in the grouting report. The records indicate that surface injection pressures used during the grouting program were sufficient to hydrofracture of the formations. The information supplied in the grouting report is used as part of the analysis of the size and distribution of soft zones in the K Area, which is presented in Section 4 of this document.

Between 1952 and the mid 1980s, no site specific work was done in the K Area. In the mid 1980s, soils investigations were done as part of the preconstruction work on the K Area cooling tower by Mueser Rutledge Consulting Engineers. Documentation of those investigations is presented in a series of reports. Additional borings were drilled as part of those soil investigations, and the associated drill logs were examined as part of the work done in the preparation of this document.

A substantial amount of work has recently been and continues to be conducted by the Savannah River Laboratory (SRL). A significant portion of this work has been directed at defining the hydrologic conditions on a regional and site-wide basis. Information on the stratigraphic relationships of the subsurface units and their hydrologic characteristics, compositions, and environments of deposition has been presented by various authors under the direction of SRL. Particularly significant were the continuous whole core samples of the entire sedimentary section from the surface to crystalline bedrock that were obtained in 30 wells at SRS. Detailed descriptions of eight of these cores were reported by Everest Geotech (1985). Recent work by Aadland and Bledsoe (1990) revised the stratigraphic unit designations based on extensive analysis of the subsurface information. This latter work forms the basis for developing a model of the environments of deposition for the subsurface stratigraphic units, which is presented in Section 3 of this document.

Additional K Area site specific work was performed recently as part of the Safety Analysis Report (SAR) for K Reactor restart. This work includes additional exploratory drilling, which was performed by Geotechnical Engineering Inc. (GEI) under the direction of Westinghouse (WSRC) (GEI/WSRC 1991). The work included additional subsurface samples, specialized laboratory analyses, and development of a model to evaluate the soil stability and potential subsidence under seismic stress conditions. The sampling and analyses performed in the study were used to evaluate the subsurface conditions, which are discussed in Section 4 of this document.

The most recent deep investigations performed in the K Reactor area were conducted as part of the 1991 soil subsidence investigation program (WSRC/BSRI, 1991).

3.0 GEOLOGY OF THE K REACTOR SITE

3.1 Introduction

The following discussion presents an integrated analysis of the available geologic and geotechnical data for the immediate area of the K Reactor building. The majority of the subsurface data and geologic descriptions presented in this report are from borings in the immediate area of K Reactor. The interpretation of age and depositional environment in the local area, particularly of the Tobacco Road Formation, differs somewhat from what is described in documents concerning the regional conditions. The objective of the following discussion is to:

- Define the occurrence, distribution, and areal extent of soft zones in the subsurface sediments underlying the K Reactor building. Soft zones are defined in this document as intervals in which water loss or rod drop occurred during drilling. The term, rod drop, refers to the advancement of the drill string under the weight only of the rods or the rods plus the hammer. No open cavities or voids were encountered in any of the deep borings where the drill string fell free.
- Determine the relationship of the development of soft zones to the formation of surface depressions in the K Reactor area.

Data used for the preparation of this discussion were supplied by the persons involved in the soil stabilization and soil subsidence programs in the K Reactor area. Data from the Corps' 1952 grouting reports, previous foundation studies, geologic reports, and personal communication with members of SRL staff also have been incorporated into this discussion. Over five hundred subsurface data points, including borings, grout holes and cone penetrometer tests, are the basis for this analysis of local geologic conditions. The data are considered adequate to develop a model of the subsurface conditions, depositional history, and the stratigraphic relationships of the subsurface units in the immediate area of the K Reactor building.

3.2 Regional Geology

The following discussion presents a brief summary of the regional geology for the Carolina coastal plain southeast of the Fall Line in the immediate area of SRS. This discussion presents only information that is pertinent to the site-specific evaluation of the K Reactor study area. An expanded discussion of the geologic history, stratigraphy and structural development of the region is beyond the scope of this document. As such, certain general statements are made in the following discussions without exhaustive development of the logic and citing of references. Where conclusions are interpreted, they are noted as such.

3.2.1 Stratigraphy and Structural Development

The sedimentary section underlying the Savannah River Site (SRS) is composed predominantly of clastic sediments (sands, silts and clays) deposited in fluctuating coastal plain depositional environments during the Mesozoic and Tertiary periods. The Tertiary sedimentary section overlies crystalline bedrock and sediments of Triassic age. At SRS the Tertiary sediments vary in thickness from 800 feet near the north boundary of SRS to greater than 1000 feet at the southern boundary. The structural relief of the crystalline bedrock in the local area is characterized by Triassic horst and graben structural features.

The Dunbarton Basin is an example of a significant Triassic graben. This Triassic basin underlies the extreme southern portion of the site and extends southwest into Georgia. High-standing blocks of crystalline rock and Trassic sediments form the northwestern perimeter of the basin. One of these large high-standing blocks underlies the C, K, and L areas (see Figure 1, a general site map for place reference). This block influenced the type and distribution of sediments in the local area throughout geologic time. Figure 2 is a contour map of the base of the Cretaceous sediments (Everest 1985), and clearly shows the area affected by the presence of the bedrock horst block. The area overlying this block is interpreted to have remained higher than the surrounding terrain throughout geologic time and is still subtly expressed in the present surface relief. The effect of this block on the deposition of carbonate material in the shallow Santee formation (formerly called the McBean formation) is shown on the regional cross section, Figure 3 (Aadland and Bledsoe 1990). This cross section shows that the thickness and lateral continuity of the carbonate-rich layers of the Santee formation are significantly reduced over the K-Area.

Approximately the lower 60% of the stratigraphic section is composed of sands, silts and clays deposited during the Cretaceous period. Some thin glauconitic sand layers occur in this lower section indicating brief periods of marine influence. The majority of the Cretaceous sediments are interpreted to have been deposited by high energy streams that transported large amounts of clastic sediments from the Appalachian highlands eastward to the coast, which was located approximately 100 miles further to the east than the present coastline (Sheridan/1974). The Cretaceouse sediments are characterized as coarse grained sands and silty sands that were deposited in fluvial to deltaic depositional environments. No carbonate material has been found in this lower portion of the sedimentary section anywhere on site.

Carbonate sediments are present in the shallow Tertiary portion of the section above the Cretaceous formations. The Tertiary sediments are, however, composed predominantly of clastic materials that were deposited in fluvial and/or marine environments. Marine incursions into the area of the SRS occurred during the Tertiary period and had their major influence during the Paleocene and Eocene. The Ellenton, Congaree, Santee (McBean) and Dry Branch (lower portion of the Barnwell group) formations were deposited during intermittent marine incursions. The only significant occurrence of carbonate material is restricted generally to the Santee formation (McBean). A map of the distribution of glauconitic facies in the lowermost Santee formation is presented as Figure 4. Glauconitic sediments are interpreted to indicate intermittent shallow marine conditions. This map also shows the northern limit of the area of predominately carbonate sediments in this portion of the Santee portion of the section. The K Area is located near well P-25 north and west of the area of dominate carbonate deposition as shown on the map (Figure 4).

The sedimentary section above the Ellenton formation is the zone of primary interest in the immediate area of the 105-K building and is described in detail below.

The geologic section examined in detail in this study extends from the surface to a depth of 220 feet. This section represents approximately twenty-five percent of the total sedimentary section above bedrock in the study area. The interval is composed primarily of sands, silty sands, and clays with some minor amount of carbonate in the lower portion of the section studied. These sediments were deposited in fluctuating fluvial, near-shore marine, and estuarine environments during the Tertiary period.

3.2.2 Stratigraphic Nomenclature and Depositional Environments of the Shallow Section

The stratigraphic nomenclature used in this report was established by Aadland and Bledsoe (1990) in their report on the classification of the hydrologic units at the SRS. The stratigraphic unit designations are based on regional correlations and extensive study of the hydrologic characteristics of these units and is shown in Figure 5. The local depositional environments were interpreted from site specific core data and are valid for the immediate K Area.

The type of material present in a formation or stratigraphic unit and the vertical and lateral distribution of materials are controlled by the depositional environment. By examining these relationships, the environment of deposition for each stratigraphic unit can be determined. The stratigraphic formations that are encountered in the upper 220 feet of sediments in the K Area include, in ascending order, the Congaree formation, Santee formation, Dry Branch formation, Tobacco Road formation (the Barnwell Group includes the Dry Branch and Tobacco Road formations) and the Upland Unit. The soft zones in the local area occur in both the Santee formation and the lowermost Dry Branch formation. The vertical and lateral distribution of the soft zones in the lower portion of the Santee formation was controlled at the time of deposition by the configuration of the surface of the underlying Congaree formation.

Congaree Formation

The Congaree formation is composed primarily of clean, well-sorted, fine grained, silica sands. Minor amounts of silty and clayey sands also occur in this formation. Laminar cross bedding is often noted in zones within this section, indicating a low-to-moderate-energy depositional environment. The lack of appreciable silt and clay indicates sustained energy levels and effective winnowing processes. This unit is interpreted to have been deposited in near-shore shallow marine to tidal environments which were receiving a constant supply of clastic materials from the nearby coast. Coastal processes were dominate, resulting in the formation of a laterally continuous sand unit. This unit was deposited probably during a relatively high sea-level stand, corresponding to a lower Eocene eustatic event. As sea level slowly dropped toward middle Eocene time, the surface of the Congaree formation developed as a series of retreating offshore bars. These sand bars paralleled the coast, similarly to the present day barrier islands of the Middle Atlantic States.

Santee Formation

As sea level continued to fall, the environment of deposition in the study area changed. Mixed sands, silts and clays were deposited in low-energy, shallow bay, and estuarine conditions. The Santee formation is composed predominately of silty sands, which are laterally discontinuous and semi-confined by intervening clays and clayey sand units. The configuration of the upper surface of the Congaree formation continued to influence the configuration of the bottoms of the bays and estuaries. Low swales and subtle ridges affected the flow and circulation of water entering the bays through tidal channels and cuts. These conditions (warm shallow water) were conducive to the development of invertebrate fossil communities (bioherms). Oysters and other filter feeding mollusks and brachiopods formed banks and mounds in the back bay areas, where conditions were favorable. Borehole data indicates that the communities of organisms which formed carbonate banks grew in the low swales. These banks correspond to the sediments at a depth of 155 to 170 feet below the surface grade elevation of 270 feet above mean sea level (MSL) in K Area. For further clarification refer to the D-D' cross section Figure 11, which shows the lateral relationships of the biohermal banks in the area of the K1004 and K1005 wells. As sea level began to rise, depositing middle Santee sediments, the bioherms moved up onto the crests of the low ridges. These banks occur at a depth of 135 to 150 feet below the surface. The banks that grew at this level are the best developed in the local area. This environment is similar to the present day Florida Bay conditions.

Bioherms trap fine grained sands and muds between the shelled organisms. As the mounds grow upward and the lower level oysters die, the cemented shells shield the trapped sediments from consolidation. As a result, even after burial, sediments associated with these mounds never become well consolidated and persist as weak or soft zones in the sediments.

The most extensive bioherms in the study area are generally poorly developed, small, and limited in both vertical and lateral extent. Maximum vertical thickness is about 15 feet, and the maximum lateral extent is on the order of 200 feet by 50 feet. In some areas of the site small bioherms may merge to form a larger complex of soft zones and associated underconsolidated sediments (hereafter referred to as a complex).

Sea level is interpreted to have continued to rise slowly during the deposition of the remainder of the Santee formation in the local area. At a depth of approximately 120 feet, another zone is encountered in which poorly developed soft zones occur. This interval probably represents a short duration sea level stand that allowed bioherms to develop, but was too brief to result in significant growth of carbonate banks.

Dry Branch Formation

Coastal marine conditions were reestablished over the study area, following deposition of the Santee formation, resulting in the deposition of the Dry Branch formation. This formation is similar to the Congaree formation in that it is composed of a clean laterally-continuous sand. This sand unit is interpreted to have been deposited in a medium-to-high-energy environment and has never been buried to any appreciable depth (approximately 100 feet in the study area). The result of this shallow burial is that there are zones within the sand that remain underconsolidated. These underconsolidated zones occasionally result in water losses during drilling. These zones occur at a depth of 90 to 110 feet below the surface elevation of 270 feet (MSL) in K Reactor area. Water losses that occurred at this depth during the 1951 grouting program were probably in the Dry Branch formation.

The coastal marine conditions that had been reestablished were, however, of short duration. An apparent rapid and significant drop in relative sea level occurs following deposition of the marine sand unit. This change in relative base level for the area probably corresponds to the contact between the Dry Branch formation and the overlying Tobacco Road formation.

Tobacco Road Formation

The result of the rapid drop in sea level is a significant change in environmental conditions from medium to-high-energy marine to intermittent marginal marine alternating to fluvial conditions. The Tobacco Road formation in the local area was probably deposited in fluctuating marginal marine to fluvial conditions. This formation is composed of interlayered clean, silty, and clayey sands. Clean channel sands in the Tobacco Road formation are laterally discontinuous and frequently semi-confined by intervening clay layers. Some minor biohermal mounds in the lower portion of this unit have been encountered outside the study area. The Tobacco Road formation extends from the surface to a depth of approximately 100 feet over the majority of the site. In portions of the area, the upper section was removed by erosion and infilled with Upland unit sediments.

Upland Unit

The Upland unit is separated from the Tobacco Road formation by an erosional unconformity. Erosion of the upper portion of the Tobacco Road probably occurred as the result of another significant sea-level drop. Relief on this unconformity may be as much as 20 to 30 feet in K Area and has been reported as much as 60 feet on site. As much as 15 feet of the Upland unit may be present in the eastern portion of K Area. The Upland is primarily composed of very fine grained sands with high percentages of fine silts and clays, interbedded with channel lag deposits (coarse sands and gravel). It was deposited in a fluvial/alluvial environment in the erosional lows cut into the surface of the underlying Tobacco Road formation. It is unconsolidated and has never been buried. Thus it is subject to both wind and water erosion. Some local surface depressions develop in this unit possibly as the result of deflation phenomena (wind scour) and fluvial processes. In the local area, this is a possible cause of the subtle surface depressions observed on aerial photographs. The Upland unit, where found in the K Area, extends from the surface to a maximum depth of 20 feet.

3.3 Development of Subsurface Soft Zones

The following discussion is an interpretation of the subsurface data and presents a model that explains the formation of soft zones and fits all of the presently available information.

The development of soft zones and zones in which water losses occur underground is interpreted to result directly from the dissolution of carbonate materials in the Santee formation. Sediments surrounding the zone of dissolution move to fill the created pore space, resulting in underconsolidated layers developing in the overlying sediments. Figure 6 is a diagrammatic sketch showing the development of subsurface soft zones. Figure 6 Panel A shows the development of a bioherm (oyster bank) on a sand bar. The development of the underlying sand bar precedes the formation of a bioherm. Minor amounts of carbonate material are incorporated in the sands. As the conditions for development of biohermal banks improve, the percentage of carbonate materials incorporated in the sands increase. The ultimate development, size, and areal extent of biohermal banks in any local area are directly related to the environmental conditions that existed at the time of deposition. Oysters, like most marine invertebrates, are extremely sensitive to their environment. These organisms thrive only in areas where bottom conditions, currents, and food supplies meet their special requirements. Oysters extract calcium carbonate from sea water and use it to construct their shells. The mounds form by accretion of the shell material and accumulation of sediments in the shell material substrate. Oyster banks will develop in different areas as conditions change. If environmental conditions change radically or rapidly, the oyster banks will die off completely.

After an oyster bank dies or if sedimentation rates in the area increase significantly, the bank will be buried with sediments. Buried shell material is the primary source of the carbonate in the subsurface sediments of the Santee formation. Panel B on Figure 6 shows the burial of an oyster bank with clay, silts, and sands.

Dissolution and reprecipitation of carbonate in sediments can occur any time following burial. Dissolution of carbonate has been described in detail by other authors. The following discussion is based on work done regarding carbonate dissolution processes. Dissolution of carbonate will often occur soon after burial while the shell material is near the surface. This results in mobilization of some carbonate and reprecipitation as calcite cement in the surrounding sediments. Conditions that are most conducive to the dissolution of carbonate occur when the surface sediments are exposed. Under these conditions, plant material becomes incorporated into the near-surface sediments. Infiltrating rainwater containing dissolved carbon dioxide will react with the organic material to form a mild carbonic acid. This acidic water will dissolve the carbonate contained in the underlying sediments. Carbonate material in the vadose (unsaturated) zone will dissolve much more rapidly than carbonate present below the water table. This is because the carbonic acid becomes diluted by the ground water as the saturation of the sediments increases.

Dissolution of shell materials in a buried oyster bank results in the formation of moldic porosity. Panel C, Figure 6 shows the development of moldic porosity. The shell material is dissolved out of the sediments leaving a skeletal matrix behind. Generally, the shell material does not disappear completely; some calcite will be replaced with silica, iron or other minerals by ion exchange. Dissolution of carbonate material in the vadose zone, even under the most favorable conditions, is a very slow process.

The additional porosity does not persist as an open void but becomes filled with fine silts and clays carried by moving ground water. These fine grained sediments are generally unconsolidated and have a high water content. As these processes continue, a soft zone forms and enlarges until the carbonate is removed or reaches chemical equilibrium with the subsurface environment. The soft zones can persist indefinitely if the surrounding sediments are able to bridge the underconsolidated zone effectively.

If the surrounding sediments cannot bridge the soft zone, a collapse will occur. This will result in the overlying sediments slumping downward in response to the collapse, thereby becoming underconsolidated. Overlying underconsolidated zones are noted during drilling as zones of water loss without rod drops.

3.4 Formation of Underconsolidated Layers Associated with Soft Zones

Underconsolidated sedimentary layers are encountered above and below the soft zones in the Santee formation. These layers often correspond to water loss zones encountered during drilling. The underconsolidated sediments are interpreted to have formed by two processes that are directly related to the presence of carbonate material in the subsurface:

First, portions of the clastic sediments that comprise the Santee formation, and particularly the sands immediately underlying the oyster banks, originally contained low percentages of carbonate material in the form of detrital grains and calcite cements at the time of deposition. The presence of a calcite cement in a clastic sediment will tend to prevent the sediments from becoming well consolidated during burial. This phenomena, in conjunction with the ultimate dissolution of the carbonate material from the section, results in underconsolidated sediments forming in the sedimentary section. Dissolution of the soluble material in these clastic units does not result in the formation of significant additional porosity; thus the units are not subject to collapse. Dissolution does, however, remove enough solid material to leave the sediments in an underconsolidated state.

Second, underconsolidated sediments overlying soft zones may develop as the direct result of the dissolution of minor amounts of carbonate contained in the sediments and may also occur as the result of the downward redistribution of the sediments to fill available space created as the result of the collapse of a bioherm. Significant redistribution of sediments occurs contemporaneously with dissolution. Substantial slumping of overlying material occurs only where significant additional pore space has been created by dissolution of carbonates.

Remobilized sediments will occupy a slightly larger volume because of bulking or swelling. The remobilizied sediments will persist in an underconsolidated condition until deeper burial occurs. Thus an appreciable remobilization of the overlying materials would result only if substantial additional pore space had been created.

4.0 SITE SPECIFIC ANALYSIS, K REACTOR AREA SUBSURFACE CONDITIONS

Extensive geological information has been acquired for the K Reactor site. Information on the occurrence, thickness and extent of soft zones in the K Reactor study area is provided by 418 fishtail borings drilled during the 1952 grouting program (CORPS 1952), 30 Standard Penetration Tests (SPT)s conducted during the initial site investigations (CORPS 1951), 14 SPTs and 42 Cone Penetrometer Test soundings (CPT)s completed as part of the GEI investigations (GEI/WSRC 1991) and 19 SPTs and 8 CPTs completed as part of the soil subsidence investigations in the area of the K Reactor (WSRC/BSRI, 1991). Geophysical logs, tomographic survey information, and hydrologic data were also reviewed and incorporated in the following analysis. Information from the drill holes and the geophysical data are more than adequate to establish the occurrence, thickness, and extent of the soft zones and the associated underconsolidated sediments.

Occurrence, Thickness, and Extent of Soft Zones in K Area

Work done for Savannah River Laboratory (SRL) by Aadland and Bledsoe (1990), and Everest (1985) indicates that the K Area is located over a high standing bedrock block and probably has persisted as a high area throughout Tertiary time. As such, the development of conditions which result in the formation of carbonate materials in the K Area are interpreted to have been of short duration. A regional cross section through the K Area shows that the percentage of carbonate material in the K Area is very low, substantially lower than areas to the northeast, and south (refer to Figure 3). Detailed descriptions of the Santee interval in Well P-25, which is located immediately southeast of the K Area, delineate two thin intervals containing carbonate shell material. These intervals occurred at a depth of 136 to 143 feet (refer to Figure 7). These intervals correspond to the primary interval in which soft zones are encountered in the K Area.

Based on the extensive geologic information available in K Area, the occurrence, thickness, and extent of soft zones and associated underconsolidated zones can be determined with good certainty. Deposition of carbonate material was limited apparently to three layers within the Santee interval. These layers occur at depths of 120 to 130, 135 to 150 and 155 to 170 feet below the present surface elevation of 270 feet (MSL). The most well developed bioherms occur in the 135 to 150-foot layer. Figures 8 to 12 are cross sections showing the vertical and lateral stratigraphic relationships of subsurface sediments. Figure 18 shows the plan view locations of the cross section lines.

Direct Indications of Soft Zones

Direct indications of soft zones in this report are considered to be rod drops in borings and low tip pressures and sleeve resistance in CPTs. The term rod drops is used to denote zones in which the drill string advanced under the weight of only the rods or hammer. Relatively few well-developed soft zones, which correspond to rod drops, have been found in the immediate area of the K Reactor building. Rod drops occurred in only eight of the 418 fishtail grout holes drilled by the Corps' 1951-1952 grouting program. Two zones were encountered in two of these eight holes, for a total of 10 soft zones (corresponding to rod drops) identified by this drilling program. Five of the fourteen SPT borings drilled in the GEI/WSRC program encountered intervals in which the drill string advanced with the weight of the rods or hammer. The GEI/WSRC program was specifically targeted at sampling these zones and yet had only a 36% contact ratio. Of the four deep borings drilled in the Soil Subsidence Investigation

Program (WSRC/BSRI, 1991), only one encountered two very thin (18-inch) soft zones in the interval from 145 to 160 feet, in which the drill string progressed under the weight of the rods. The three other deep borings in that 1991 program were drilled specifically to recover samples from soft zones, but they failed to encounter any. In the SPT borings drilled as part of the GEI/WSRC 1991 and the WSRC/BSRI 1991 programs, all of the soft zones encountered were thin and filled with silty and clayey sands.

In these two programs only minor amounts of carbonate shell material was found in the core material from soft zones and associated underconsolidated sediments. The shell material generally had little or no reaction to hydrochloric acid, indicating mineral replacement of the original carbonate material had occurred. The lack of any significant quantity of carbonate in the samples is interpreted to indicate that the dissolution process is essentially complete in the K Area.

No open voids or cavities were encountered in any of the borings. The soft zones that were encountered ranged from 0.5 to 3.0 feet thick. In the GEI/WSRC 1991 program, the two soft zones encountered in SPT Boring K-1003A corresponded to lean clay units, one at a depth of 95 feet in the Dry Branch formation and the other immediately below the Dry Branch sands in the uppermost portion of the Santee formation. Neither of these zones correspond to the interval from which carbonate material was recovered (135 to 150 feet). The other soft zones encountered in the SPT borings generally correspond to the zones in which carbonate materials are intrepreted to have been originally deposited.

A representative soft zone is shown on Figure 13, which is a copy of a portion of the SPT Boring K-1005. In this zone the drill string advanced under the weight of the hammer from a depth of 117 to 119 feet. This interval overlies a section (120 to 130 feet) composed primarily of sands, silty sands, and clay in which calcareous shell fragments and cemented particles were recovered. The soft zone in this boring is three feet thick, extending from a depth of 117.5 to 120.5 feet. Below this soft zone is an eight-foot thick section of silty sand that is underconsolidated, as indicated by the low dry density (Table 1) and low tip pressure and sleeve resistance as recorded on the CPT KC-8 (located approximately six feet north of the boring, see Figure 13). This is interpreted to be a typical profile of a soft zone with associated underconsolidated sediments. The zone from 117.5 to 120.5 feet probably had a significant amount of solid material removed by dissolution. This zone most probably corresponds to the original oyster mound. In other areas shell materials have been preserved in similar depositional settings. The underlying silty sand layer is interpreted to correspond to the sand substratum that contained a lower percentage of carbonate material at the time of deposition and persists as an underconsolidated interval. The total thickness of this complex is approximately 11 feet.

Void ratios were calculated based on dry densities reported on Table 1. In the upper (top three feet) portion of the interval corresponding to the low tip pressure and sleeve-resistance values, void ratios are in the range of 1.85 to 2.55. In the lower portion of the zone corresponding to the underconsolidated silty sand section, void ratios ranged from 0.91 to 2.01 with the mean value of 1.38. Conservative estimates indicate that the amount of additional porosity in these intervals probably resulting from dissolution of carbonate is in the range of 30% for the upper soft zone and 10 to 15% in the underconsolidated silty sand section. In all cases the soft zones were partially filled with fine grained materials. No voids or cavities were found in any of the borings in the K Reactor study area.

TABLE 1
LABORATORY TEST SUMMARY

Boring No.	Sample No.	Test No.	Top Depth of Specimen (Elev.)	ASTM Symbol	Dry Unit Weight in tube pcf	Dry Unit Weight in situ pcf	% Fines	Water Content in tube	Void Ratios	Porosities
K1005	FP4A	C7	119.6 (150.0)	SC	18.0	47.7	47.8	92.4	2.55	71.8%
	FP4B	UW8	119.8 (149.8)	SC	34.6	49.7	49.8	86.5	2.41	70.8%
	FP4D	C2	120.5 (149.1)	SC	27.0	59.6	59.4	64.6	1.85	64.9%
	FP5A	UW1	120.9 (148.7)	SC	33.5	78.6	72.5	41.2	1.25	55.5%
	FP5B	UW2	121.6 (148.0)	SP-SC	-	71.5	65.9	47.7	1.47	59.5%
	FP5C	UW3	122.2 (147.4)	SC	26.2	58.7	54.1	68.7	2.01	66.8%
	FP7A	RC2	125.0 (144.6)	SW-SC	10.7	73.3	72.5	40.0	1.33	57.1%
	FP7C	C6	125.8 (143.8)	SC-CH	50.5	62.3	61.6	57.0	1.74	63.5%
	FP7D	C3	126.4 (143.2)	SC	15.4	75.8	75.0	37.6	1.25	55.5%
	FP8A	UW4	128.2 (141.4)	SP-SC	-	80.6	85.4	36.7	1.05	51.2%
	FP8B	UW5	128.7 (140.9)	SC	-	86.6	91.7	33.5	.0.91	47.6%

According to the direct drilling indicators described above, soft zones occur sporadically at three depth intervals throughout the study area. Individual soft zones are apparently small, thin, and limited in lateral extent. Commonly, soft zones encountered in a boring will be absent in offset locations as near as 25 feet away. Closely spaced CPT soundings performed by GEI indicated that rapid lateral changes can occur within five feet from borings. The data show the soft zones are poorly interconnected and limited in their distribution and extent.

Indirect Indications of Soft Zones and Underconsolidated Sediments

Water losses may occur in consolidated semi-confined sediments in which pore pressures are slightly below normal, such as in clay zones with high void ratios or in soft zones that developed as the result of carbonate dissolution. Depending on the applied fluid pressures, water losses are expected in poorly consolidated sediments like those underlying the K Reactor area. Water losses may also occur along zones of weakness whenever the fluid pressure in the well bore exceeds the confining pressure of the sediments.

SPT borings are drilled with mud and a positive surface pressure. Surface pressures in this type of a drilling operation are generally low, 20-25 psi. Fluid losses do occur during drilling of SPT borings at these low surface pressures. This is due to bottom hole pressures exceeding the effective vertical stress. The calculated effective vertical stress at the level of the soft zones is 3,800 pcf* (GEI/WSRC 1991). Assuming a pump pressure of only 20 psi, the net effective bottom hole pressure at the depth of the soft zones would be approximately 6,700 psf, which is significantly higher than the effective vertical stress. By exceeding the vertical stress, hydrofracturing of the section likely would occur.

Significant water losses occurred in 52 of the 418 grout holes drilled in the Corps' 1951-1952 grouting program (11% of the total number of holes drilled). These holes were drilled using a tricone bit and drilling fluid injected into the drill string. Present drilling operations have recorded surface pressures as high as 70 to 100 psi. We assume that the 1951-1952 program was performed in a similar fashion. At these drilling pressures the bottom hole pressure would

* Surface pressures are reported in pounds per square inch (psi). The calculated bottom hole pressures are taken from the GEI/WSRC 1991 report in which pressures are given in pounds per square foot.

be significantly in excess of 7,000 psf, which is quite adequate to hydrofracture the surrounding formation.

Grout injection will also have a tendency to initiate hydrofracturing of the sedimentary section. The calculated effective grout pressure at the depth of the soft zones, based on information from the Corps' 1952 grouting report, was about 14,400 psf. This calculation assumes a grout pressure of 40 psi at the ground surface (surface pressures actually ranged up to 100 psi), a total weight of 109 pcf for the grout, and a ground water depth of 40 feet. (Ground water in the study area is at a depth of 60-65 feet. However, the computed bottom hole pressures would not be significantly changed by this difference in ground water levels.)

As stated above the effective vertical pressure in the soft zone averages 3800 psf, therefore the computed bottom hole grout pressure is approximately 3.8 times the effective average vertical stress.

In borings drilled in the study area, water losses occurred generally at depths of 100 feet or more, which corresponds to the Dry Branch and Santee formations. Once fluid losses started, they generally continued until the hole was completed. This continued loss of water and cuttings is interpreted to indicate that hydrofracturing of the formation had commenced and then continued throughout drilling of the hole. Hydrofracturing in soft sediments occurs generally along planes of weakness, such as bedding surfaces and depositional boundaries, and will propagate laterally until injection pressures are reduced or neutralized by formation pressures. Zones in which water losses commenced in the 1951-1952 grout program appear to correspond to depths at which soft zones occur. Initial hydrofracturing probably started in the soft zones or the associated underconsolidated sediments. Since hydrofracturing occurs with the application of significant and continued pressure, the fracture zone can extend well beyond the boundaries of the soft zone. Therefore, the volume of lost fluids does not accurately represent the amount of additional pore space or extent of the underconsolidated sediments. Figure 14 is a diagrammatic sketch showing the relationships of the soft zones and underconsolidated sediments to created hydrofractures.

Hydrofractures induced by grouting will exhibit the same behavior as those induced by the drilling fluids as just described above. The grout-induced hydrofractures will most probably initiate in a soft zone or a zone of underconsolidated sediments. The hydrofractures will, however, continue to propagate beyond the boundaries of the soft zones in thin lenses or fingers of grout material along bedding surfaces and depositional boundaries. The observation by the Corps that grout vented from nearby borings when grout was being injected in a given boring is, therefore, not a direct indication of either the interconnectedness or the volume of a soft zone. The fact that grout behaves in this fashion is evident clearly in the geologic descriptions from Boring K-1008B. In the interval from 130 to 145 feet in this boring, three lenses or seams of grout were recovered in the split spoon and core samples. A 33 cm (13 inches) seam of grout material was recovered at a depth of 130 to 132 feet in sample SS20, a 50.8 cm (20 inches) thick grout seam was recovered in the 134-foot core sample C2, and a 28.0 cm (11 inches) seam was recorded in core sample C3 at a depth of 139 feet. The presence of these seams at these levels indicates that the grout initiated hydrofractures immediately above the soft zone and they propagated for considerable distances along horizontal bedding surfaces.

The above discussion leads to the conclusion that while significant quantities of grout were injected into the sediments, a substantial quantity of the grout resides probably in thin seams. Thus, the volume of grout-take in a boring is not a reliable indicator of the extent of a soft zone.

Extent of Magnitude of Soft Zones and Associated Underconsolidated Sediment Complexes

Using the direct (rod drops) and indirect (water loss) indicators of soft zones, the complexes can be determined. The best statistical basis for this analysis is provided by the map produced during the initial 1951-1952 grouting program. A generalized redrafted version of this map (Figure 15) shows the distribution of the grout holes in the K Reactor building area. Rod drops, water loss zones, and grout-takes are recorded on a large format version of this map (Figure 16). Five significant areas of grout takes are shown on Figure 15: two south of the 105-K building, one under the east wall of the building, and one northeast of the building. A fifth area underlies the north end of the 190-K building located east of the reactor building. These five areas are referred to in the following discussion as large complexes A, B, C, D, and E respectively (refer to Figure 15).

The most obvious characteristic of this map (Figure 15) is that the vast majority of the borings did not take grout. Of the 418 borings drilled, 91 took grout (22%). Direct and indirect indications of soft zones and underconsolidated sediments occur in 52 holes. Of these 52 holes, fluid losses commenced at shallow levels (100-foot depths or above) in seven holes. These depths correspond to clay units in the Dry Branch and lowermost Tobacco Road formations and are not indicators of soft zone complexes. These intervals most probably correspond to isolated semi-confined units that had below normal pore pressures.

Water losses commenced at deep levels (170 feet and below) in two holes, corresponding to the upper Congaree formation. These zones are also probably not associated with soft zone complexes. The remaining 43 grout holes represents approximately 10% of the total number drilled in this program. These 43 grout holes are assumed to be associated with soft zones at the levels where water losses commenced.

Close examination of the five large complexes illustrates the sporadic occurrence and distribution of the soft zones. A detail of the large Complex A immediately south of the K-105 reactor building is presented as Figure 17. This Figure is a copy of a portion of a detail map for the reactor building site and was taken directly from the Corps' 1952 grout report. Complex A extends from Row K on the east to Row R on the west and from Row 22 on the north to 28 on the south. This is an area 175 feet by 150 feet. The borings in this area are on a 25-foot offset as the result of infill drilling of the original program. Indications of soft zones were encountered in 11 borings. There are apparently two separate small soft zone complexes in this area. One is defined by the five borings M-23, N-24, O-25, P-26, and Q-27 (referred to herein as M-23), the other by borings O-23, P-23, P-24, Q-23, Q-24 and R-24 (referred to herein as O-23).

The M-23 complex (Figure 17) shows a clear southwest orientation. Borings offset from this complex, both to the southeast and to the northwest, had no indication of soft zones. The M-23 complex is approximately 200 feet long and less than 50 feet wide*. The main soft zone in this complex is at a depth of 140 to 155 feet, as indicated by the first losses of drilling fluids in borings M-23, P-26, and Q-27 and second zone of mud losses in N-24. Mud losses were also encountered at shallower depths (87 and 96 feet) in borings M-24 and O-25 respectively. These depths correspond to thin clay intervals in the Dry Branch formation. These clay intervals were encountered in Boring K10008B (refer to copy of log included for reference).

* There are no SPT borings through this complex or the O-23 complex, so thickness of the zones has not been determined. These soft zones are interpreted to be similar to the one encountered in boring K-1005 (refer to discussion on page 5). Fifteen feet in total thickness, five as soft zone and ten as unconsolidated sediments.

The O-23 complex (Figure 17) shows the same northeast to southwest orientation as M-23. O-23 is approximately 140 feet long and 60 feet wide. The soft zone in the O- 23 complex is slightly deeper than the M-23 soft zone (147 to 155 feet). There are no indications of shallower underconsolidated sediments associated with either the M-23 or the O-23 complex. Stratigraphic relationships indicate that the O-23 complex is slightly older than the M-23 complex and is offset to the northeast. The O-23 feature probably developed on the northwest flank of the underlying sand bar, the M-23 complex appears to have developed slightly later on the crest of the sand bar.

The same characteristics of small discontinuous soft zones are apparent in a detailed examination of the large Complex C located to the northeast of large Complex A (Figure 17). There is an elongated narrow alignment of borings that has the same well defined southwest trend as the M-23 complex. And there are two small groups of borings that occur in the flank position. Complexes A, C, and probably E are aligned to the southwest and are probably associated with the same underlying sand bar. The configuration of the depositional surfaces is expressed upward through the section as the result of differential compaction of the sediments. As such, a strong southwest trend is clearly expressed in the surface of the Dry Branch formation (see Figure 18). These three complexes (A, C and E) form a very obvious trend that has the same orientation as the isolated soft zones, eg. M-23. The other large complexes (B and D) probably are associated with similar trends. These secondary trends are not as well defined by the subsurface penetrations in the area.

The large Complex B is poorly developed, only two borings in this area had indications of soft zones and no clear orientation is apparent. Large Complex D to the northeast of the 105 building had nine wells with indications of a soft zone. The soft zone in Complex D is developed at a depth of 130 to 140 feet. This complex shows a slight southwesterly trend paralleling the A and C complexes.

The large Complex E located under the north end of the 190-K building also is poorly developed. The soft zone in this complex also formed at the shallower level, and no strong trends are observed. Stratigraphic relationships indicate that Complex E probably is associated with the same trend as the A and C complexes but developed later in less favorable conditions.

Conclusions Regarding Occurrence, Thickness and Extent of the Soft Zones and Associated Underconsolidated Sediments

The following conclusions are based on the preceding discussions.

- Soft zones underlying the K Reactor building occur primarily in three intervals of the Santee formation. These intervals are at depths of 120 to 130, 135 to 150, and 155 to 170 feet below the present surface grade of 270 feet (MSL).
- Soft zones are distributed sporadically along three southwest trends. Direct indications of soft zones are encountered in approximately 10% of the deep penetrations in the study area.
- The most well developed soft zone complexes are approximately 15 feet thick composed of an upper soft zone 3 to 5 feet in thickness having porosities in the range of 65-75% (void ratios of 1.85-3.0), and a lower zone of underconsolidated silty sands 8 to 10 feet thick having porosities in the range of 50-65% (void ratios of 1.00-1.85) as shown on Figure 13, which is interpreted as a typical soft spot at K Reactor site.
- The areal extent of the most well developed soft zone is approximately 200 feet long by 50 feet wide and exhibits a strong southwest orientation.
- Soft zones in the K Reactor area are poorly developed, limited in size and areal extent, and poorly interconnected.

5.0 RELATIONSHIP OF SURFACE DEPRESSIONS TO SUBSURFACE SOFT ZONES

In order for a surface depression to form as the result of dissolution and collapse of a carbonate-rich layer, the sediments in the entire column above the collapse zone must be remobilized by slumping downward to compensate for the additional porosity created by dissolution. This situation has not been documented as occurring in association with isolated carbonate deposits (bioherms) anywhere on SRS. This remobilization initially results in the overlying sediments becoming underconsolidated. Remobilized sediments will persist in an underconsolidated state until either additional material is introduced into the formation by movement of ground water or the section becomes more deeply buried as the result of deposition at the surface. For a surface depression to form, this downward slumping and recompaction process must occur progressively upward through the sedimentary section.

In the study area there is no evidence to indicate that underconsolidated sediments occur above the level of the Dry Branch formation (approximately 90 feet subsurface). No significant zones of water losses were encountered in the Tobacco Road formation in any of the borings drilled in the study area. There is no evidence to indicate that slumping has occurred in the sediments of the Tobacco Road section. Thus, it can be concluded that there is no relationship between any of the surface depressions in the study area and the subsurface soft zones.

Four SPT borings were drilled in the area of the 920K Fan Room to determine if deep subsidence was occurring. Two thin (eighteen-inch) soft zones were encountered in boring SPT-1 at a depth of 145 and 155 feet. Three offset borings were drilled to comparable depths to recover samples from this soft zone. No soft zones were encountered in these borings, indicating that the soft zones are small and limited in their areal extent. One grout hole in the area (V-18 drilled in the Corps' 1951-1952 program) lost drilling fluid at a depth of 155 feet. This grout hole continued to lose mud to total depth, indicating that hydrofracturing was probably occurring during drilling.

None of the other grout holes drilled in this area encountered soft zones or water losses, further indicating the small discontinuous character of the soft zones in this local area. No underconsolidated sediments were encountered above the 145-foot level in any boring in the local area. No disruptions of marker horizons were observed in the local area. All of the evidence indicates that no subsurface remobilization of sediments has or is presently occurring. Thus, there is no connection between the surface depression in the area of the 920 K Fan Room and subsurface conditions (cross section E-E' Figure 12). The line location is shown on Figure 18, the 920 fan room is located near the SPT-1 location.

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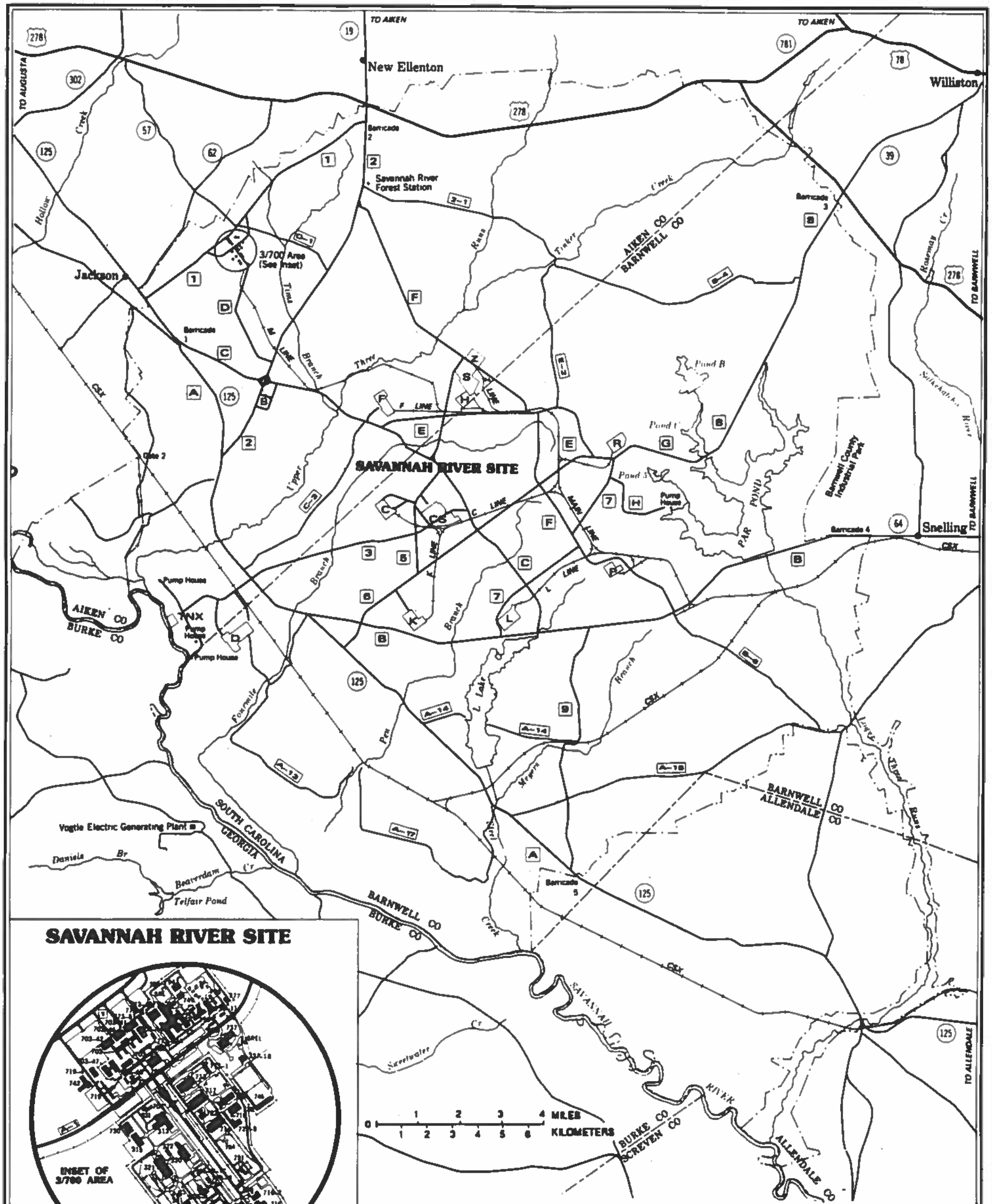


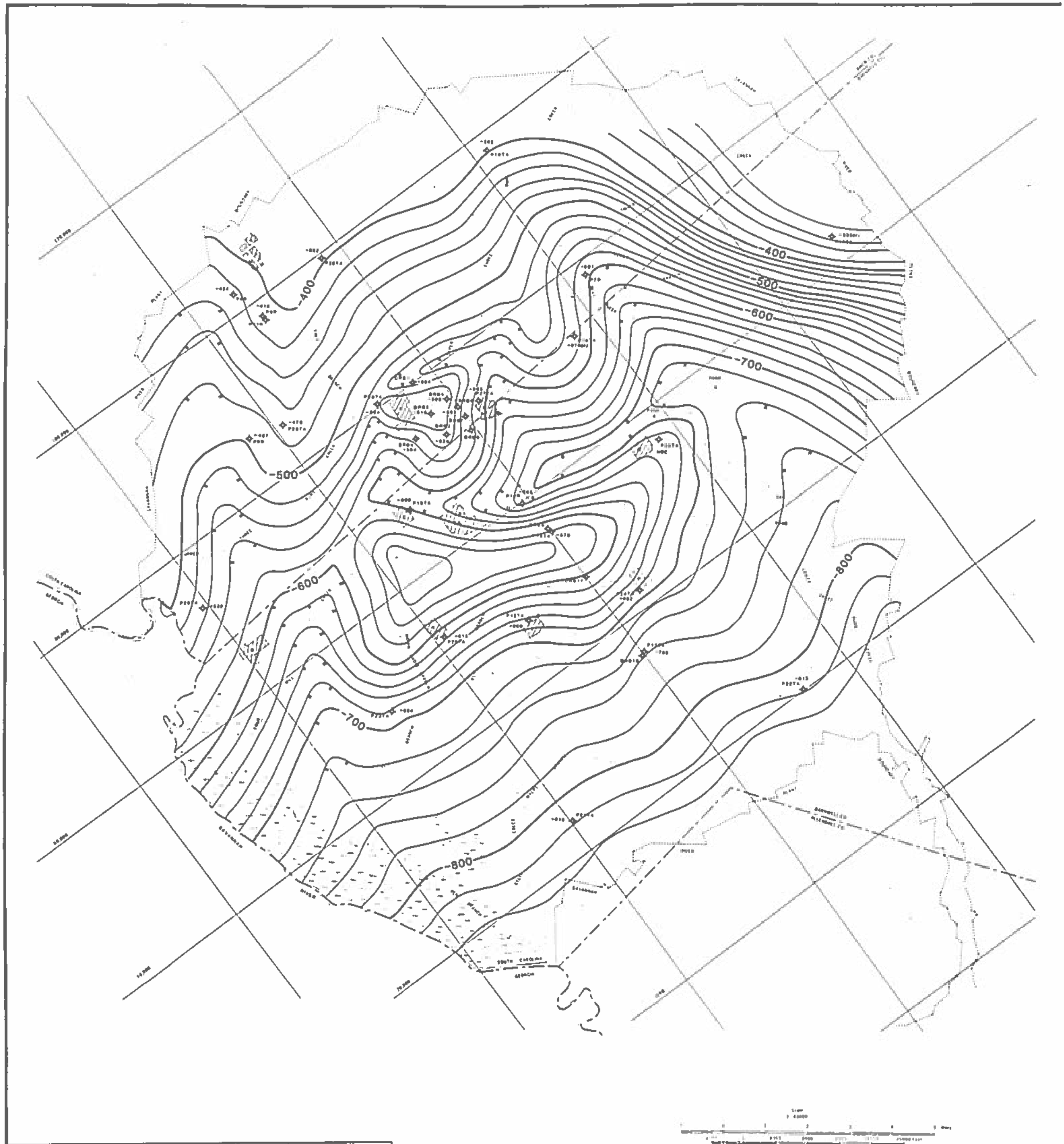
SRS SAVANNAH RIVER SITE

SITE MAP

NOVEMBER 1991

INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

FIGURE 1

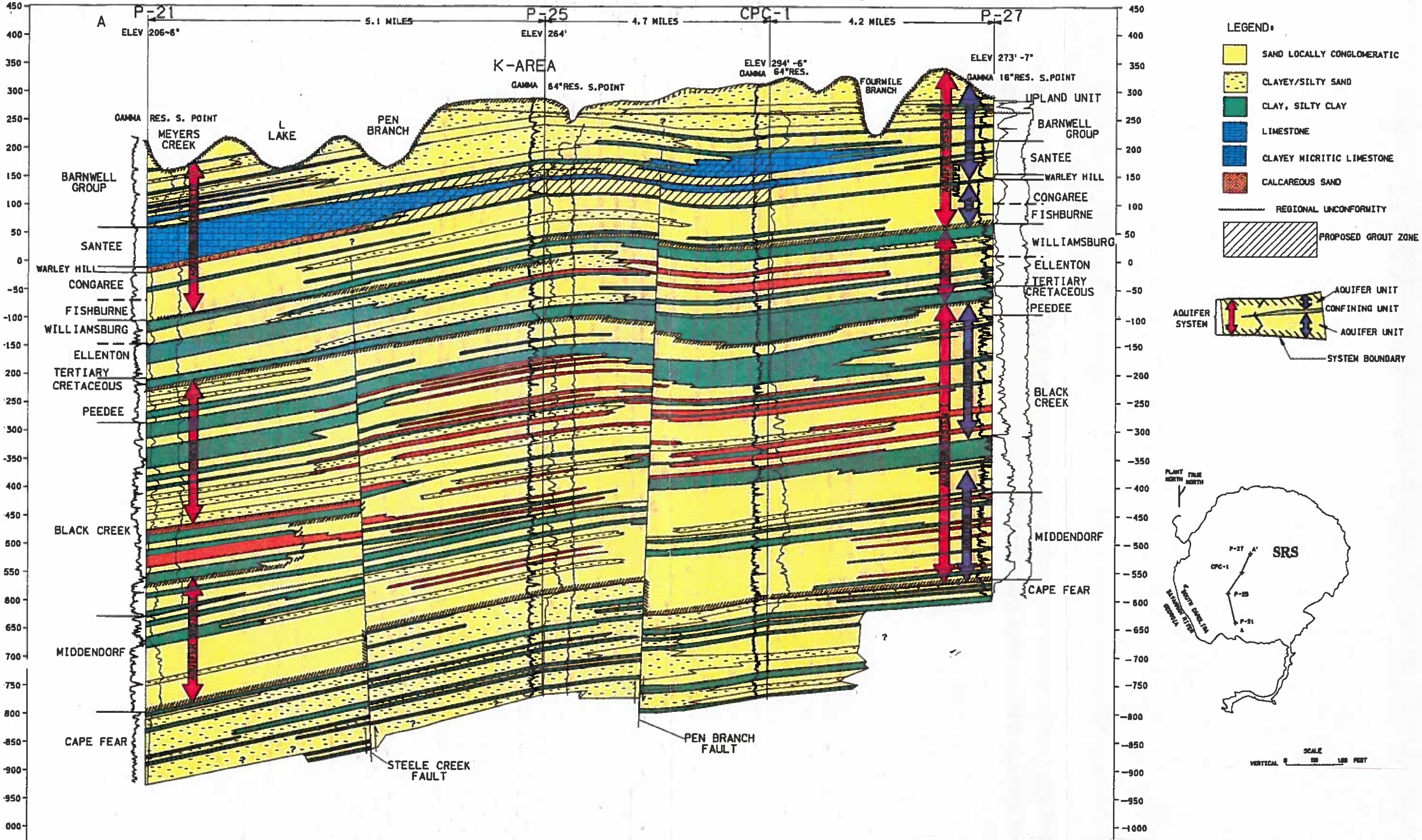


SRS

STRUCTURAL CONTOUR BASE OF CRETACEOUS SEDIMENTS	NOVEMBER 1991
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 2

TAKEN FROM EVEREST GEOTECH (1985)

GENERAL GEOLOGIC CROSS-SECTION K AREA



Source: see text, Aadland and Bledsoe (1990)

SRS SAVANNAH RIVER SITE	REGIONAL GEOLOGIC CROSS SECTION OF K AREA	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 3

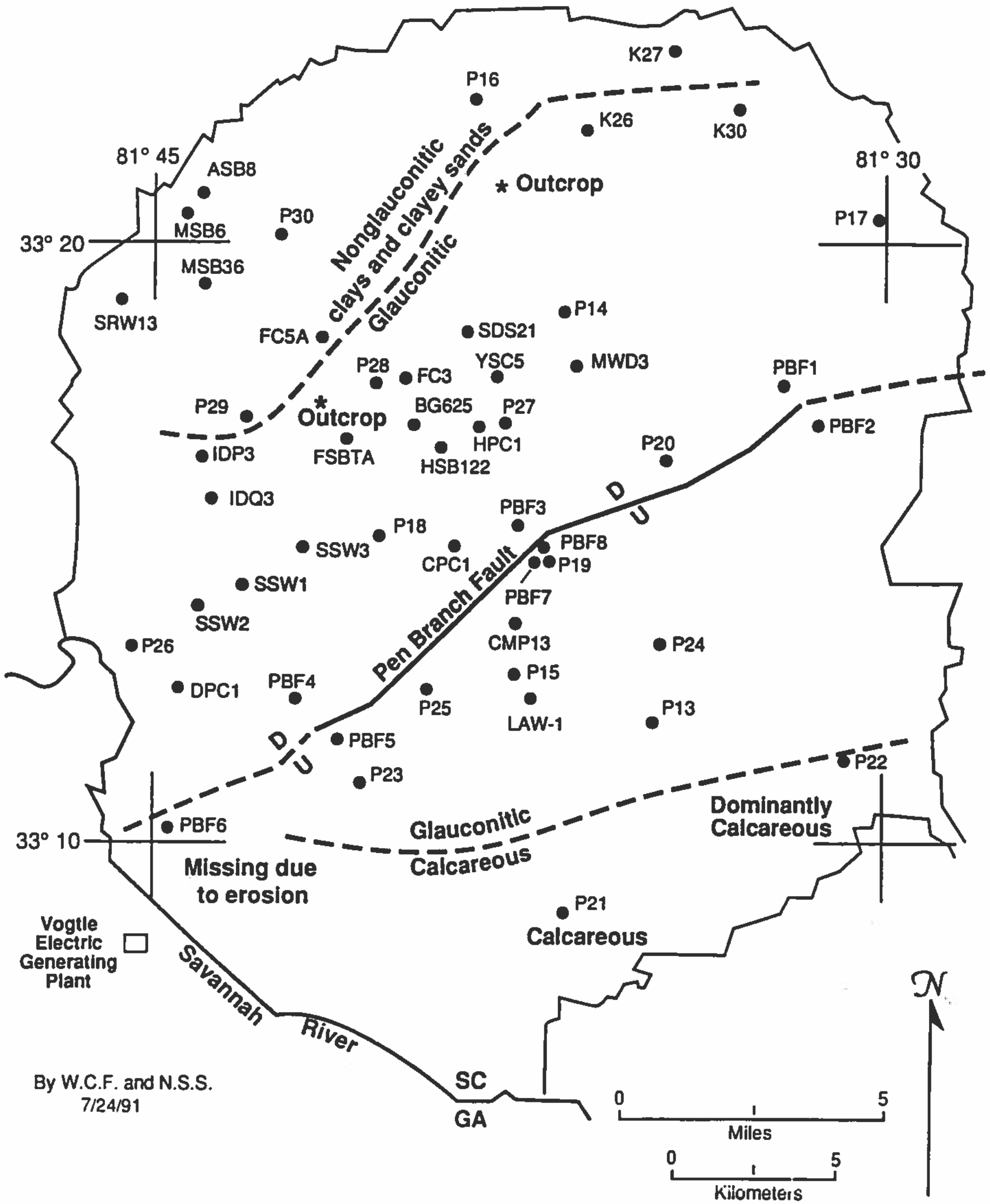
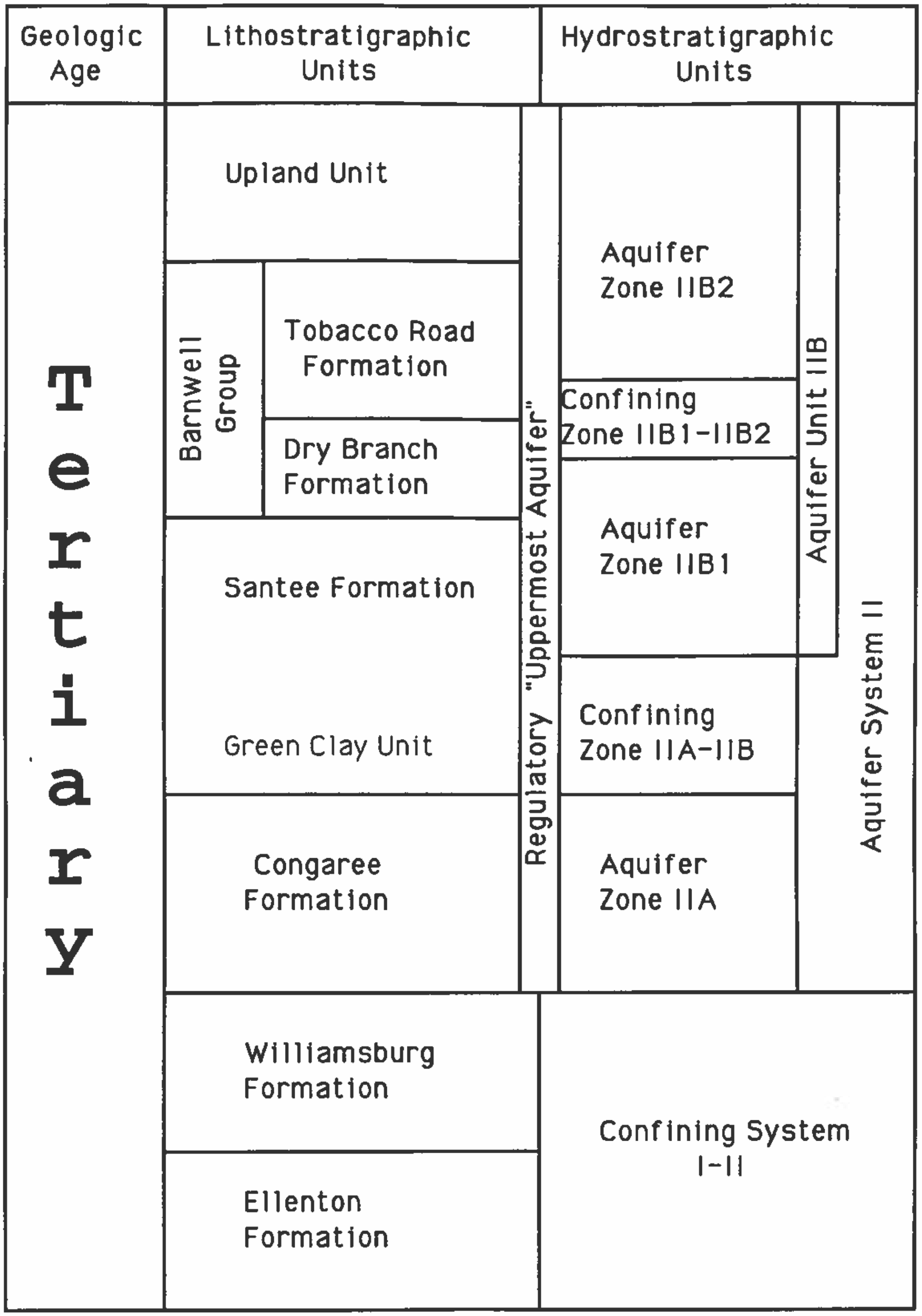


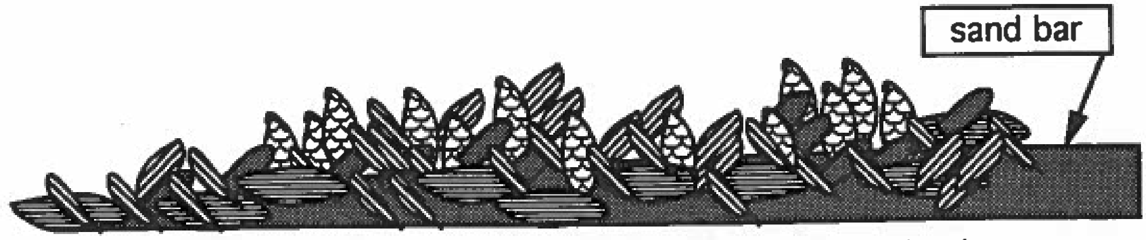
Figure XX. Maps s howing the updip and downdip limits of the glauconitic facies in the "green clay" interval at SRS. Data on wells K26, K27 and K30 are from Steele (1985). Wells P16, PBF2, PBF6 and SSW1, 2 and 3 are from the present investigation. The remaining well data is based on written communications by M.K. Harris (1988-1990) compiled by Fallaw (written communication,1991). The outcrop data are based on field work by Snipes assisted by Fallaw, Price and Kegley.

SRS	DISTRIBUTION OF MARINE SEDIMENTS	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 4

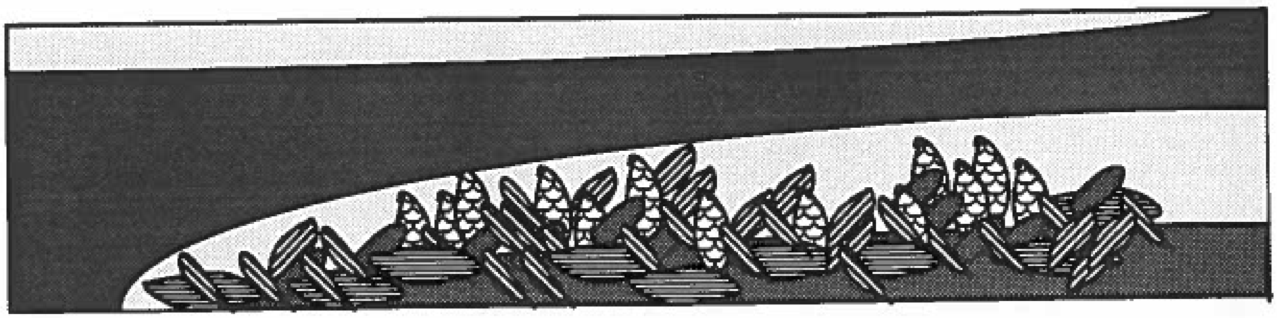


Source: see text, Aadland and Bledsoe (1990)

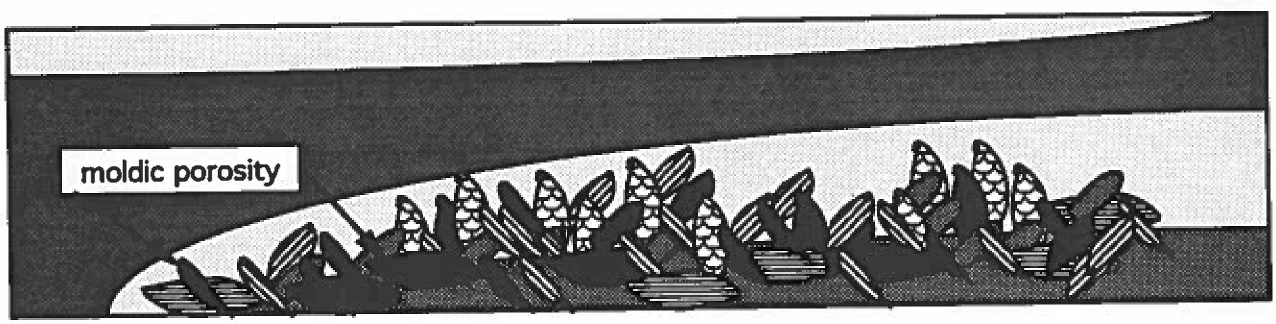
SRS	HYDROSTRATIGRAPHIC AND LITHOSTRATIGRAPHIC NOMENCLATURE	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 5



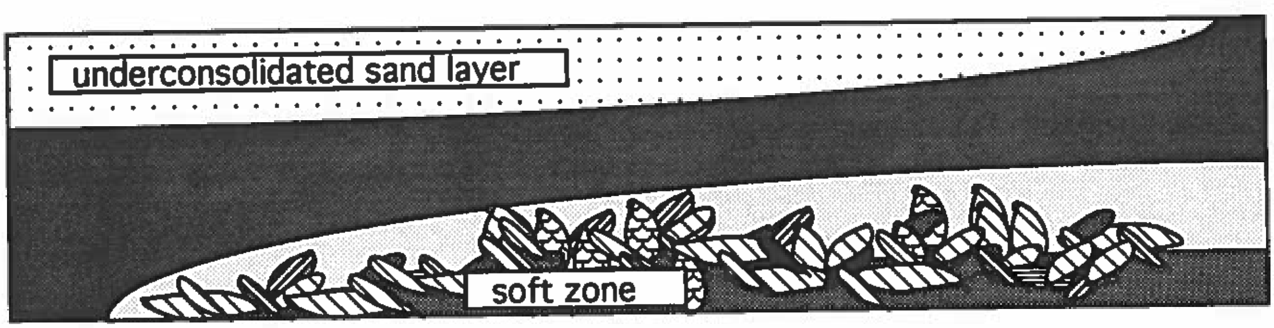
A Deposition of carbonate by development of oyster banks



B Burial of the abandoned banks with sand and clay



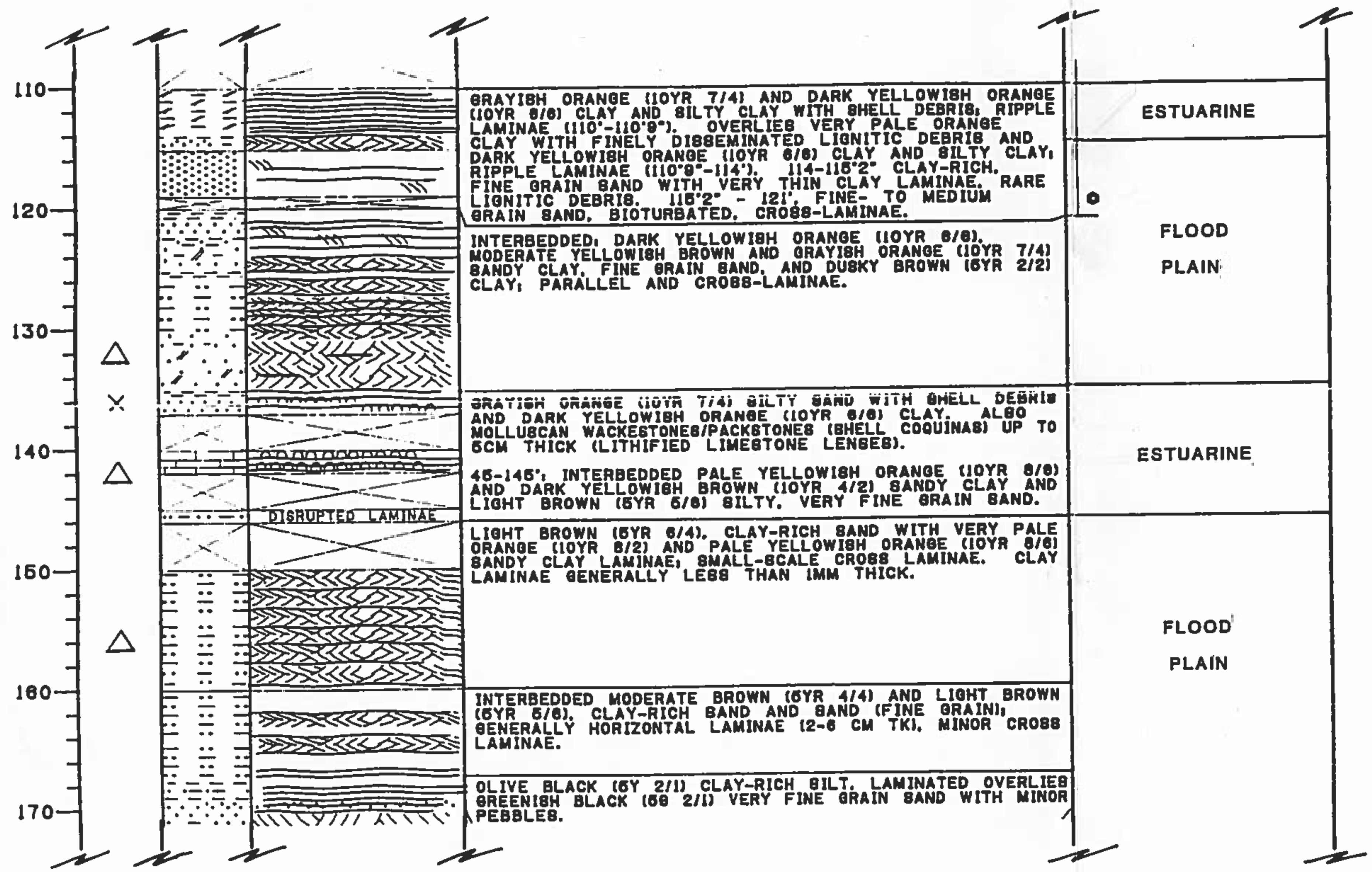
C Partial dissolution of carbonate

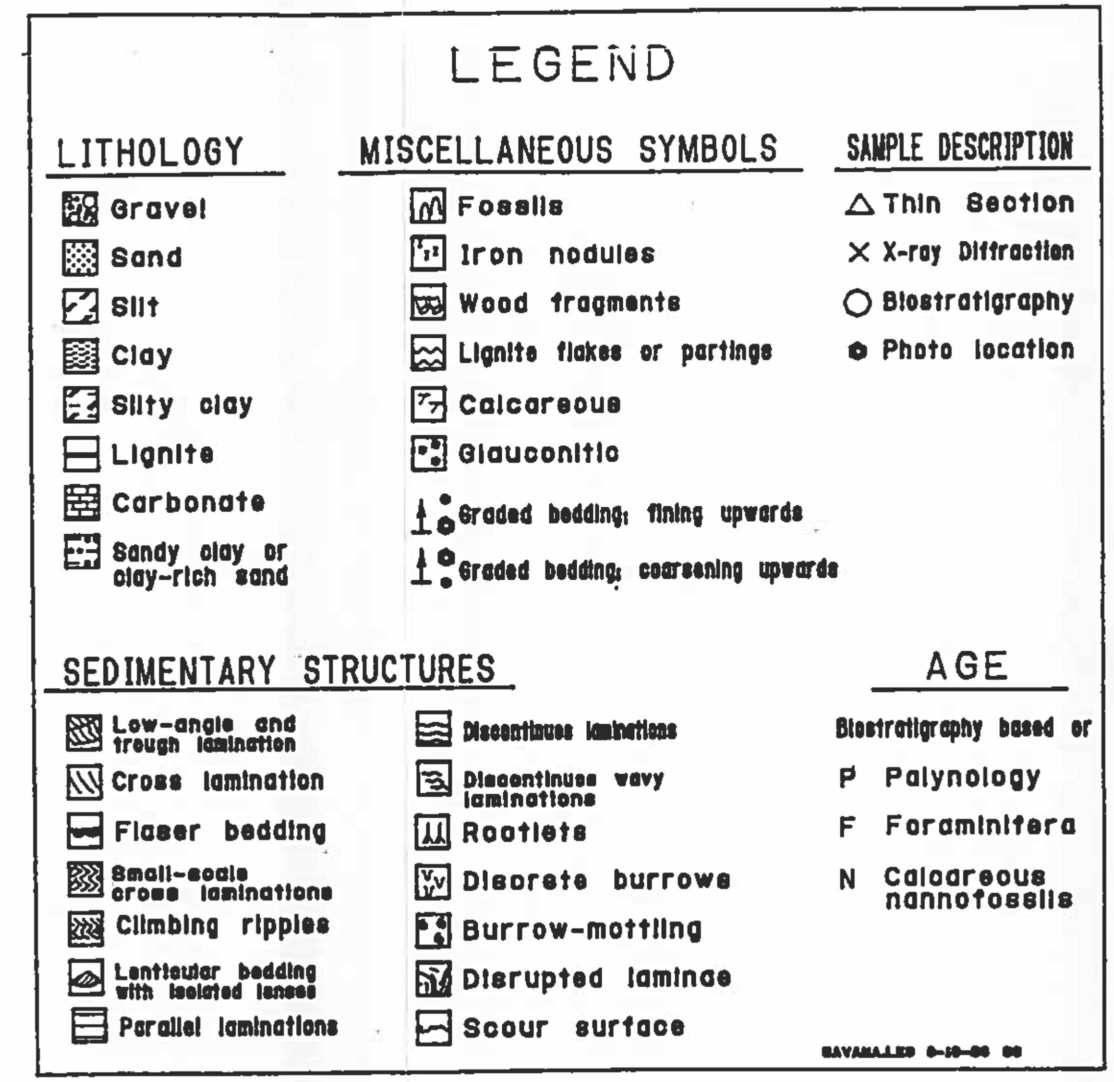


D Filling of moldic porosity with silts and partial collapse of the mound resulting in the formation of a soft zone.

Diagramatic sketch

SRS	DEVELOPMENT OF SUBSURFACE SOFT ZONES	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 6

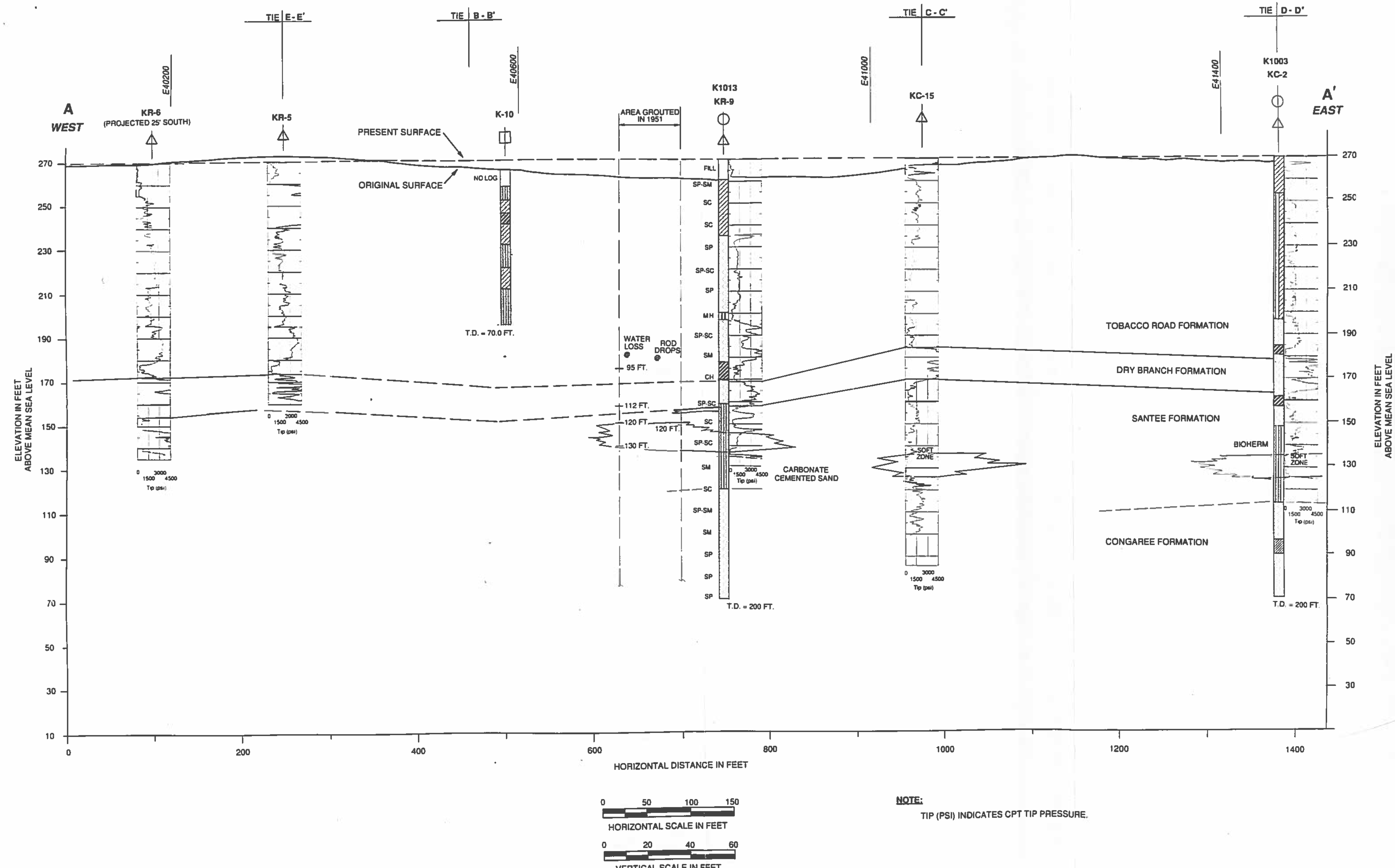




TAKEN FROM: EVEREST GEOTECH (1985)

SRS SAVANNAH RIVER SITE	DETAIL DESCRIPTION OF CARBONATE ZONE LOG OF P25-TA	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 7

SIZE D 22 X 34



NOTE:

TIP (PSI) INDICATES CPT TIP PRESSURE.

SRS

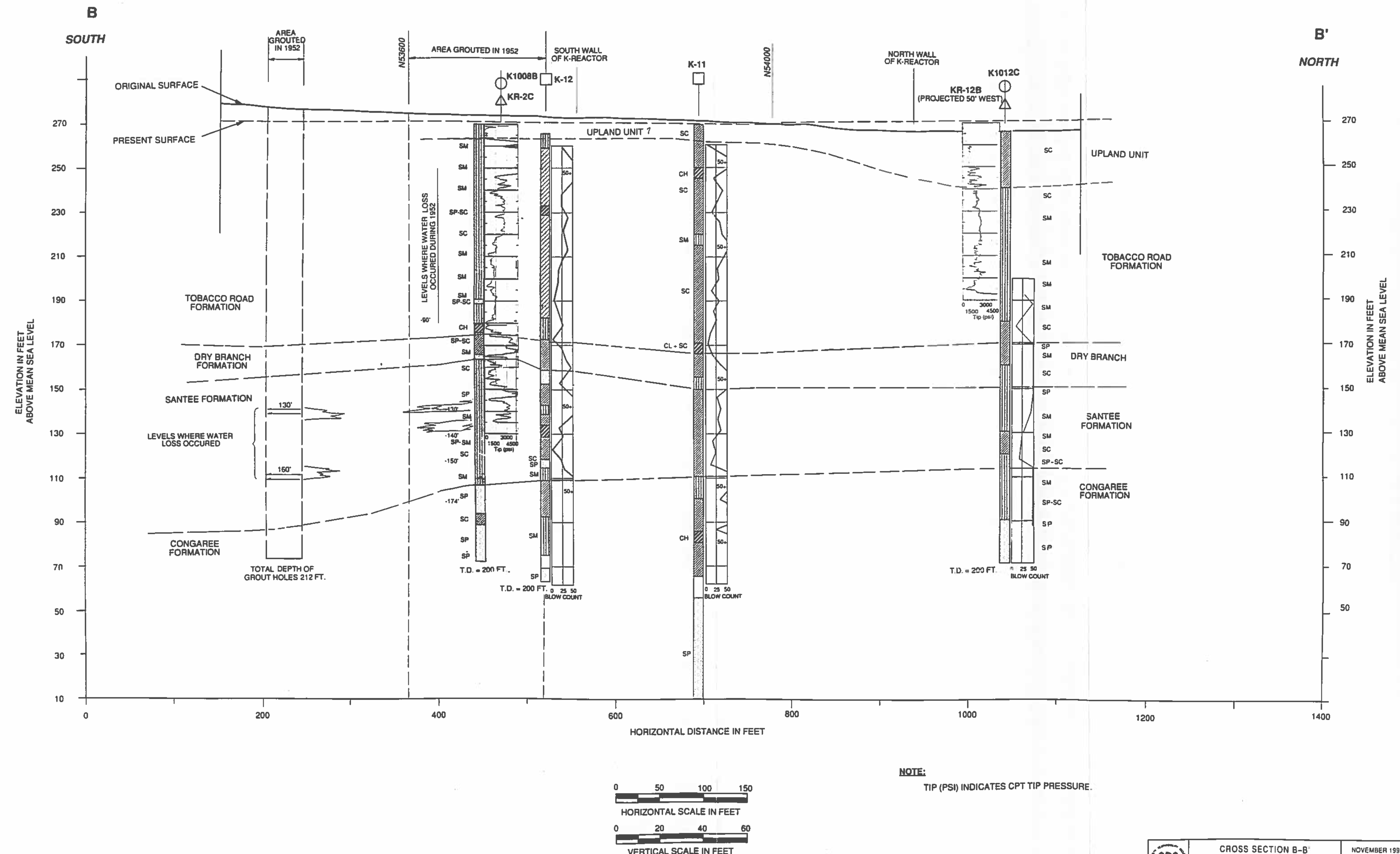
CROSS SECTION A–A'

INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

NOVEMBER 1991

FIGURE 8

SIZE D 22 X 34



NOTE:

TIP (PSI) INDICATES CPT TIP PRESSURE.

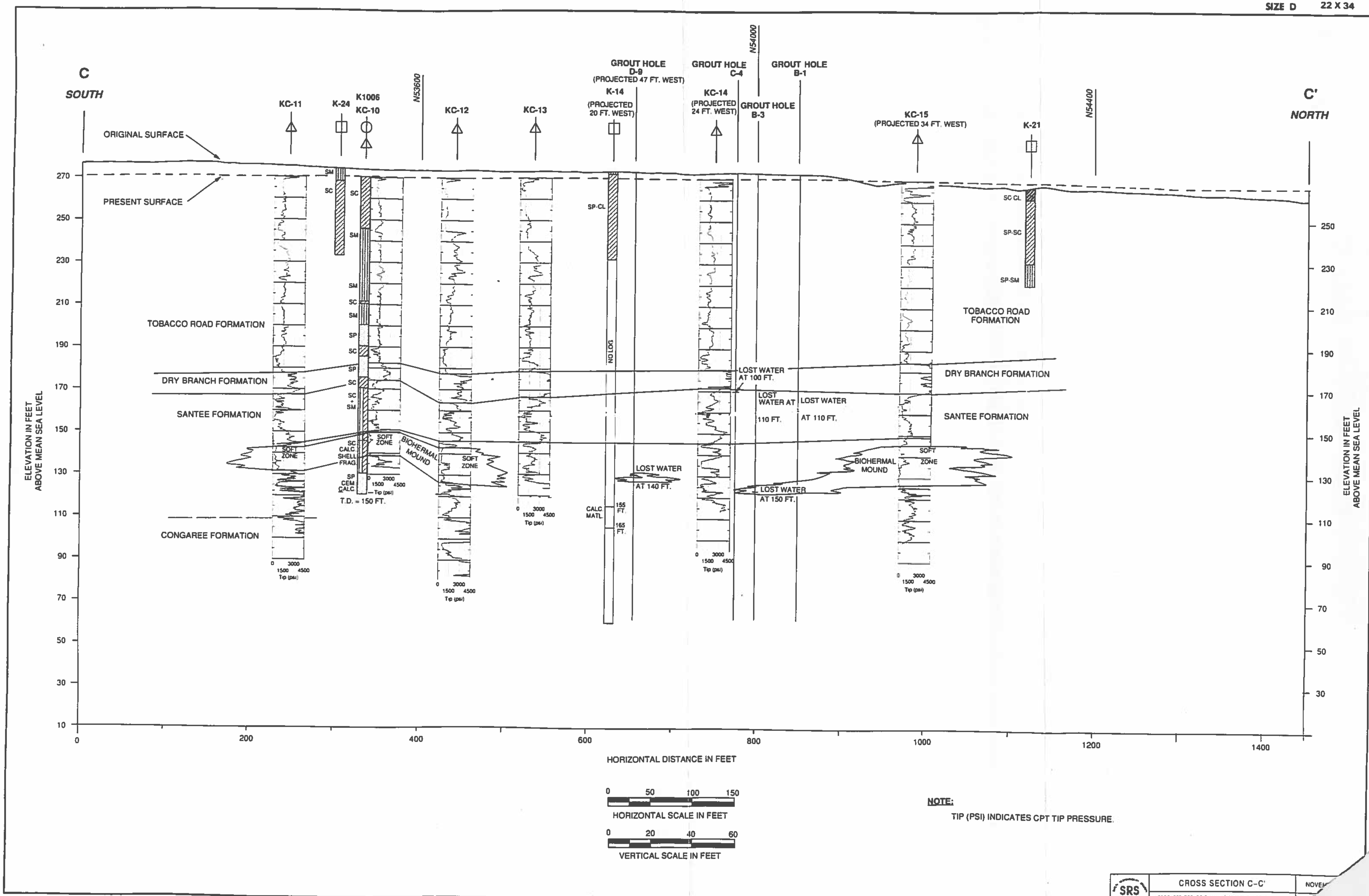
SRS

CROSS SECTION B-B'

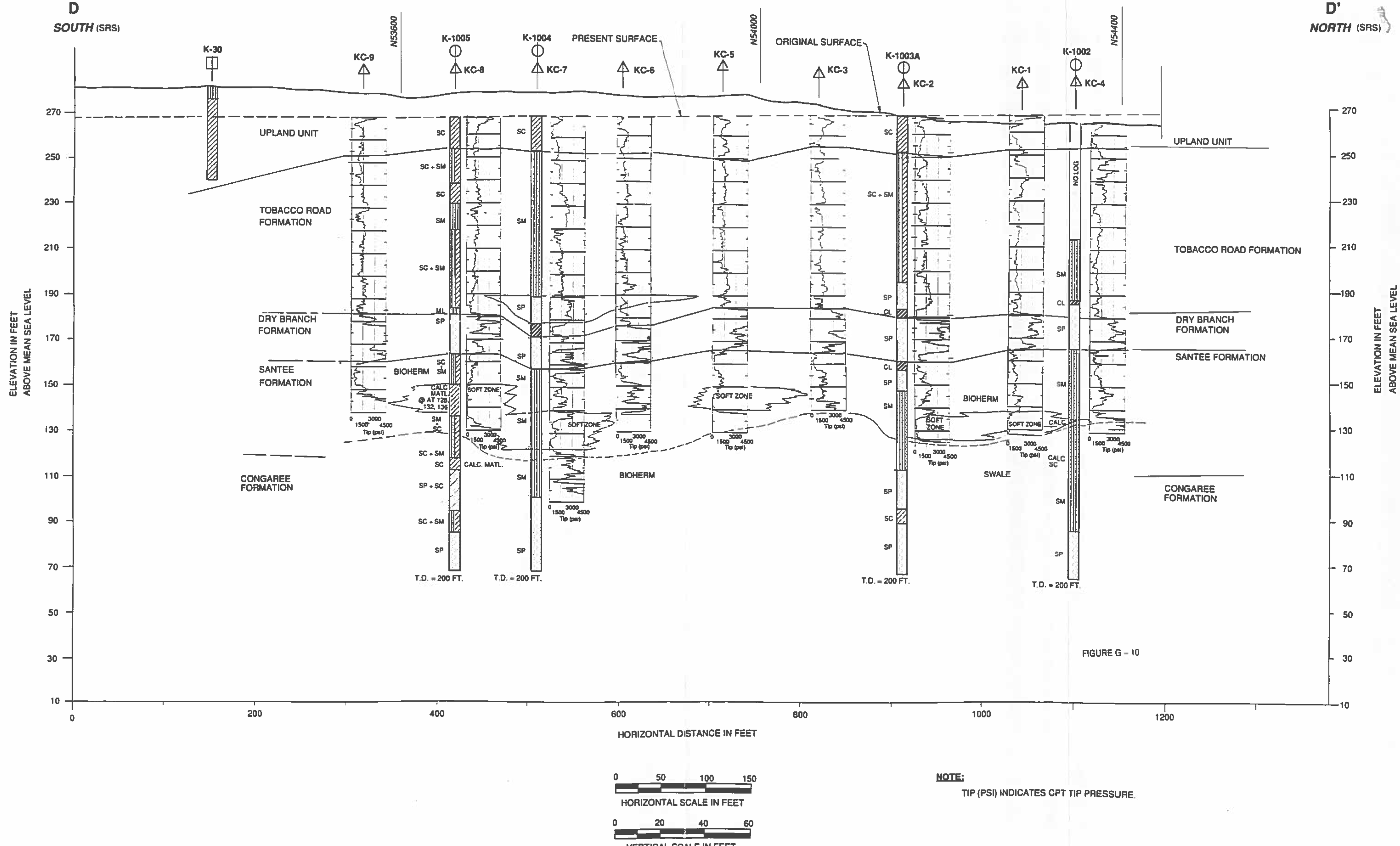
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR A A

NOVEMBER 1991

FIGURE 9


SIZE D 22 X 34
C
SOUTH
C'
NORTH
ORIGINAL SURFACE
PRESENT SURFACE
KC-11
K-24
K1006
KC-10
N53600
KC-12
KC-13
GROUT HOLE D-9 (PROJECTED 47 FT. WEST)
K-14 (PROJECTED 20 FT. WEST)
GROUT HOLE C-4
KC-14 (PROJECTED 24 FT. WEST)
N54000
GROUT HOLE B-3
GROUT HOLE B-1
KC-15 (PROJECTED 34 FT. WEST)
K-21
N54400
TOBACCO ROAD FORMATION
DRY BRANCH FORMATION
SANTEE FORMATION
CONGAREE FORMATION
SOFT ZONE
BIOHERMAL MOUND
T.D. = 150 FT.
NO LOG
CALC. MATL.
LOST WATER AT 100 FT.
LOST WATER AT 110 FT.
LOST WATER AT 140 FT.
LOST WATER AT 150 FT.
Tip (psi)
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
HORIZONTAL DISTANCE IN FEET
HORIZONTAL SCALE IN FEET
VERTICAL SCALE IN FEET
NOTE:
TIP (PSI) INDICATES CPT TIP PRESSURE.
SRS
CROSS SECTION C-C'
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

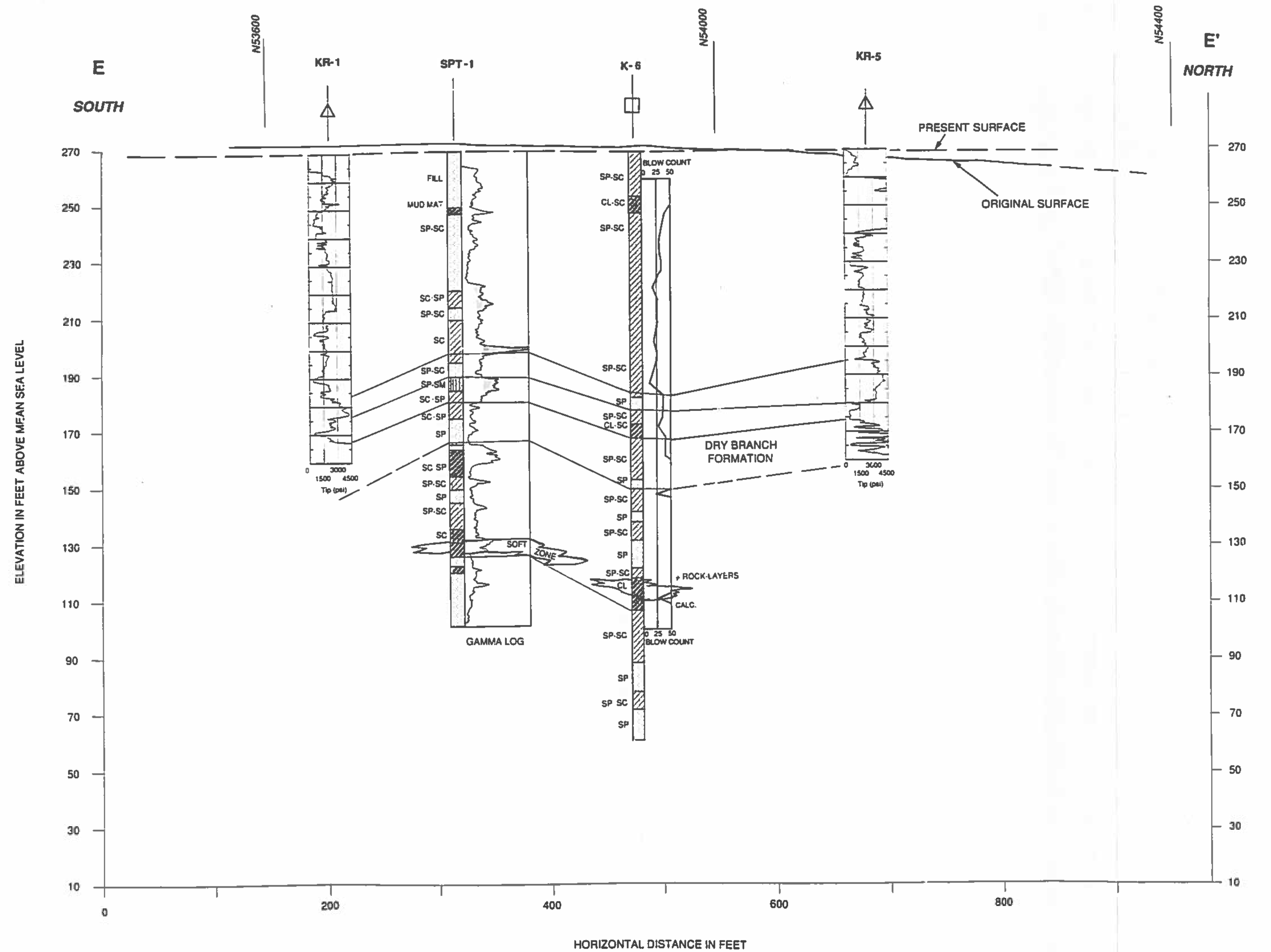
SIZE D 22 X 34

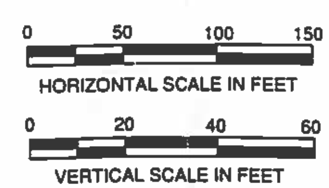


SRS | CROSS SECTION D-D' | NOVEMBER 1991
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA | FIGURE 11

SIZE D 22 X 34

ELEVATION IN FEET





NOTE:

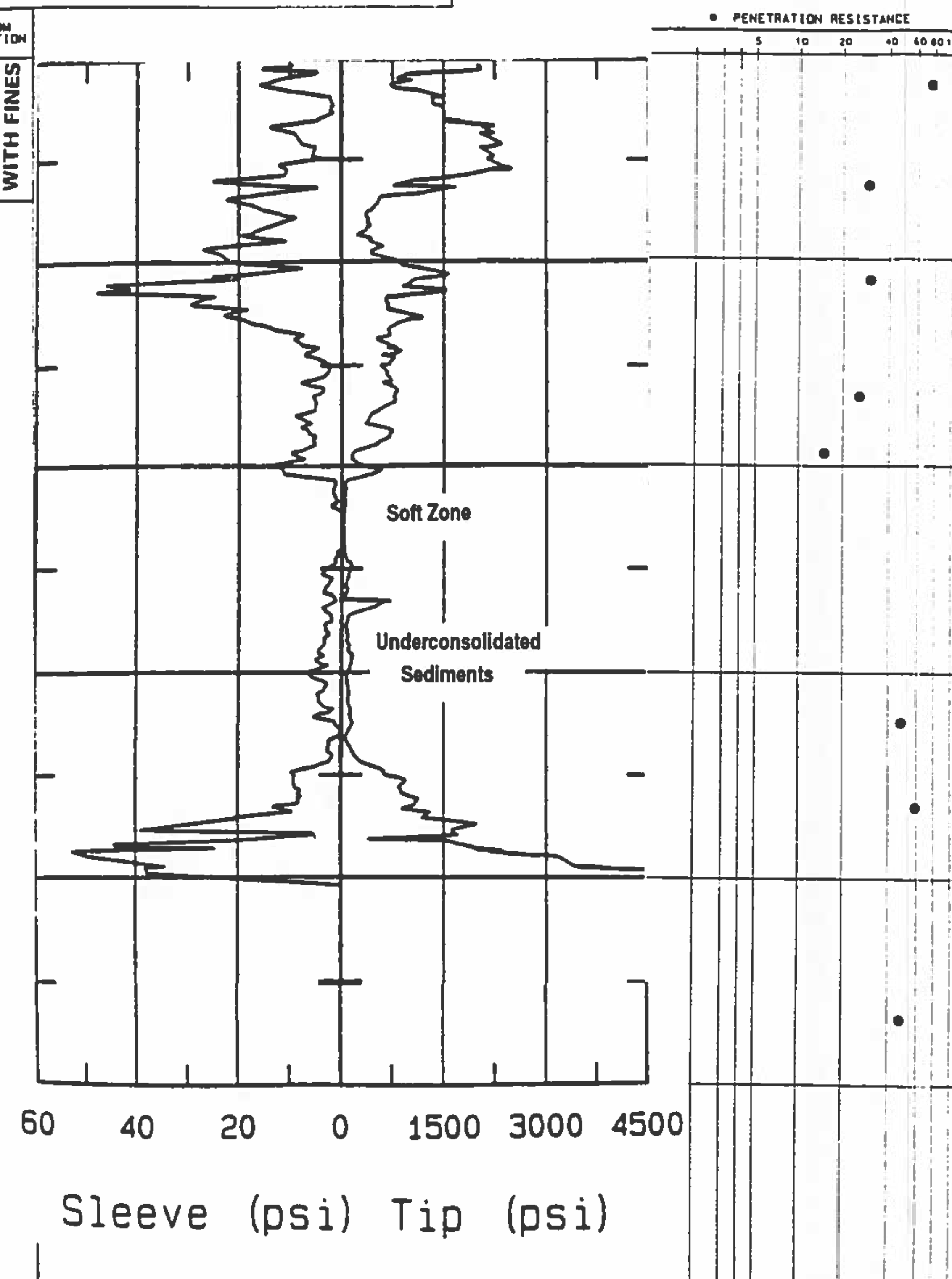
TIP (PSI) INDICATES CPT TIP PRESSURE.

SRS	CROSS SECTION E-E'	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 12

SOIL BORING RECORD

BORING NO. K-1005
PROJECT NO. 4133-90-545
DATE START/FINISH August 6, 1990/August 15, 1990
DRILLED BY/COMPANY D. White No. 876/Graves
TECHNICAL OVERSITE M. Adamski
DRILLING METHOD Mud Rotary

DEPTH FT	SAMPLE	SAMPLE DESCRIPTION	STRATUM DESCRIPTION	BLOWS /6 IN.	REC. IN.
100	SS13A	SS13A: CLAYEY SAND (SC); homogeneous, 15% clay, medium grained, subangular, no reaction with HCl, saturated, brownish yellow.	NARROWLY GRADED SAND WITH FINES	7 39/38 49	9
	SS14	SS14: Top 6 inches: similar to SS13A, with thin seams of clayey sand. Bottom 3 inches: NARROWLY GRADED SAND WITH CLAY (SP-SC); 5-10% clay, medium and coarse grained, no reaction to HCl, sub-rounded, saturated, brownish yellow.		9 17/14 18	9
110	SS15	SS15: SILTY SAND (SM); lenses of clay, (< 1 inch), 30% silt, 5-10% clay, fine grained, no reaction to HCl, moist, light brownish yellow.	SILTY SAND AND CLAYEY SAND	7 13/18 22	20
	SS16	SS16: SILTY SAND (SM); homogeneous, 20-25% silt, fine and medium grained, no reaction with HCl, saturated, brownish yellow.		8 12/13 14	16
	SS17	SS17: Similar to SS16. See Notes 3 and 4		WOH 9/7 WOH	12
120	FP4	FP4: CLAYEY SAND (SC); 30% clay, fine and medium grained, none to slow dilatancy, no reaction with HCl, saturated, brownish yellow.			
	FP5	FP5: Similar to FP4, light brown.			
		FP6: No sample removed from tube.			
	FP6	FP7: WIDELY GRADED SAND WITH CLAY (SP-SC); 10% clay, medium grained some large cemented particles (< 1/4 inch), no reaction with HCl, sub-angular, saturated, light brown.			
	FP7				
	FP8	FP8: SILTY SAND (SM); fine to coarse grained, 15% fines, cemented in areas, positive with HCl, calcareous, angular, saturated, yellowish grey, shell fragments.			
130	FP9	FP9: SILTY SAND (SM); fine and medium grained, 15-20% silt, positive with HCl, shell fragments, saturated, light brown.			
	SS18	SS18: SILTY SAND (SM); homogeneous, 20-25% silt, fine and medium grained, positive with HCl, calcareous, saturated, light brown.		14 21/27 31	9
	SS19	SS19: SILTY SAND (SM); homogeneous, 20-25% silt, fine and medium grained, positive with HCl, calcareous, saturated, shell fragments, yellowish grey.		10 26/34 100/1.5	
140					
	SS20	SS20: Top 8 inches: SILTY SAND (SM), homogeneous, fine to medium grained, 20% silt, no reaction with HCl, saturated, shell fragments, top inch, yellowish red. Bottom 7 inches: CLAYEY SAND (SC); top (1-3 mm) lenses of clay, 15-20% clay, fine and medium grained, no reaction with HCl, saturated, brownish yellow.		21 22/22 26	15
150		Continued on page 4 of 4.			



(GEI/WSRC 1991).

SAMPLE SYMBOLS
- SPLIT SPOON (SS)
- FIXED PISTON (FP)
- CORE (C)
- PITCHER BARREL (PB)

LOCATION N 53,656.80
E 41,487.13
ELEVATION 269.6

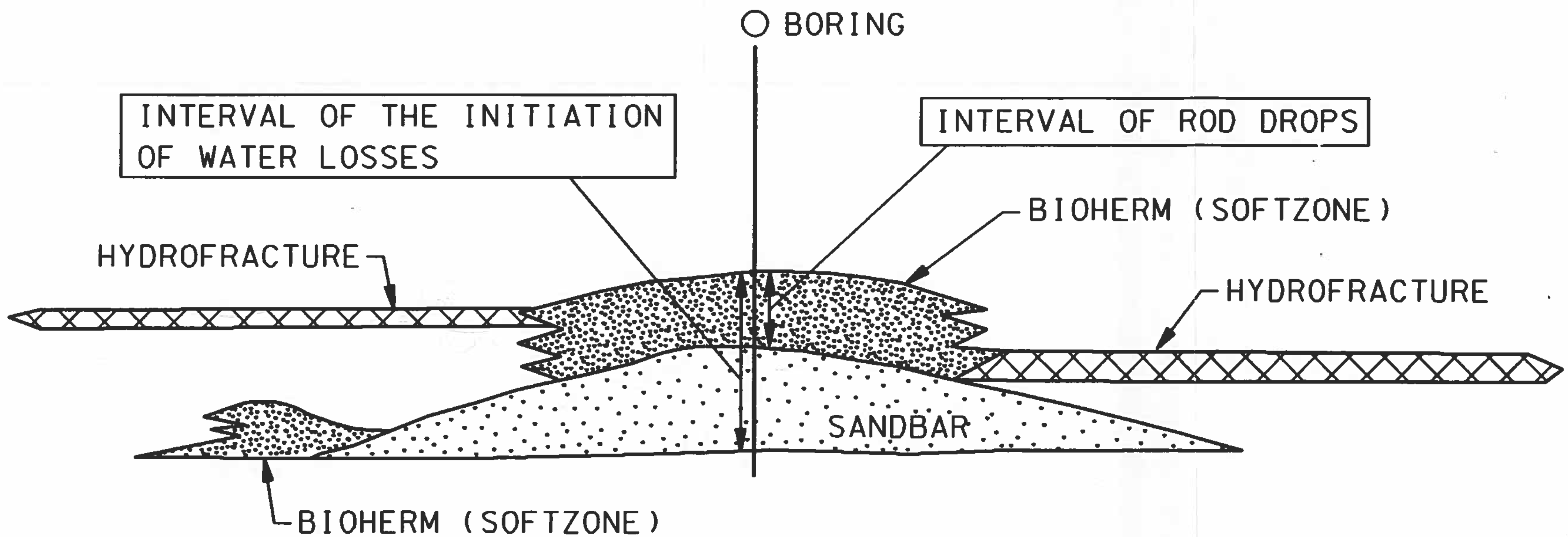
NOTE:
BLOWS 6" FROM 140 lb.
HAMMER FALLING 30 IN.
REQUIRED TO DRIVE 2.0" O.D.
1.4" I.D. SAMPLER

K-AREA SEISMIC EVALUATION
SAVANNAH RIVER SITE
AIKEN, SOUTH CAROLINA

WESTINGHOUSE ENVIRONMENTAL AND GEOTECHNICAL SERVICES, INC.

SRS SAFETY · RESPONSIBILITY · SECURITY SAVANNAH RIVER SITE

LOG OF K-1005	NOVEMBER 1991
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 13



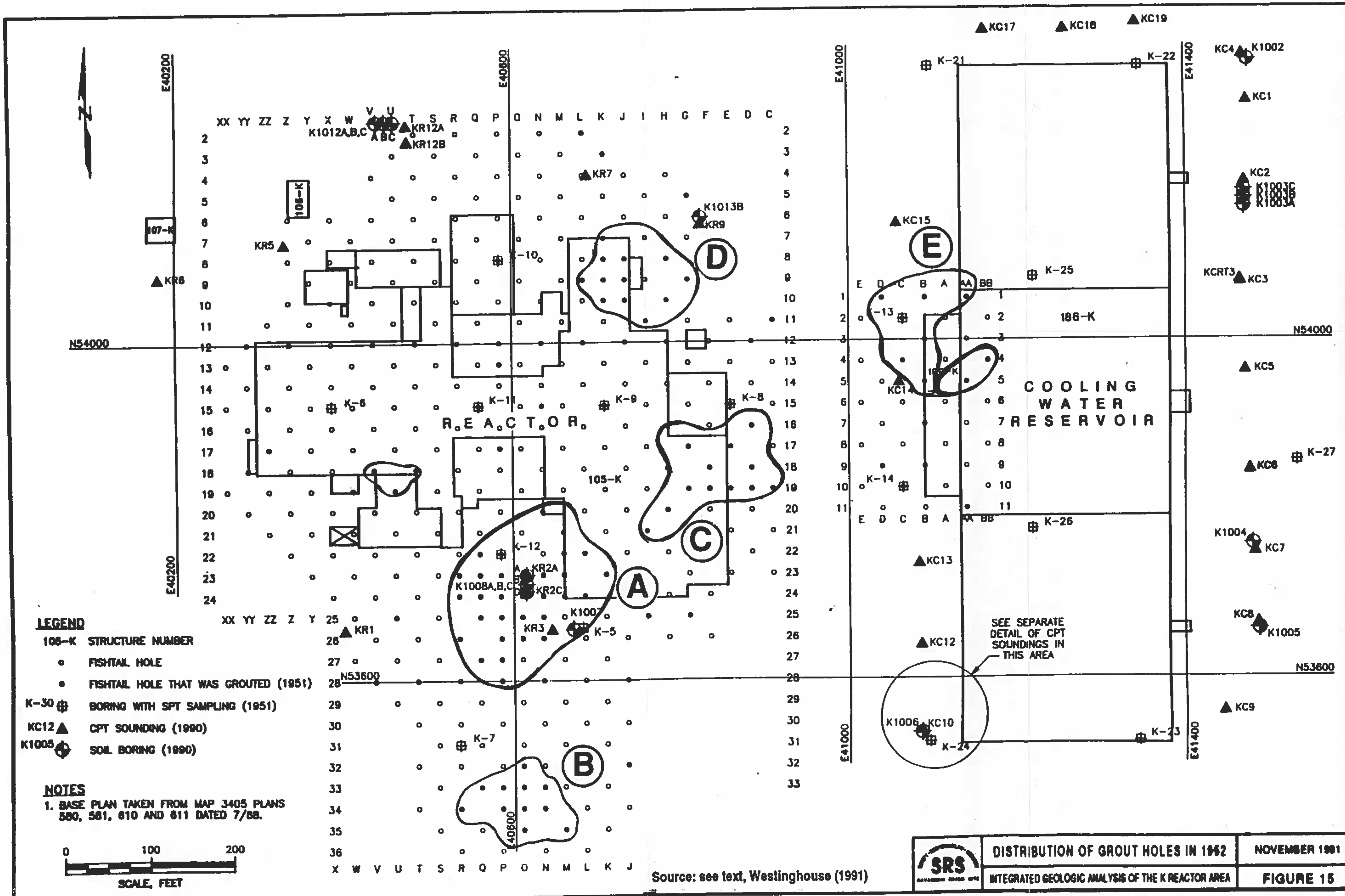
SRS

DIAGRAMMATIC SKETCH OF SOFT ZONES

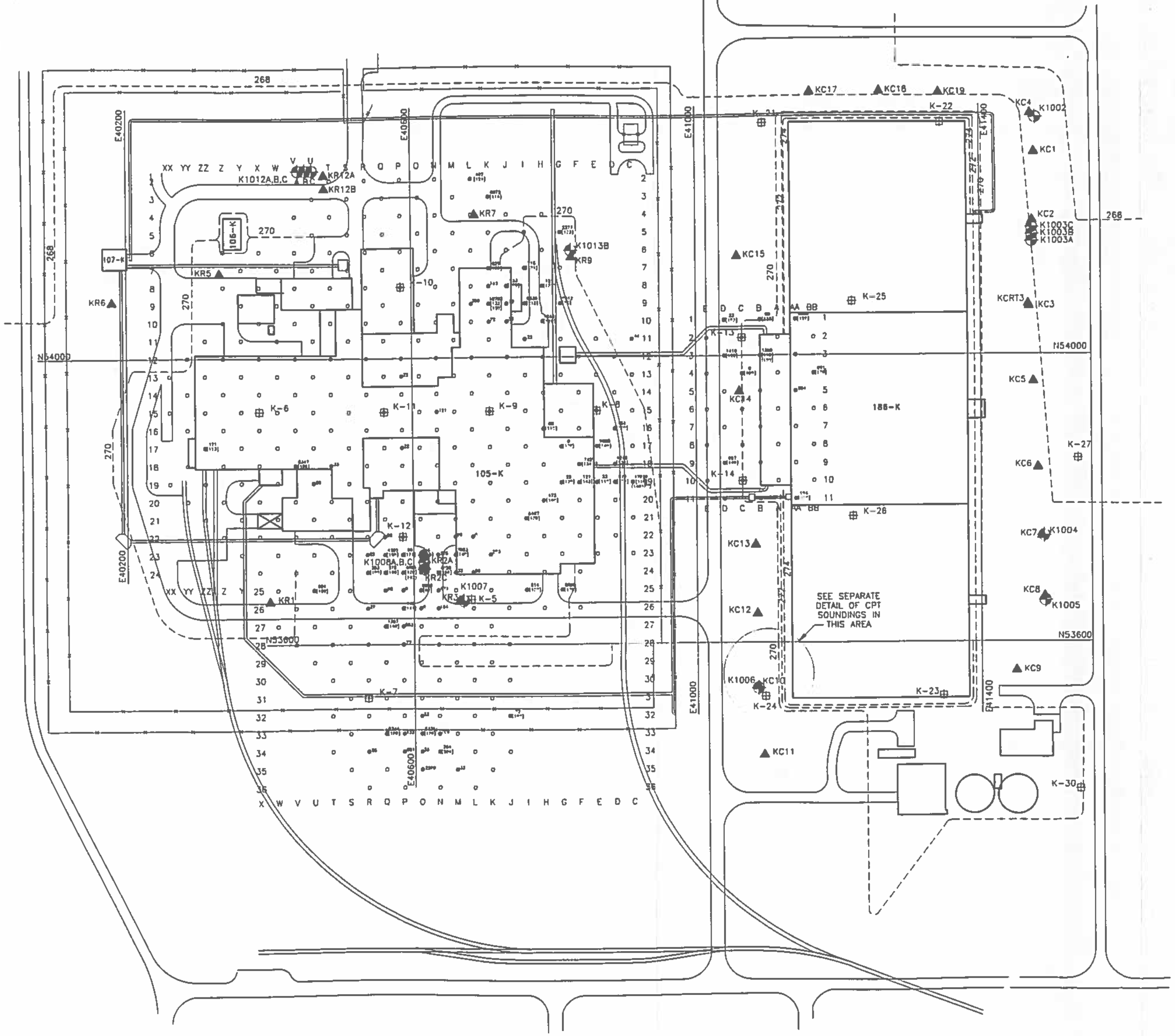
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

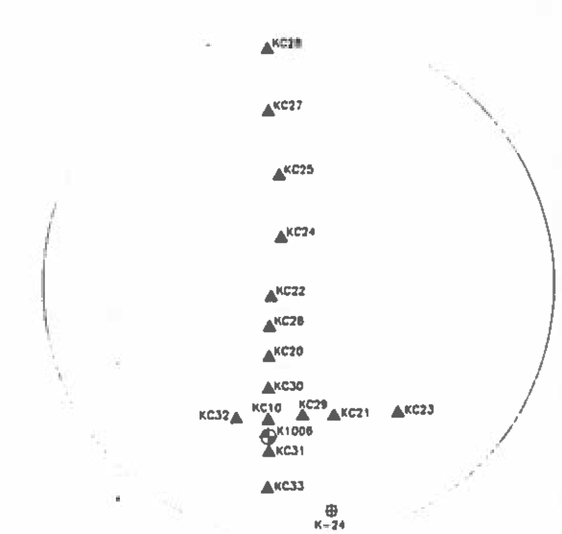
NOVEMBER 1991

FIGURE 14



DISTRIBUTION OF GROUT HOLES IN 1952 — INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA — NOVEMBER 1991 — FIGURE 15





DETAIL OF CPT SOUNDINGS
SCALE: 1"=15'

LEGEND

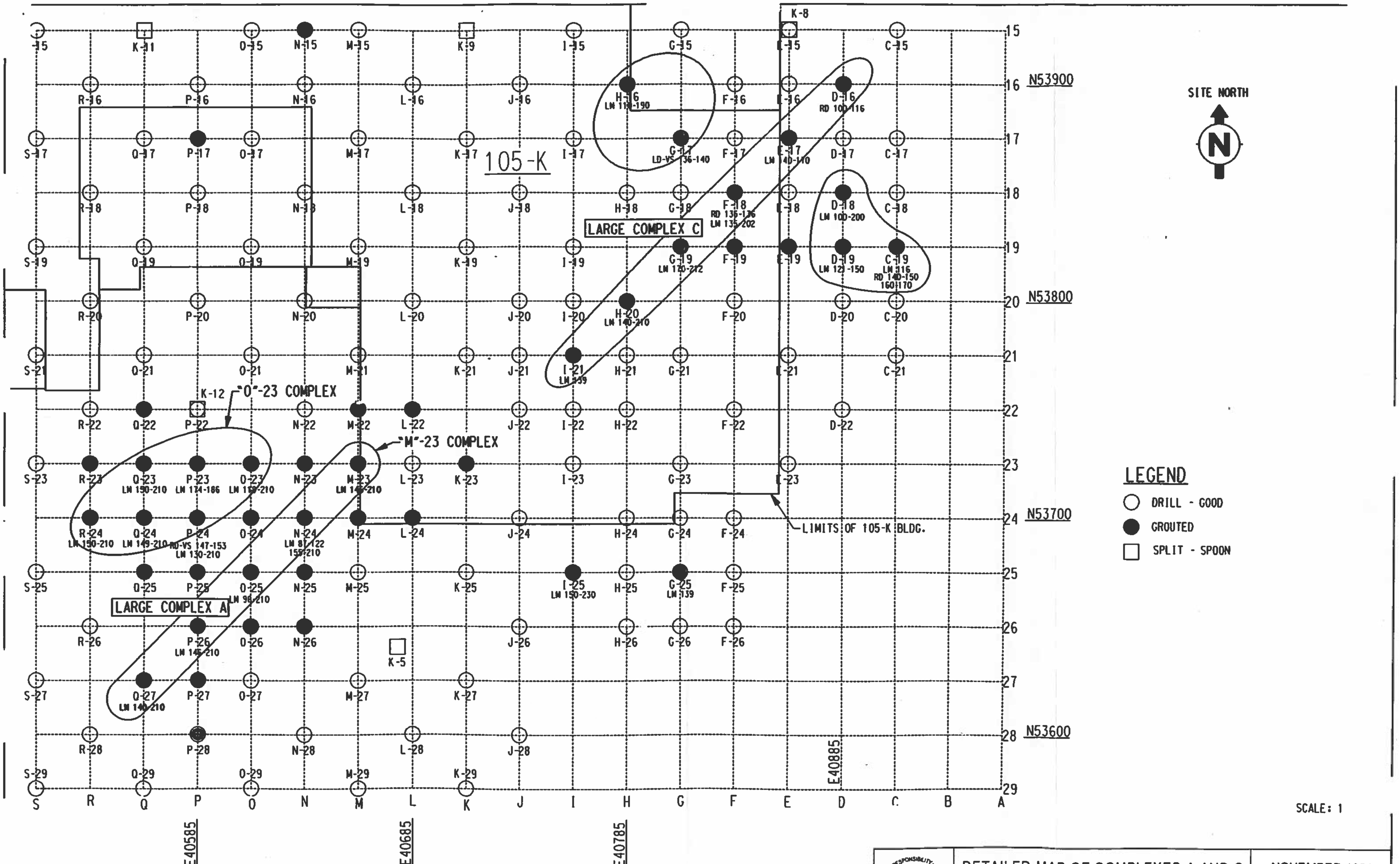
105-K	STRUCTURE NUMBER
	FISHTAIL HOLE
	FISHTAIL HOLE THAT WAS GROUTED (1951)
	VOLUME
	WATER LOSS
	ROD DROP
K-30	BORING WITH SPT SAMPLING (1951)
KC12	CPT SOUNDING (1990)
K1005	SOIL BORING (1990)

NOTES

1. BASE PLAN TAKEN FROM MAP 3405 PLANS 580, 581, 610 AND 611 DATED 7/88.
2. LOCATION OF SINKS AND BASINS TAKEN FROM DRAWING NO. SRP-FGR-15 (UNDATED).

0 80 160
SCALE, FEET

SRS	G.E.I. EXPLORATION LOCATION PLAN	NOVEMBER 1991
	INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA	FIGURE 16



DETAILED MAP OF COMPLEXES A AND C

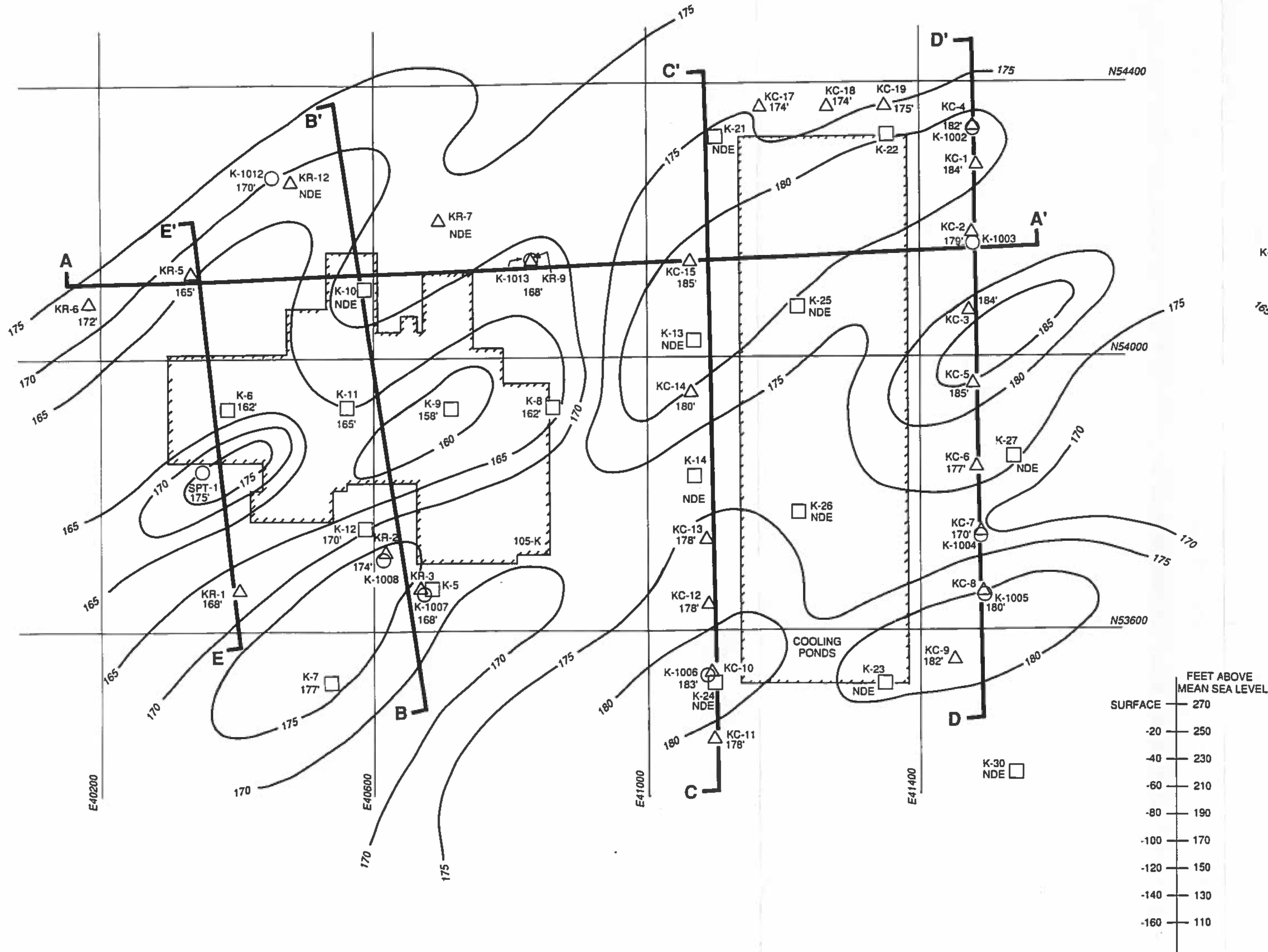
INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

NOVEMBER 1991

FIGURE 17

SRS SAVANNAH RIVER SITE · SAFETY · RESPONSIBILITY · SECURITY

SIZE D 22 X 34

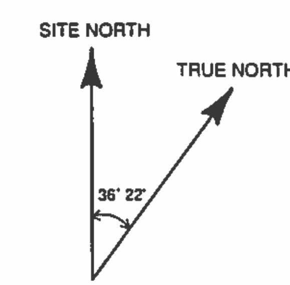


EXPLANATION

A — A'	Cross section
K-6 □ 162'	Boring with SPT sampling (1951) with elevation above mean sea level of top of Dry Branch Formation
KR-5 △ 175'	CPT sounding (1990) with elevation above mean sea level of top of Dry Branch Formation
K-1012 ○ 170'	Soil boring (1990) with elevation above mean sea level of top of Dry Branch Formation
NDE	Not deep enough
165	Contour along approximate top of Dry Branch Formation

NOTE:

1. Contour interval = 5 feet.



SRS

CONTOURS OF TOP OF DRY BRANCH FORMATION

INTEGRATED GEOLOGIC ANALYSIS OF THE K REACTOR AREA

NOVEMBER 1991

FIGURE 18