SUBSURFACE INVESTIGATION OF LIQUEFACTION,
IMPERIAL VALLEY EARTHQUAKE, CALIFORNIA,
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ABSTRACT

Subsurface investigations were made to study the effects of liquefaction caused by the October 15, 1979 earthquake (M=6.6), at Heber Dunes County Park and at River Park, Imperial Valley, California. Highly detailed profiles were constructed from cone penetration tests, standard penetration tests, large volume disturbed samples, and undisturbed tube samples. Liquefaction effects including sand boils, ground cracks, and lateral spreading occurred at the Heber Road site in a 5-m deep, loose, channel-sand deposit. The deposit occurs in an abandoned channel that is part of an ancient delta. The banks of the channel contain a moderately dense overbank deposit, and a dense point bar deposit. Other than a few sand boils over a buried pipeline, no liquefaction effects occurred in the denser sand deposits outside the channel. Hundreds of sand boils erupted on the flood plain of the New River at River Park. The sand boils at River Park originated from 3-m deep, loose, flood plain sands and silts, and from 6-m deep, medium dense channel sands. A 1.5-m thick, soft, clay layer is sandwiched between the two sand layers that liquefied. The behavior of the sands that did and did not liquefy are in general agreement with behavior predicted by standard engineering analyses.

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INTRODUCTION

An earthquake (M=6.6, Caltech Seismological Laboratory) struck the Imperial Valley on October 15, 1979. The earthquake was caused by right lateral movement on a 35-km long segment of the Imperial Fault (figure 1). Maximum right-lateral offset of 0.56 m occurred near Heber Dunes County Park (Real, 1979, p. 259). The earthquake generated liquefaction at 36 identified locations in the Imperial Valley, and caused damage to roads, canals and fields (Youd and Wieczorek, in press).

Two sites where liquefaction effects were particularly pronounced were selected for subsurface investigation (figure 2): a lateral spread that crossed Heber Road 16 km southeast of El Centro, California; and River Park, in the southwest part of Brawley, California, where hundreds of sand boils erupted during the earthquake. Between December 3 and 19, 1979, and between January 5 and 30, 1981, subsurface investigations were made at Heber Road and at River Park. These investigations included, cone penetration tests (CPT), standard penetration tests (SPT), continuous, disturbed sampling, and thin-walled tube samples.

METHODS OF INVESTIGATION

Cone Penetration Test (CPT)

A linear array of cone penetration soundings was made to determine (1) a subsurface cross section of sediment layers, (2) the types of sediment penetrated and (3) an estimate of the compactness of granular layers penetrated. A mechanical friction-cone penetrometer was used to determine point resistance and sleeve friction values. The values are obtained by following the procedures outlined in ASTM standard D-3441-75T (ASTM, 1978, p. 450). The penetrometer used in this study was a Begemann friction-cone (figure 3), the cone has a 60^{0} point with a base area of 10 cm^2. The friction sleeve has a surface area of 150 cm^2. A Mobile B-50 drill rig was used to advance the penetrometer using a conversion kit described by Drnevich (1974, p. 125). Measurements were made at 20-cm intervals by alternately advancing the cone and the friction sleeve (figure 3). The cone measures point resistance (q_c), the friction sleeve measures side friction (f_s). Point resistance data is used to estimate relative density (Schmertmann, 1978a, p. 40). The friction ratio ($f_s/q_c=R_f$) is used to identify soil types (Schmertmann, 1978b, p. 6). In general, cohesionless sand and silt have friction ratios less than 3 percent. Cohesive clayey silt and clay have friction ratios greater than 4 percent (Schmertmann, 1978b, p. 7; Sanglerat, 1972, p. 211).

Standard Penetration Test (SPT)

Standard penetration tests were made at selected points in the soil profile to determine N-values (blows per foot) for evaluating liquefaction susceptibility and to obtain samples for soil classification. The equipment and procedures used in this investigation generally follow the recommendations of ASTM standard D1586-67T (ASTM, 1978, p. 235). The procedure was modified to use hollow-stem auger. A hollow-stem auger (25 cm o.d., 10 cm i.d.) was used to drill holes and act as casing. The step by step procedure for conducting the tests is shown in figure 4a. A pilot bit was used inside the auger to drill to the first sampling depth. As the auger advanced to within about 15 cm of the sampling depth the rate of advancement was reduced to lessen the disturbance to soils below the auger. After reaching the proper testing depth, the auger was lifted 10 to 15 cm and suspended from a fork at the surface. Water was added to create a hydrostatic head and prevent sand from being sucked into the auger as the pilot bit was removed. In instances where a pilot bit was not used, the depth of the hole was measured to determine the amount of sand inside the auger. If sand was inside the auger a hose was lowered to the bottom of the hole to flush out the sand. On the end of the hose was an attachment for directing flow outward and upward rather than downward. After flushing sand out of the auger, the sampler was lowered to the bottom of the hole. The drill rod was then marked with 6, 12, and 18 in (15, 30, and 45 cm) reference lines and the sampler driven 18 in (45 cm) with a 140 lb (63.5 kg) Mobile safety hammer falling 30 in (75 cm). The hammer was lifted and dropped using a reversing winch that allows the hammer to free fall. The sampler was driven 6 in (15 cm) for seating. The number of hammer blows required to drive the sampler the next 12 in (30 cm) was the penetration resistance, N. After the test, the auger was advanced to the next testing depth with the sampler acting as a pilot bit. Near the testing depth drilling was slowed to minimize soil disturbance. When the testing depth was reached the auger was lifted 10 to 15 cm and suspended with a fork. The split-spoon sampler was removed from the hole as noted in step 4. A clean sampler was then lowered to the bottom of the hole, any change of hole depth noted, and the driving and drilling procedures repeated (steps 4 through 6, figure 4a).

Although we have not made extensive comparisons of standard penetration results obtained by the hollow-stem auger technique described above with other SPT techniques, we do have data from parallel tests at one site near Salinas, California. At that site, we conducted SPT tests in two parallel borings and also made cone penetration soundings. Martin and Douglas (1981, Figs. A34-A41) conducted SPT tests in 8 borings at the same site. In 4 of the borings they used a conventional rope-around-a-cathead technique, and in the other 4 borings they used an automatic trip hammer. All of the Martin and Douglas tests were conducted in rotary drilled holes filled with drilling mud. Averaged blow counts from the three sets of SPT tests plus USGS cone resistance data are plotted on figure 4b. The N-values obtained by the hollow-stem-auger technique are generally consistent with, but average about 25 percent less than the values obtained with the automatic trip hammer. SPT values obtained with the conventional procedure are all considerably greater than those obtained by the hollow-stem-auger or automatic-trip-hammer techniques. The average ratio of the conventional to the hollow-stem-auger SPT resistance is 2.5. The cone penetration resistance and blow counts from the automatic trip hammer and hollow-stem-auger techniques all increase essentially linearly with depth, indicating a rather uniform relative density of the deposit to a depth of about 10 meters. N-values from the conventional test generally increase with depth, but have some variations not seen in the other records. Also, the latter N-values have a wider range of scatter than the values obtained by the other methods. These data indicate that the conventional SPT test does not produce as consistent results as the more automated procedures, even under the carefully controlled conditions maintained during the Martin and Douglas investigation.

Continuous, Disturbed, Sampling

Continuous, disturbed samples were taken for visual classification and laboratory grain-size analysis. Disturbed samples 1.5 m long were obtained by "cork-screwing" solid-stem augers into the ground. In this procedure, a solid-stem auger 6 in (15 cm) in diameter was advanced into the ground at a rotation rate that minimized soil movement up the auger (figure 5). After an advance of 1.5 or 3.0 m, the augers were pulled vertically out of the ground without rotation. Field classification and photographs were made while the sediment was on the auger. Changes in texture and color could be seen very well by this technique. Unfortunately, most of the structure and fine layering was disturbed.

When drilling in soft clay or loose sand only a few centimeters of sample displacement occur along the augers. In dense sands or very stiff clays, upward displacement was as much as 0.50 m. When used in conjuction with CPT and SPT, sediment can be easily located in its proper stratigraphic position. In addition to the disturbed samples, six Shelby tube samples were taken at the Heber Road site for identification of small-scale sedimentary structures.

Soil Classification

Field and laboratory tests were used to classify soils according to the Unified Soil Classification system (D2487-69, ASTM, 1978, p. 325). Field classification included general descriptions of texture, stratification, and color (using the Munsell soil color chart). Laboratory tests included grain size distribution and Atterberg limits. Grain-size measurements were made using procedures prescribed in ASTM standard D422-63 (ASTM, 1978, p. 71). Atterberg limits were determined using procedures in ASTM D424-59 (ASTM, 1978, p. 86) and D423-66 (ASTM, 1978, p. 82).

GEOLOGY

The Imperial Valley occupies the northern part of the Salton Basin which is a northward extension of the crustal rifting that opened the Gulf of California. The basin is tectonically active as evidenced by movement on the Imperial and Brawley Faults. The basin ranges from 5 to 130 km in width and is about 200 km long. The central part of the basin contains the Salton Sea, 70 m below sea level. The basin contains up to 6,100 m of Tertiary and Quaternary marine, continental and lacustrine sediment. Pleistocene and Holocene sediment (Holocene sediment is as thick as 100 m in some areas) has been derived from two sources; (1) the Colorado Plateau, through the Colorado River and its distributaries which include the Alamo River, and (2) local hills and mountains bounding the basin. Sediment from bounding hills and mountains has carried into the basin through the New River system. The Holocene depositional history includes thick lacustrine deposits, channel-fill deposits, alluvial fans and eolian deposits.

Channel-fill deposits of the Alamo River form shoestring sand bodies within the lacustrine mud and deltaic sand facies. The channel deposits range from 3 to 20 m thick, and 65 to 300 m wide (Van De Kamp, 1973, p. 835). The Alamo and New Rivers contain distinctly different sediment because the rivers have different source areas. The Alamo, supplied by the Colorado River, contains red-brown, well-sorted fine sand and clay, whereas local sources supply the New River with yellow-white, medium to coarse, moderately sorted sand and pale green and tan clay. The juxtaposition of the channel, delta, and lacustrine deposits produces rapid changes in vertical and lateral profiles.

Between 300 and 1600 years ago natural flooding from the Colorado River filled the Imperial Valley and created Lake Cahuilla (Van De Kamp, 1973, p. 829). Fine-grained muds deposited in Lake Cahuilla commonly interfinger with sand beds. Variations in lake level caused sand to prograde over the muds. The source of the muds can be identified from color. The brown-red muds originated from the Colorado River system, whereas pale green and tan muds originated from local valley margins (Van De Kamp, 1973, p. 832).

Before agricultural modification, small lakes filled many depressions along river channels that meandered across the old lake bed. Sediment accumulated in these small lakes as deltas similar to the modern deltas in the Salton Sea (Van De Kamp, 1973, p. 834). The position of the deltas are controlled by; location of depressions, course of channels, and fluctuations in lake level. Van De Kamp (1973, p. 834) reports that there probably are numerous small deltaic sequences in the southern part of the Imperial Valley.

One of these deltas, fed by a now abandoned channel, occurs west of the Alamo River between Holtville and the Mexican border. Archaelogic and stratigraphic evidence indicate that Lake Cahuilla covered this area 300 to 400 years ago (Sharp, in press). The delta is identified by topographic contour lines that show a lobe of higher ground (Youd and Wieczorek, in press) and by soil surveys (Strahorn and others, 1924) that indicate the lobe of high ground is composed of sandy soils (figure 6). Aerial photography, from 1937, of the delta shows one major remnant stream channel, outlined by levees and vegetative photolineaments, running down the axis of the delta (figure 7). Since 1937, most of the channel features have been obliterated by land leveling and cultivation.

Liquefaction effects produced by the 1979 earthquake were concentrated within the delta and particularly in the naturally and artifically filled channel. The Heber Road site is located across the relict channel.

SITES

Heber Road

At Heber Road a lateral spread formed in the naturally and artifically filled channel described above. The spread disrupted the pavement on Heber Road 1 km east of Mets Road and shifted the roadway and an adjacent canal 1.2 m southward. The lateral spread is about 160 m wide and 100 m long. Arcuate ground cracks and scarps formed around the margins and across the interior of the failure (figure 8). Scarps up to 0.9 m high formed at the southern edge of the road. Many sand boils erupted on the lateral spread, primairly along cracks north of the road. The eastern edge of the channel is marked by ground cracks. East of the former channel no ground cracks or ground displacements occur although sand boils erupted over a buried drain. No cracks or sand boils formed west of the channel.

In December 1979, and January 1981, subsurface investigations were made across the lateral spread and parallel to Heber Road to define the sediment profile and to classify the soil properties. Figure 9 is a photograph of the site south of Heber Road. Figure 10 shows the location of the holes in relation to the failure. The preliminary subsurface investigation in December 1979, consisted of 8 static cone penetration (CPT) soundings 30 m apart (holes 1 through 8) and 2 CPT soundings (holes 9 and 10) 4.5 m apart near hole 7 to define the east margin of the old channel. Continuous, disturbed samples were taken from holes 1, 4, and 7. Standard penetration tests were made at holes 1, 4, 6, and 7. Shelby tube samples were taken from holes 1 and 7. The Heber Road site was visted again in January 1981, to make shear wave velocity measurements. This work was performed in conjunction with Kenneth Stokoe

(University of Texas, Austin) under USGS Research Contact no. 14-08-0001-19777. In this study 3 lines of tests were set up parallel to the relict channel; 1) one site was located west of the lateral spread, 2) one site was located within the lateral spread, 3) one site was located east of the lateral spread. One CPT was made at the ends of each line. One SPT was made near the middle of each line. Approximately 40 thin-walled tube samples were taken from the 3 sites for further testing by the University of Texas and Woodward-Clyde Consultants, Clifton, N. J., another participant in the USGS contract noted above. Figure 11 is an aerial photograph that shows all drilling locations at Heber Road.

River Park

Hundreds of sand boils and numerous small (less than 5 cm wide) ground cracks developed in a large graded area along the east side of the New River at the southwest edge of Brawley. The graded area called River Park contains a rodeo ground, picnic area, stock pasture, and an unpaved parking area. The eruption of sand boils flooded the parking area and covered parts of that area, the stock pasture, and the picnic ground with water and sand. Water continued to seep from some sand boils for 2 weeks following the earthquake.

A rotational slump developed in a zone of artifical fill in part of the picnic area near the New River. The slump scarp runs 30 m along the river and extends 5 m to 15 m inland from the rivers edge. The height of the scarp varies from 1.2 m at its northern end to a negligible height at its southern end where it merges with small cracks that were very common along the river. At the northern end of the slump a dome-like toe buldged out at river level.

At River Park 5 CPT soundings were made across the flood plain at intervals of 60 m (figure 12). Six additional soundings at intervals of 10 m were made across the slump near the New River. Standard penetration tests were made at hole 1 on the flood plain and at hole 6 on the slump. Cork-screw samples were obtained at two of the CPT sounding sites on the flood plain and at four of the sounding sites near the slump. In January 1981, the River Park site was revisted. Four CPT were made, 3 were on the slump, north of the previous tests, and one was near hole 4 on the flood plain. Standard penetration tests were made at hole 13, near the slump, and near hole 15, on the flood plain. The location of all the tests is shown in figures 13 and 14.

RESULTS

Heber Road

As noted above, the investigation of the lateral spread at Heber Road included 16 CPT soundings, seven SPT soundings, four holes for continuous, disturbed sampling, and five holes for undisturbed shelby tube samples (figure 10). Tables 1 through 17 contain CPT and SPT data, geologic logs, soil classifications, grain size analyses, and Atterberg limits. The samples, and penetration data were used to construct the profile in figures 15 and 16. As shown in figures 15 and 16 the upper 5 m consists of 3 different units of sand and silty sand, units A_1, A_2, and A_3. The average penetration resistance and the relative density of the units are shown in figure 17.

Fluvial Units

Unit A_1. Unit A_1 occurs on the west side of the channel and was penetrated by soundings and borings at holes 1, 11, and 12 (tables 2, 12, and

13). The sediment in the unit is dark brown, dense to very dense, well sorted, very fine-grained sand. The unit shows a well defined upward decrease in grain size. The unit is wedge shaped, tapering from 5 m thick at hole 1 to less than 0.5 m thick in hole 4. The sand consists of about 95% rounded to subrounded quartz and feldspar grains. The other 5% of the sediment consists of heavy minerals, mica, and fragments of organic material. No gastropod shells or other shell fragments were present. A shelby tube sample from 1.1-1.7 m shows ripple bedding (figure 18). A Shelby tube sample from 2.1-2.7 m contains 0.6 m of horizontally laminated sand (figure 19).

Well sorted, upwarding-fining sand, with horizontal laminations in the lower part, and ripple beds in the upper part, indicate that unit A_1 is a point bar deposit (Reineck and Singh, 1975, p. 231; and Allen, 1965, p. 142).

Unit A_2. The channel part of the profile is represented by a dark brown, very loose (average N=4), moderately sorted silty sand and sand (tables 3-7, 14 and 15). Unit A_2 contains abundant fresh-water gastropods of two unidentified types. The three holes (4, 6, and 13-14) in which samples were taken showed no regular stratification except for a grayish-brown bed at a depth of about 1.8 m (which probably represents the base of the artifical fill), and shell stratification in hole 4 at 3.6 m.

The position of the unit in the channel, the fine grain size of the sediment, and the abundance of fresh-water gastropods, indicate that the lower part of the unit is channel-fill. From the 1937 aerial photographs and recent topographic maps we estimate that the top 1.8 m of unit A_2 is artifical fill. Also, the height from the ground surface at the site to the bottom of the channel in Heber Dunes park is 2.0 m. Natural filling of the channel probably followed a sequence of events similar to events described by Allen (1965). Channel shift caused by a chute cut-off slowly shifts the stream from an old to a new channel (Allen, 1965, p. 119). The slow shift allows continued deposition to take place, but under relatively low-energy conditions of overbank flooding. This process allowed the channel to be filled with loose sand and with a minimum amount of silt and clay.

Unit A_3. Unit A_3 occurs on the east side of the channel at holes 7, 8, 15, and 16 (tables 7, 8, 15, and 16). The unit consists of dark brown, medium dense, moderately sorted sand and silty sand. The sediment is angular and consists of about 95% quartz and feldspar grains. The other 5% of the sediment consists of heavy minerals, mica, and fragments of organic material. The unit is sharply truncated between holes six and seven. A Shelby tube sample from 3 to 3.6 m shows thinly bedded sediment with convolute structures (figure 20). Osterberg piston samples were taken for bulk density measurements near holes 15 and 16. Between 1.83 and 2.59 m we measured the dry density of the overbank silty sand as 1.54 gm/cm^3. Beween 4.11 and 4.88 m the dry density was 1.47 gm/cm_3. Density samples were also taken in units A_1 and A_2. Density measurements at A_1 and A_2 were made in the field after the samples had been extruded. The density measurements in units A_1 and A_2 are questionable and are not reported. The density samples from A_3 were obtained by cutting the sample tube with a tube cutter, rather than extruding the samples with a piston that compresses the sample.

According to criteria given by Reineck and Singh (1975, p. 245-246) the position of unit A_3 in relation to the channel and unit A_1, and the grain size distribution of the sediment, indicate that unit A_3 is a natural levee and overbank deposit.

Deposition of the three units (A_1, A_2, A_3) in the upper 5 m was related to the fluvial activity in the relict channel. The relationship between the three units and the channel indicate that the three units are of Late Holocene age. Because A_2 fills the channel, unit A_2 is younger than either unit A_1 or unit A_3. Although the three units are approximately the same age, the three fluvial units have distinctly different penetration resistances indicating different relative densities. Relative density may be related to the flow velocity of the stream in the respective environments. The highest relative density is found in the point bar deposit (A_1). The horizontal laminations in the lower part of the unit indicate deposition from the upper energy flow regime (Reineck and Singh, 1975, p. 10). The low relative-density portion of the point bar deposit contains ripple bedding indicative of the lower energy flow regime. Sand in medium-dense unit A_3 was deposited during overbank flooding. The least dense sediment (A_2) was deposited during low velocity channel filling.

Fluvial and Lacustrine Units

Units B, C, D, E . Alternating beds of silty clay and sand lie beneath units A_1, A_2, and A_3,. The silty clays (units B and D) are stiff, reddish-brown and contain very little sand. The uppermost silty clay (unit B) is distinctly graded; silt grades downward to a 10-cm thick layer of alternating 1.2 cm beds of silt and clayey silt, beneath this transition zone lies very fine-grained silty clay. The sands (units C and E) are brown and very dense, and contain fresh-water gastropods. The upper sand unit (C) is well sorted and has sharp contacts with adjacent units, whereas the lower sand (E) is poorly sorted and has a gradational contact with the underlying fine-grained unit.

These alternating sand and clay beds represent channel-fill and lacustrine environments. Sand units C and E are slightly coarser than the channel-fill deposit (unit A_2) in the relict channel. The clay units (B and

D) are typical of sediment laid down in a quiet lacustrine environment. The alternating environments were controlled by channel shifts of the main distributary, the Colorado River (Van De Kamp, 1973, p. 827-848). In the past, natural channel shifts of the Colorado River have inundated the Imperial Valley. During these inundations a lake was formed and lacustrine sediment was deposited. During periods of low lake level the meandering Alamo River deposited shoestring sand beds on the lacustrine sediment. The fluvial and lacustrine sediment is brown and reddish brown indicating that it originated from the Colorado Plateau.

River Park

Tables 18 through 32 contain CPT and SPT data, geologic logs and descriptions, and grain size analyses from drilling sites at River Park. The samples and SPT and CPT data were used to construct the profiles in figure 21 and figure 22. The profiles show three continuous units in the area of the flood plain and the slump. The average penetration resistance and relative density of the units are shown in figure 23.

Flood plain

Unit A. The upper unit (A) consists of loose, brown, sandy silts and clayey silts. The upward change from the clay in unit B to the sandy silt and clayey silt in unit A indicates an increasing energy source, probably a result of the main channel meandering nearer to the east side of the flood plain. The sandy silts represent a lower flood plain environment, whereas the clayey silts represent a flood basin environment (Helley and others, 1979, p. 35).

Unit B. The middle unit (B) consists of very fine-grained silty clay and clay. In hole 1 the clay is soft, black, and very organic rich. At hole four the unit contains two parts; the upper part is firm, has reddish oxidation and yellow concretions, whereas the lower part is softer, grayish-brown and more organic rich. In holes six and nine (within the slump) a very poorly sorted, asphaltic, pebbly silty sand replaces the silty clay. The latter material is artificial fill emplaced about 20 years ago. An Osterberg piston sample 76 cm long and 7.62 cm in diameter was used to take bulk density samples near holes 8 and 15. Near hole 8 we measured the wet density of the clay at 1.77 gm/cm^3 between depths of 1.52 and 2.13 m. At hole 15 the measured wet density of the clay was 1.68 gm/cm^3 between depths of 3.05 and 3.20 m.

The black, organic-rich clay represents a back swamp environment far from the high energy environment of the main channel (Reineck and Singh, 1975, p. 250, Allen, 1964, p. 168). The clay in hole 1 apparently filled in a depression in the sand. The clay remained soft because it was deposited in a depression and quickly buried (the clay shows no oxidation). Similar sediment in hole 4 was deposited in a more exposed position and became partly desiccated (in hole 4 the upper part of B has reddish oxidation and yellowish concretions).

Unit C. The lowermost unit (C) is a generally dense, well-sorted fine sand. The sand unit appears massive, the only subdivision seen was a color change from brown at the top to grayish brown at the bottom. The sand unit becomes finer away from the river and shows a well defined upward decrease in grain size in holes 8 and 11. An Osterberg piston sampler was used to recover bulk density samples at holes 8 and 15. At hole 8 the measured wet density of the sand, between 2.13 and 2.59 m, was 2.05 gm/cm^3. At hole 15 the wet density was measured at 1.93 gm/cm^3 between 3.51 and 3.66 m. The contact with the overlying clay is very sharp at hole 8. The CPT soundings show the upper 45 cm of sand to be noticeably less dense than the lower part. This lower density layer may have been produced by liquefaction and pore-water migration through the sediment during the 1979 and previous earthquakes.

The lateral extent, the thickness, and the grain size distribution of the unit C indicate that the unit is a point bar deposit (Reineck and Singh, 1975, p. 231; Allen, 1965, p. 142).

Slump

The stratigraphy in the off-slump area (holes 8, 11, and 13) is very similar to that of the flood plain. The stratigraphy within the slump (holes 6 and 9) is very different from the stratigraphy of the flood plain. The sediment encountered on the slump included an asphaltic artifical fill. We were informed by a city worker that the area near the slump had been filled about 20 years ago to extend the park. Drilling evidence indicates filling is more extensive in the southern part of the area than in the north where the slump scarp was highest. Profiles of the slump area are shown in figure 22. Data from the holes in the slump area are shown in tables 23 through 32.

Hole 6. The upper 2 m consists of very poorly sorted asphaltic fill. The fill overlies interbedded, dark brown, sand, silt, and clay (unit A) that occurs between 2 m and 3 m. This unit in turn overlies black, sandy silt and clayey silt (unit B). Unit B overlies brown, poorly sorted silty sand (unit C). This hole was only sampled to 4.6 m. It is assumed that unit C becomes coarser and increases in relative density with depth. Units A and B may not be equivalant to A and B on the flood plain. Unit C, however, is an extension of unit C beneath the flood plain. The sediments, of units A and B, in hole 6 are coarser and are more interbedded than the sediments on the flood plain. It is possible that units A and B in hole 6 are actually fill material. In the other hole (hole 9) located on the slump artificial fill rests directly on top of unit C. A profile of hole 6 is shown in figure 22. The data from hole 6 is shown in table 23.

Hole 8. The stratigraphy in this hole (off the slump) is very similar to that of the flood plain; sandy silt (unit A) overlies clay (unit B) that overlies fine sand (unit C). The sandy silt, clay, and the upper part of the sand are dark brown. The lower part of the sand is grayish brown. This color change is also seen in holes 4 and 11. The overall grain size of the sand decreases upward. A profile of hole 8 is shown in figure 23. The data from hole 8 is shown in table 25.

Hole 9. The sediment in this hole (on the slump) more closely resembles the sediment in hole 6 than that found in the holes on the flood plain. The gravelly asphaltic mixture present in hole 6 is also found in this hole. The presence of the artificial fill indicates that the silty sediment lying above is also artificial. Below the artificial fill is a dense, fine sand that is brown above 4.2 m and grayish below 4.2 m. This sand unit is similar to unit C of the flood plain. A profile of hole 9 is shown in figure 23. The data from hole 9 is shown in table 26.

Hole 11. The sediment in this hole (off the slump) is similar to the sediment in the flood plain. The upper unit in this hole is finer than unit A of the flood plain, and the middle unit is coarser than unit B of the flood plain. The lower unit is similar to unit C of the flood plain. The unit contains an upward fining sand that is brownish above 4 m and grayish brown below 4 m. A profile of hole 11 is shown in figure 23. The data from hole 11 is shown in table 28.

ANALYSIS

Based on the drilling data reported above, an analysis of liquefaction susceptibility was made for units A_1, A_2, and A_3 at Heber Road, and units A and C at River Park. The following text is summarized from Youd and Wieczorek (in press) with the analyses updated to include additional data presented in this report.

Heber Road Site

The geotechnical data in figures 13 and 14 were used to estimate liquefaction susceptibility of the soil layer penetrated by the sounding and borings along Heber Road using procedures developed by Seed (1979). Three sand and silty sand units lie in the upper 5 m of the section; a dense, point bar deposit in the west part (unit A_1), a very loose channel fill and artifical fill in the central part (unit A_2), and a medium dense overbank deposit in the east part (unit A_3). Average standard penetration blow counts below 2 m, the depth of the water table, were 4, 11 and 31 in these units, respectively. These blow counts were obtained using the hollow-stem auger technique. Other parameters needed to perform the analyses of liquefaction susceptibility included an average estimated dry density of 1.6 gm per cm^3, a depth of 4 m to the approximate midpoint of the layer that liquefied, and a maximum horizontal acceleration of 0.6 g (conservatively estimated from strong-motion data published by Porcella and Matthiesen (1979)). The equation given by Seed (1979, p. 210) for calculating cyclic stress ratio, $\frac{\tau_{av}}{\sigma_0'}$, is:

$$\frac{\tau_{av}}{\sigma_0'} \cong 0.65 \; a_{max} \left(\frac{\sigma_0}{\sigma_0'}\right) r_d \qquad (1)$$

where a_{max} is the maximum acceleration at the ground surface divided by the acceleration of gravity, σ_0 is the total overburden pressure at the 4 m depth (0.64 kg/cm^2), σ_0' is the effective overburden pressure (0.42 kg/cm^2 in this instance) and r_d is a stress reduction factor (about 0.95 for a depth of 4 m). Using the above values in equation 1 yields a cyclic stress ratio of 0.56 at the 4-m depth.

To complete the analysis corrected blow counts are required. Curves given by Seed (1979, p. 238) give a correction factor of 1.4 for an effective overburden pressure of 0.42 kg/cm^2. Applying this factor to the blow counts listed above yields corrected blow counts of 6, 15, and 43 for the channel fill, alluvial deposit, and the point bar deposit, respectively. These data are plotted on figure 24 at a cyclic stress ratio of 0.56. Based on the data in figure 4b we also assumed a correction factor of 2.5 to correct our safety-hammer standard penetration values to values that might be expected with the conventional rope-around-a-cathead technique. These corrected blow counts, for values less than 40, are also plotted on figure 24. Because of the limited data considered, the 2.5 correction factor must be considered as preliminary and very tenuous.

The plot indicates that for a magnitude 6.6 earthquake, the channel fill sand (Unit A_2) is susceptible to liquefaction. The susceptibility of the overbank deposit is marginal, plotting as liquefiable using the hollow-stem auger data and unliquefiable using the corrected data. Data for the point-bar sand (A_1) indicates that deposit is highly resistant to liquefaction. Surface effects at the Heber Road site indicate that widespread liquefaction and large ground displacements did occur in the area underlain by unit A_2. There was no indication of liquefaction in unit A_3 other than the linear group of sand boils shown in figure 8. These sand boils erupted over a buried drain line and were likely caused by liquefaction of soil disturbed during construction of the drain. There was no evidence of liquefaction in the area underlain by the point bar deposit (unit A_1). A rise of pore-water pressure could have occurred during the earthquake in either of the latter two units (A_2 and A_3) without leaving evidence in the form of lasting surface effects.

River Park

The data on figures 21 and 22 and the technique described above were used to analyze liquefaction susceptibility of the deposits at River Park. Parameters estimated for that site include a maximum acceleration of 0.2 g (estimated from a strong motion record at Brawley Airport (Porcella and Mathiesen, 1979, p. 25), a dry unit weight of 1.6 gm/cm^3, estimated average depths to the mid points of the liquefied layers of 2 m for the silty sand layer and 5 m for the unstratified sand bed, and a water table at the ground surface. From the limited standard penetration data at that site, a value of 3 blows per foot is estimated for the silty sand and a average of 7 blows per foot for the upper part of the unstratified sand. Corrected blow counts for these layers are about 4 and 10 blows per foot, respectively. The calculated stress ratio for both layers is 0.25. Corrected blow counts are plotted against this value in figure 24. Estimates of the conventional standard penetration values are also plotted using a 2.5 correction factor. The plot shows that the upper layer of silty sand (unit A) is susceptible to liquefaction. Data from the looser part of the unstratified sand (unit C) plot as susceptible for the unadjusted hollow-stem auger blow counts and nonsusceptible for blow-counts adjusted to the conventional technique using the tenuous correction factor of 2.5. As noted above, textures of the sand boil deposits at River Park indicate that liquefaction did occur in both the silty sand (unit A) and the unstratified sand layers (unit C).

The slump on the New River bank near Brawley originated from liquefaction of fine sand. The best developed surface features on the slump are at the north end where the vertical displacement is 1.5 m and a dome-like toe is developed in the river channel. The low penetration resistance in the upper part of unit C and the very poor sample recovery of the same material indicate that the low density sand is liquefiable. The shape of the slump and the low density of the underlying sand indicate that liquefaction occurred in the sand. The overlying artifical fill and the fine sediment settled and rotated into the weakened sand.

SUMMARY

Investigative Technique

The cone penetration test served as the primary tool for defining the geometry of sediment units and for estimating the density and strength of soils penetrated. The profile developed from CPT data was completed in a much shorter time than could have been done by conventional drilling and sampling methods and shows the stratification in greater detail. The main disadvantage of the CPT is that samples are not recovered. Samples and N vaules for evaluating liquefaction susceptibility were obtained from standard penetration tests. Use of the SPT in conjuction with the CPT allowed fewer but more optimally positioned SPT to be made while gaining a detailed profile. To fully sample the site under investigation, continuous, disturbed samples were taken by the cork-screw technique. Sedimentary structures are disturbed in this procedure but large amounts of material are recovered for testing.

Heber Road Site

In recent geologic time a lacustrine environment existed in the Imperial Valley due to diversions of the Colorado River and the formation of ancient Lake Cahuilla. In the central part of the lake fine-grained clays were deposited. As lake level rose and fell due to Colorado River diversions and lake evaporation, lacustrine clays were interbedded with sands deposited by meandering channels such as the Alamo River. Superimposed on the alternating lacustrine and fluvial deposits was a sequence of deltaic sands deposited at the mouth of a stream entering the lake. One such delta formed at the mouth of an ancient stream 1 to 2 km west of the present course of the Alamo River. A remnant channel marks the former course of that stream. Liquefaction and a lateral spread developed within the channel at the latitude of Heber Road where we conducted subsurface investigations.

The geology at the Heber Road site consists of; (1) fluvial sediment made up of, point bar, channel fill, and levee deposits, and (2) at least two cycles of channel sands alternating with lacustrine clay. The fluvial deposits lie within 5 m of the surface and display a wide range of geotechnical properties. The point bar deposit (unit A_1) contains medium dense to dense, thinly bedded very fine sand. An analysis showed that high density of the sand precludes any liquefaction with the accelerations accompanying the October, 1979 earthquake. This conclusion was supported by field evidence that showed no sand boils or permanent ground displacements occurred in the area of the point bar deposit. A rise of pore-water pressure could have occured in the sand during the earthquake without leaving surface evidence of the increase.

The channel fill (unit A_2) contains very loose very fine sand. Our analysis shows that this very loose channel fill is susceptible to liquefaction. A lateral spread, ground cracks, and sand boils formed in this area during the earthquake confirming that liquefaction did occur in that unit during the October 1979 earthquake.

The overbank deposit (unit A_3) contains medium dense fine sand. Our analyses indicate that this sand is either susceptible or marginally susceptible to liquefaction, depending on whether blow count adjustments to correct the data to conventional SPT values are valid. Except for a linear group of sand boils that erupted over a burried drain line, no ground displacements or sand boils were found on the overbank deposit (unit A_3). However, a pore-water presure rise may have occurred within the deposit.

The sand below a depth of 5 m is dense enough to resist liquefaction under the conditions created by the October, 1979 earthquake.

River Park Site

The three sediment units at River Park lie beneath the New River flood plain. These units represent a range of fluvial environments. The lowermost unit (C) is a medium dense fine sand typical of a high energy point bar deposit. The upper 0.5 m of this sand is loose, probably as a consequence of liquefaction during this and past seismic events. The middle unit (B) is a silty clay typical of a very low energy backswamp deposit. The uppermost unit (A) is a very loose silty sand and clayey silt typical of a moderate energy flood plain and flood basin deposit. From penetration tests the point bar deposit was found to be medium dense, the backswamp clay very soft, and the flood plain sediment, soft/loose. The uppermost part of the point bar was found to be significantly less dense, especially near the river. An analysis of liquefaction susceptibility was performed on the silty sand in the upper layer (A) and on the upper part of the fine-grained sand (unit C). The analysis showed that both units should have liquefied. Evidence that the units did liquefy include; sand boil deposits on the flood plain with two distinct grain-size distributions. Some sand boils had grain size distributions similar to the silty sands in unit A. Other sand boils had grain-size distributions similar to the fine sand in unit C.

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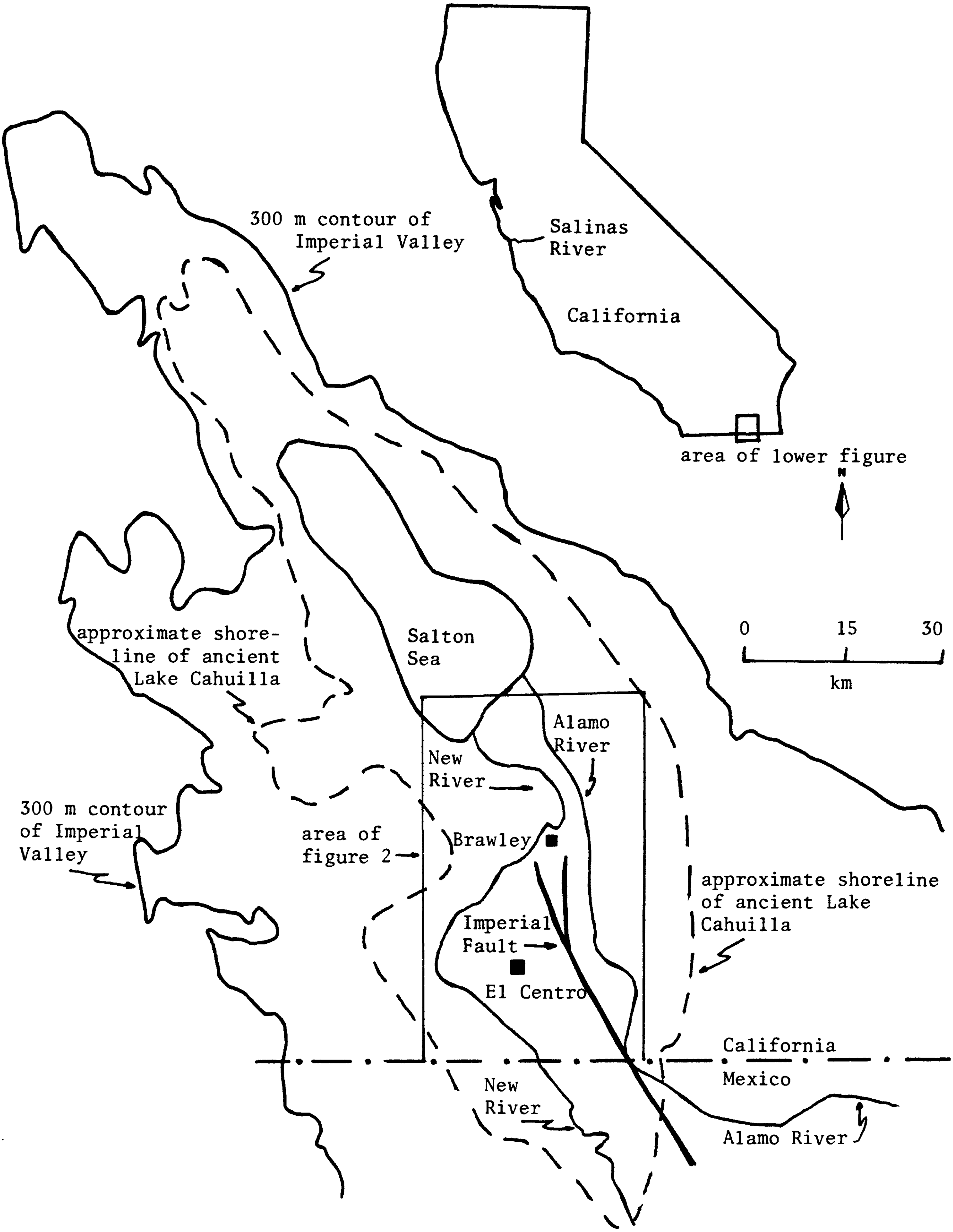


Figure 1. Imperial Valley, California, with valley outlined by the 300 m topographic contour. Extent of ancient Lake Cahuilla marked with dotted line (figure adapted from Van De Kamp, 1973, p. 830).

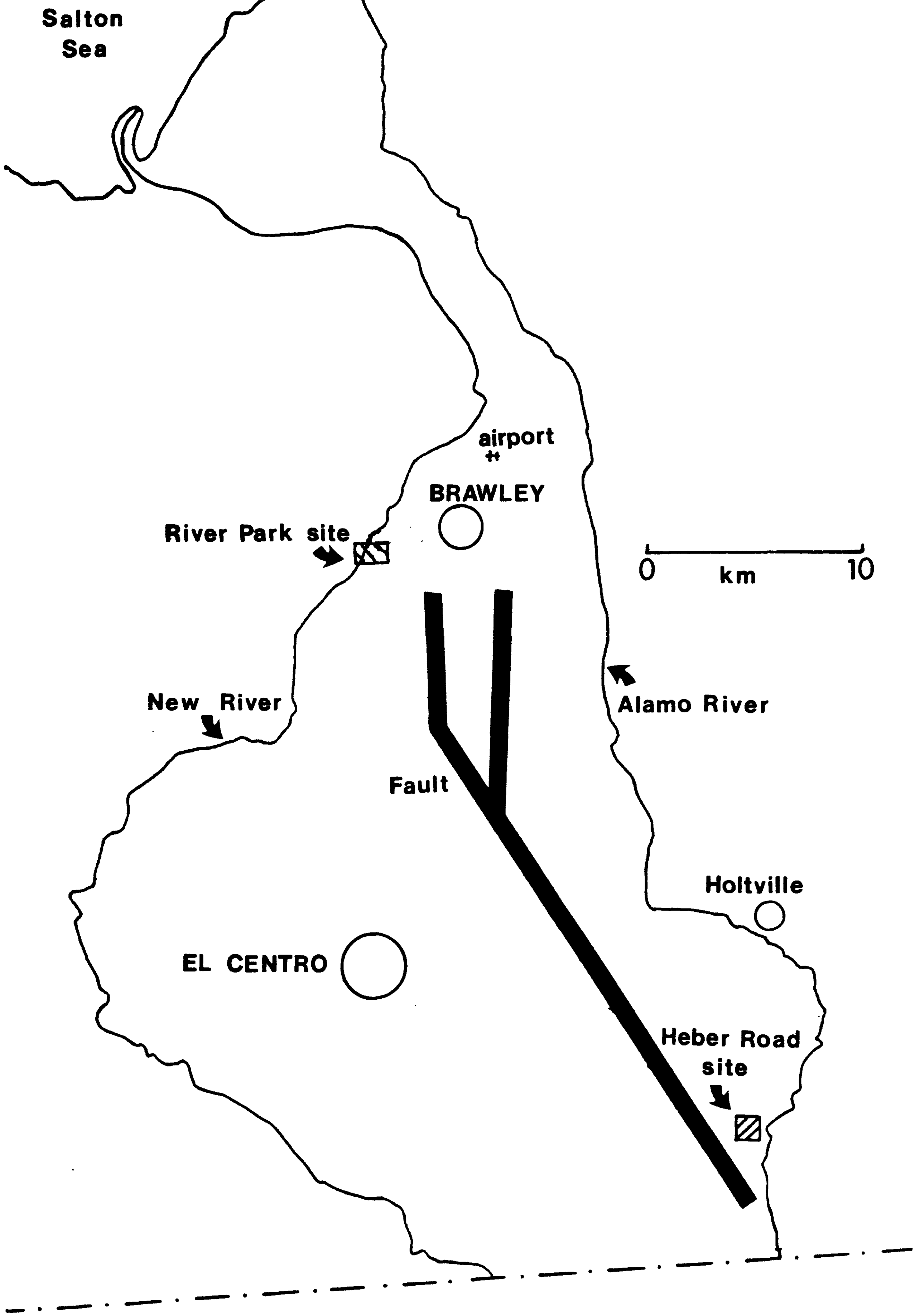


Figure 2. Southern Imperial Valley with Heber Road and River Park sites.

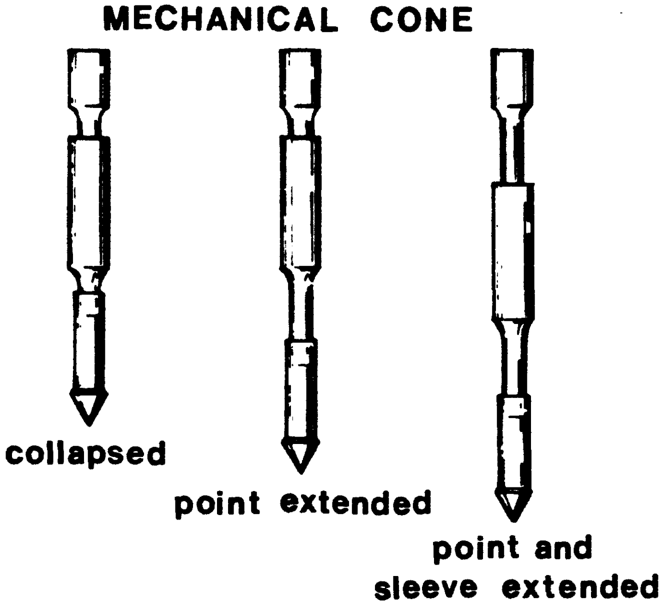
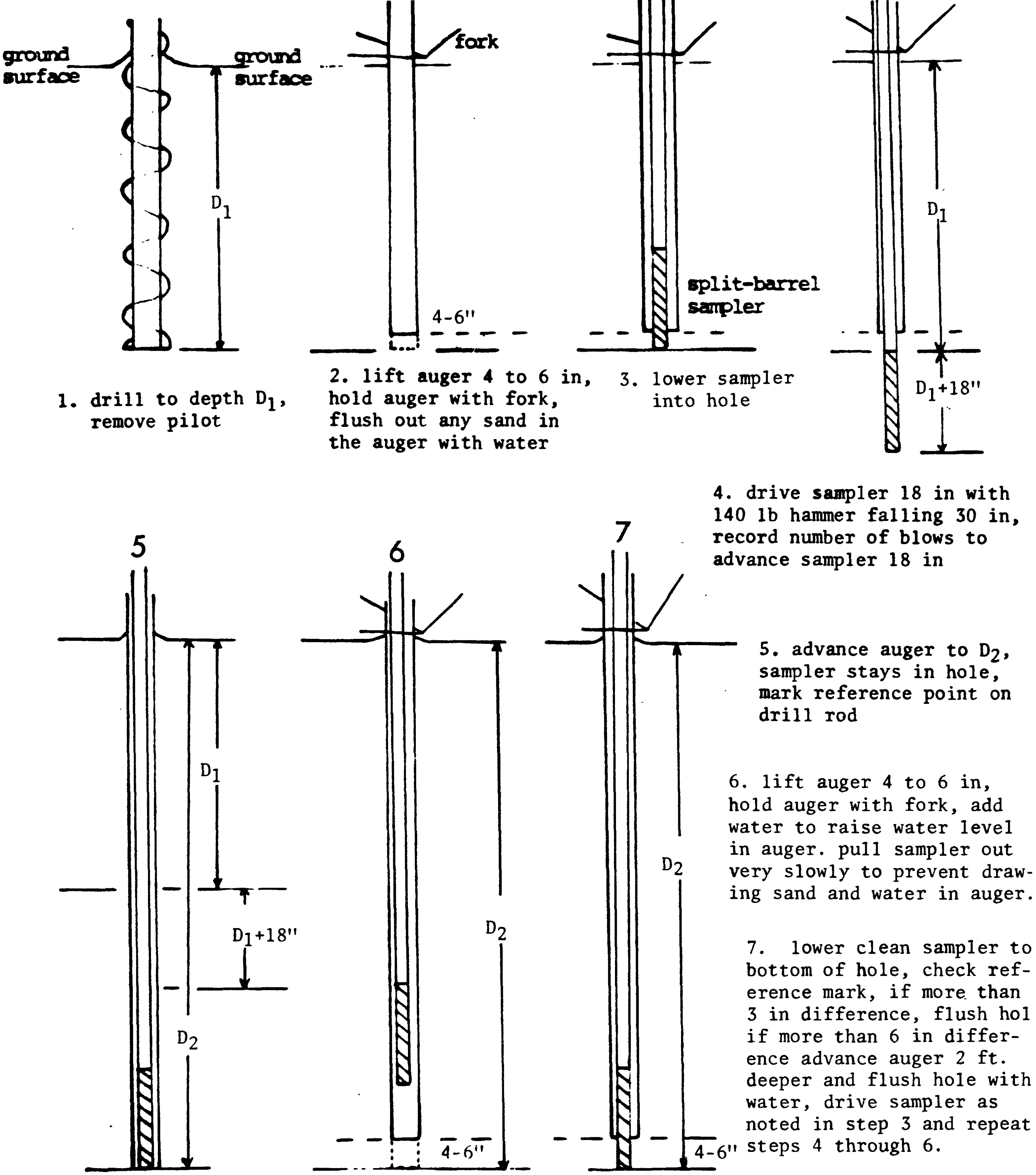


Figure 3. Mechanical, Begemann-type Dutch cone penetrometer. The penetrometer is shown in its three stage operation; 1) collasped, penetrometer is ready to advance to new testing depth, 2) point extended, point resistance is measured, 3) point and sleeve extended, side friction is measured (figure from Sanglerat, 1972, p. 9).



1. drill to depth D_1, remove pilot

2. lift auger 4 to 6 in, hold auger with fork, flush out any sand in the auger with water

3. lower sampler into hole

4. drive sampler 18 in with 140 lb hammer falling 30 in, record number of blows to advance sampler 18 in

5. advance auger to D_2, sampler stays in hole, mark reference point on drill rod

6. lift auger 4 to 6 in, hold auger with fork, add water to raise water level in auger. pull sampler out very slowly to prevent drawing sand and water in auger.

7. lower clean sampler to bottom of hole, check reference mark, if more than 3 in difference, flush hol if more than 6 in difference advance auger 2 ft. deeper and flush hole with water, drive sampler as noted in step 3 and repeat steps 4 through 6.

Figure 4a. Procedures for standard penetration test (SPT).

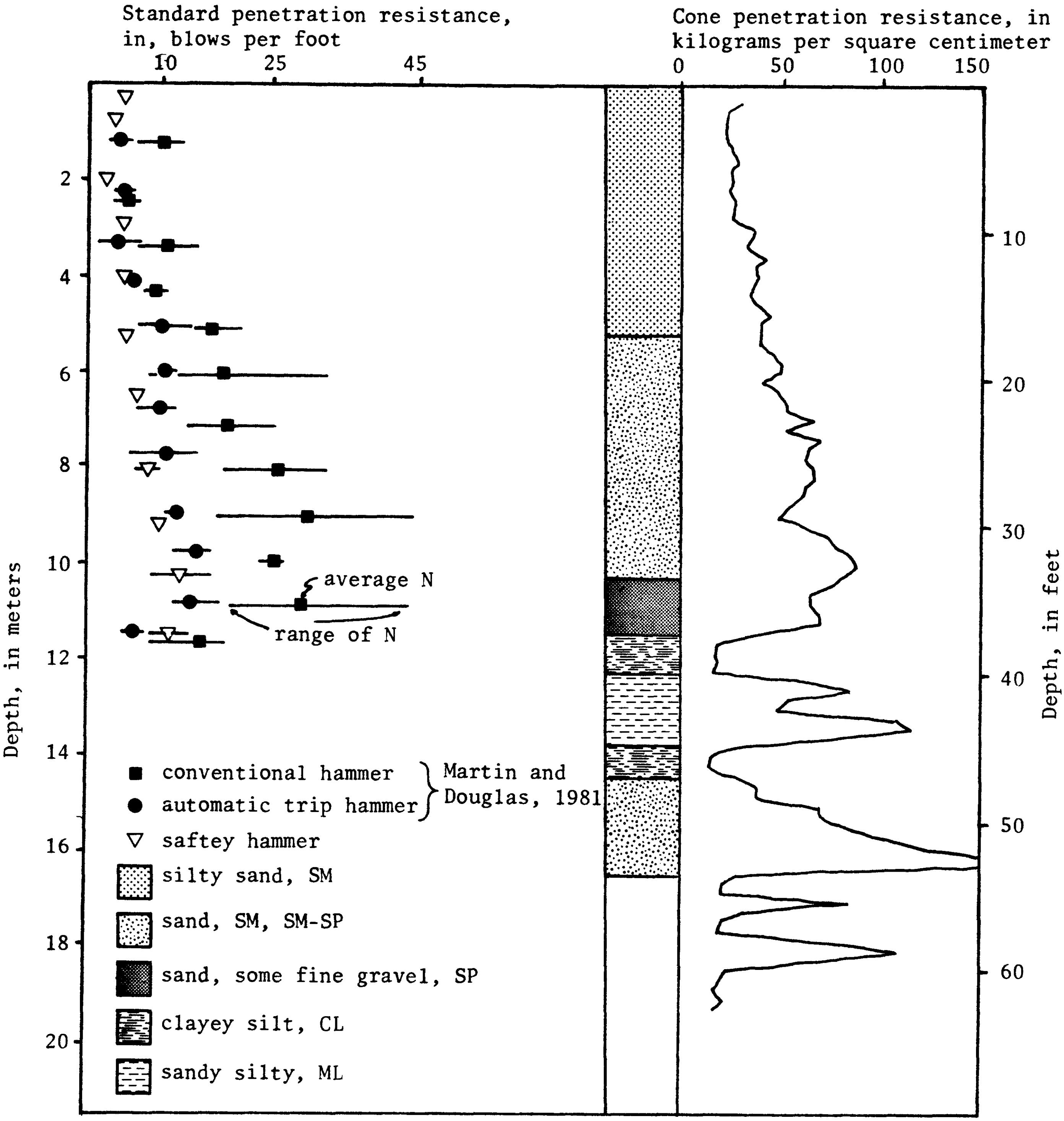


Figure 4b. Standard penetration tests made with 3 different hammers are compared to each other and to a cone penetration test (average of 3 tests) at a site near the Salinas River, California. The 3 hammers used were; 1) conventional hammer with cathead-winch (4 tests), 2) automatic trip hammer, used with a cathead-winch, that controls the fall of the hammer (4 tests), 3) safety hammer with free-fall winch (2 tests).

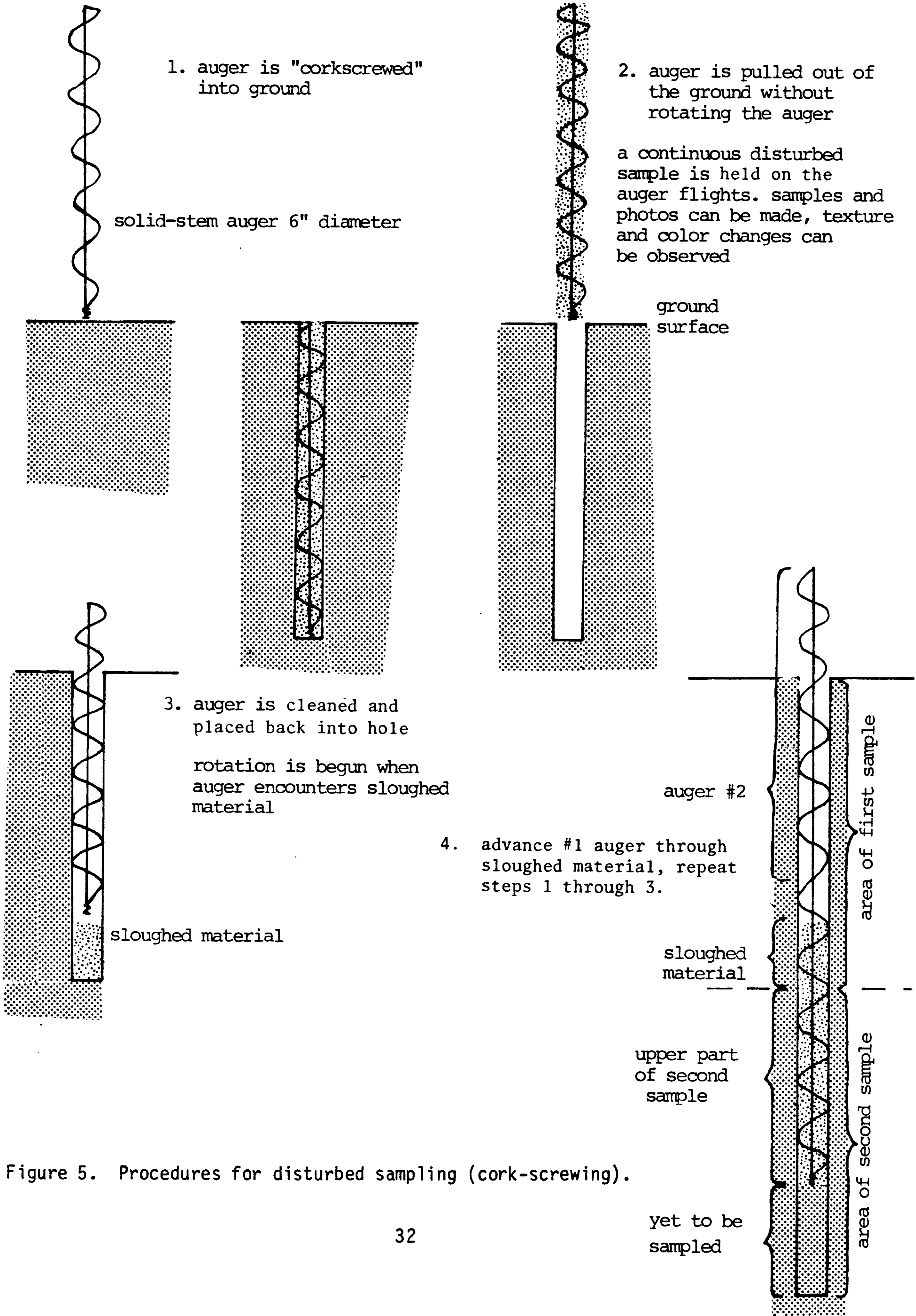


Figure 5. Procedures for disturbed sampling (cork-screwing).

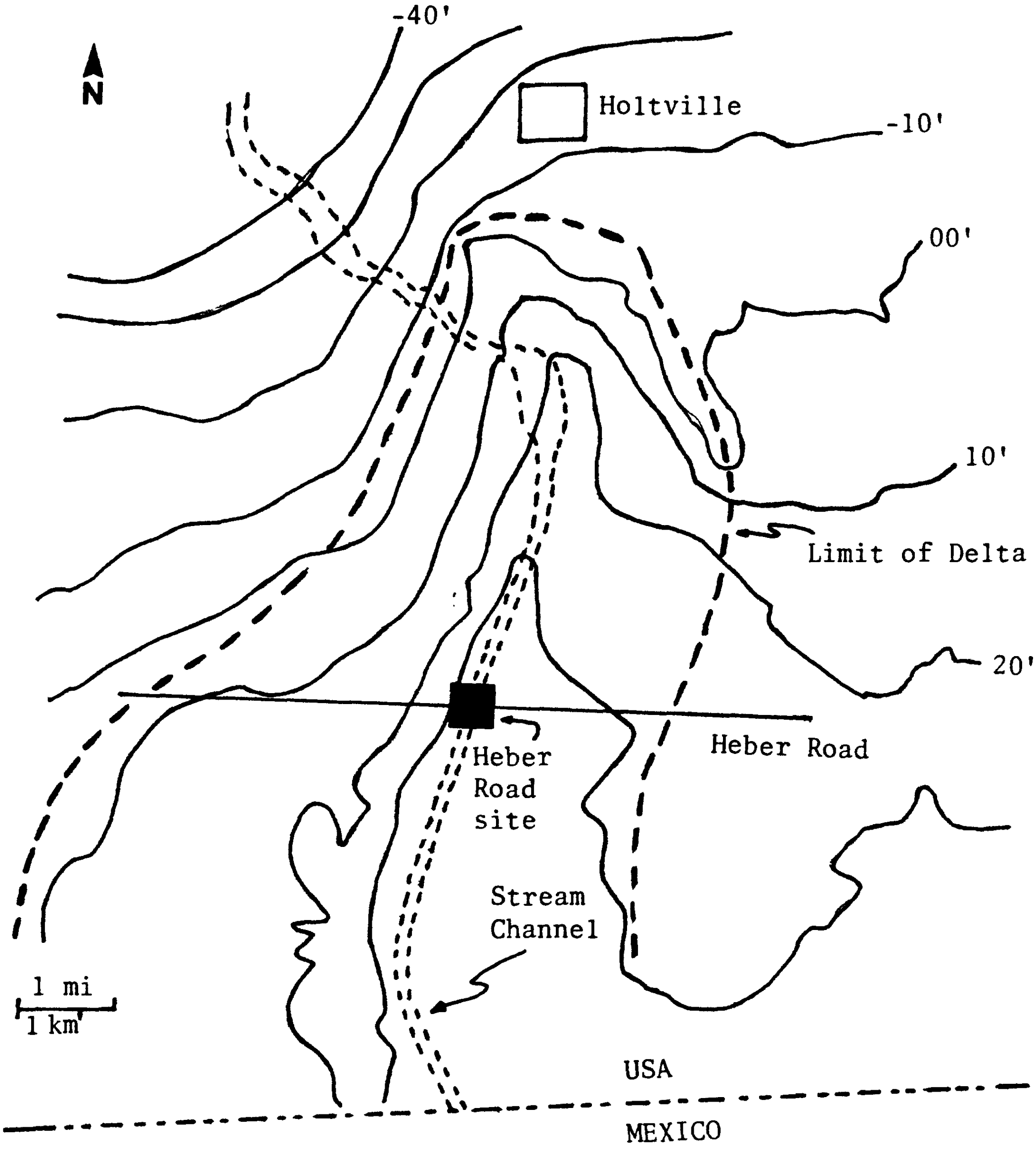


Figure 6. The Heber Road site is located across the relict stream channel that cuts through an ancient delta. The delta is defined by topographic contours and by sandy soils identified by Strahorn and others (1924). Sand boils, ground cracks, and a lateral spread were concentrated within the relict stream channel (figure from Youd and Wieczorek, in press).

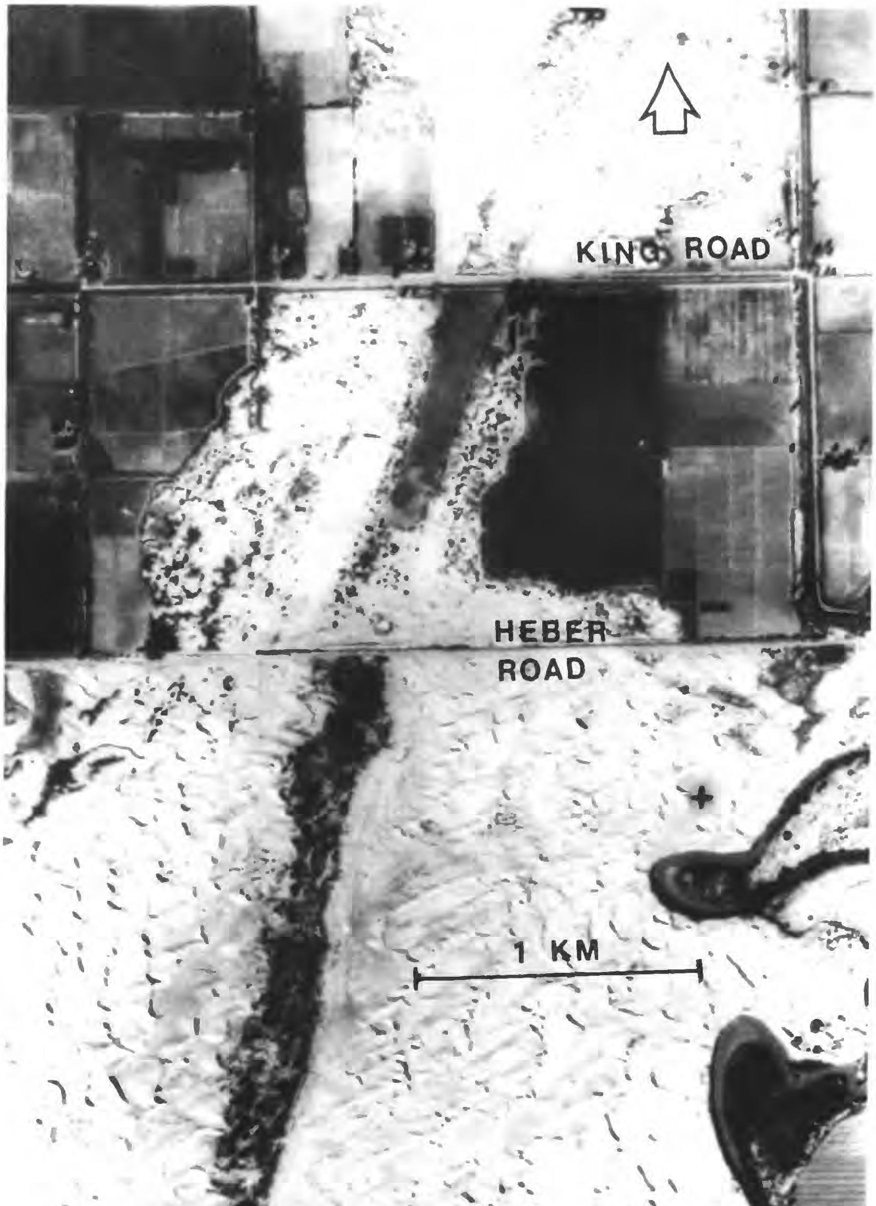


Figure 7. Aerial photograph from 1937 shows outline of relict channel (figure from Youd and Wieczorek, in press).

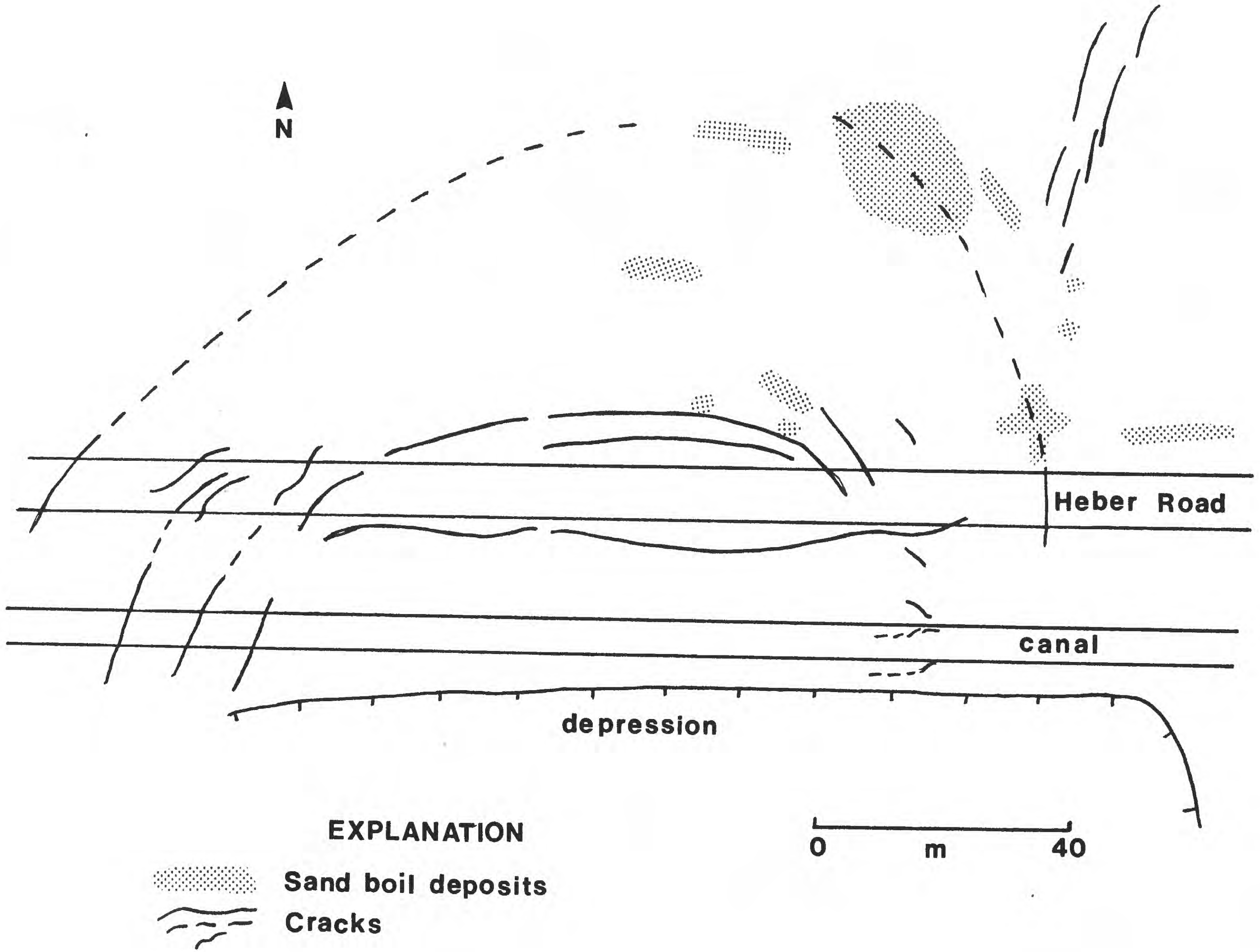


Figure 8. Location of sand boils and ground cracks at Heber Road site (figure adapted from Youd and Wieczorek, in press).

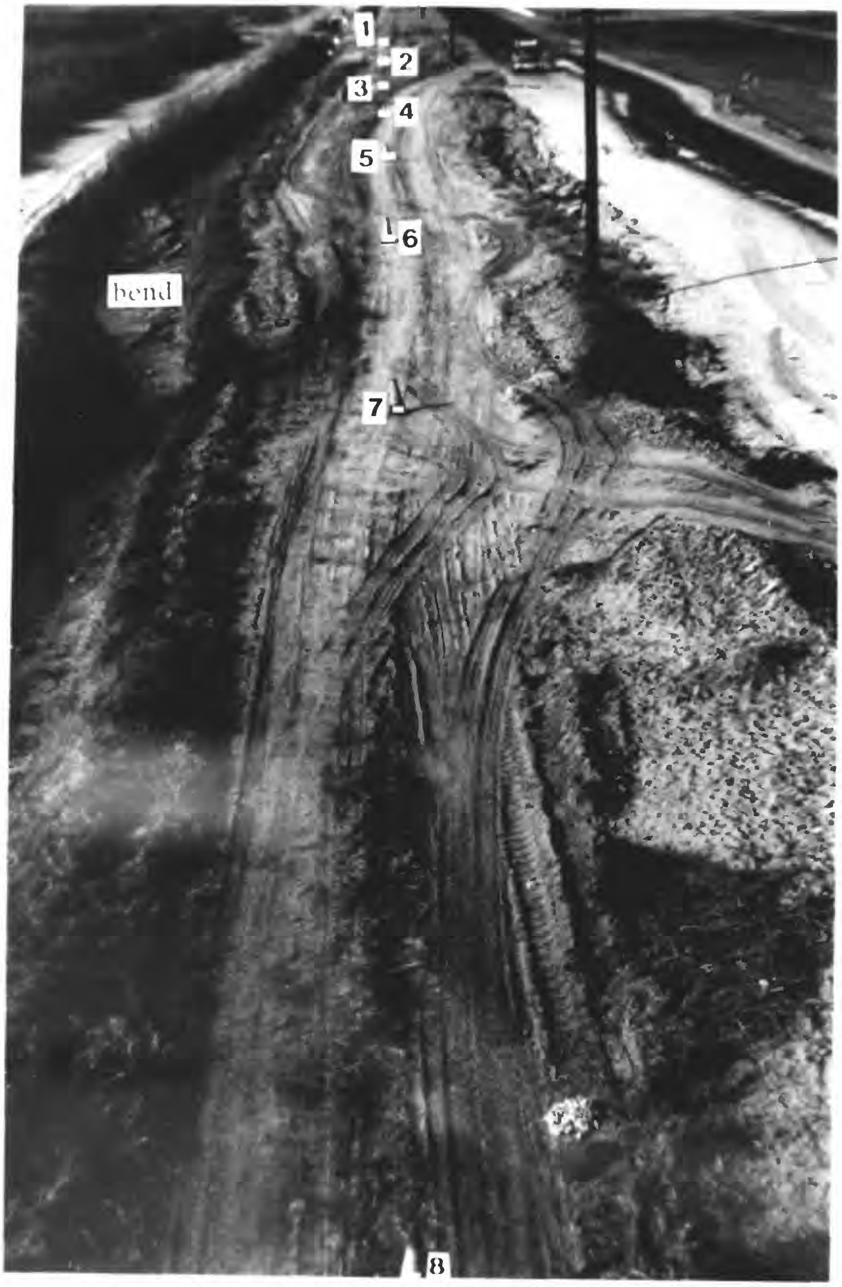


Figure 9. Location of cone penetration tests at Heber Road (view looking west). The bend in the canal was caused by southward movement of the lateral spread.

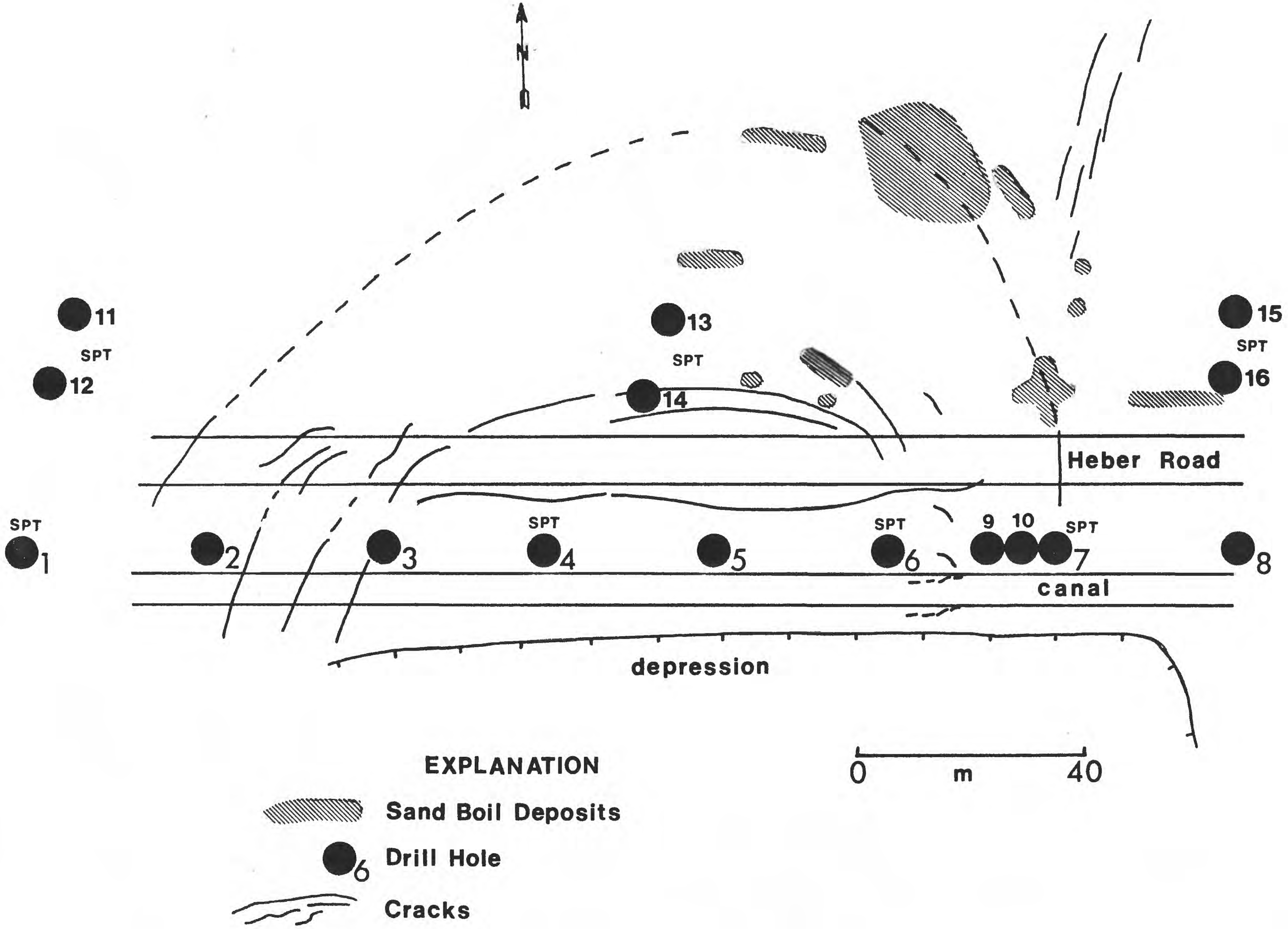


Figure 10. Location of tests at Heber Road site. Cone penetration tests were made at holes 1-16. Standard penetration tests (SPT) were made at holes 1, 4, 6, 7, and between holes 11 and 12, 13 and 14, 15 and 16. Bulk, disturbed samples were taken at holes 1, 4, and 7. Tube samples were taken at holes 1 and 7, and near holes 11 and 12, 13 and 14, 15 and 16.

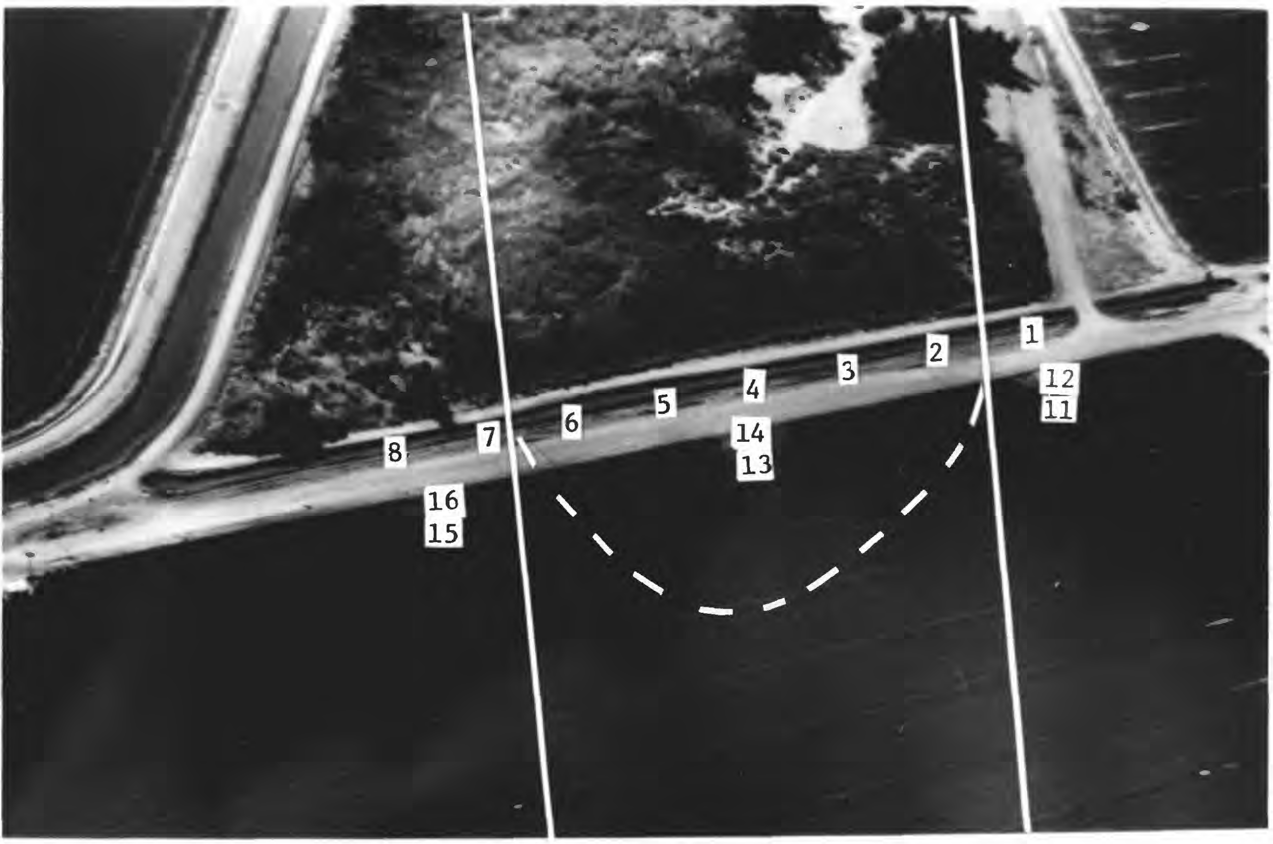


Figure 11. View of Heber Road site looking south. The relict channel is outlined by the solid lines, the general shape of the lateral spread is marked by the dashed line.

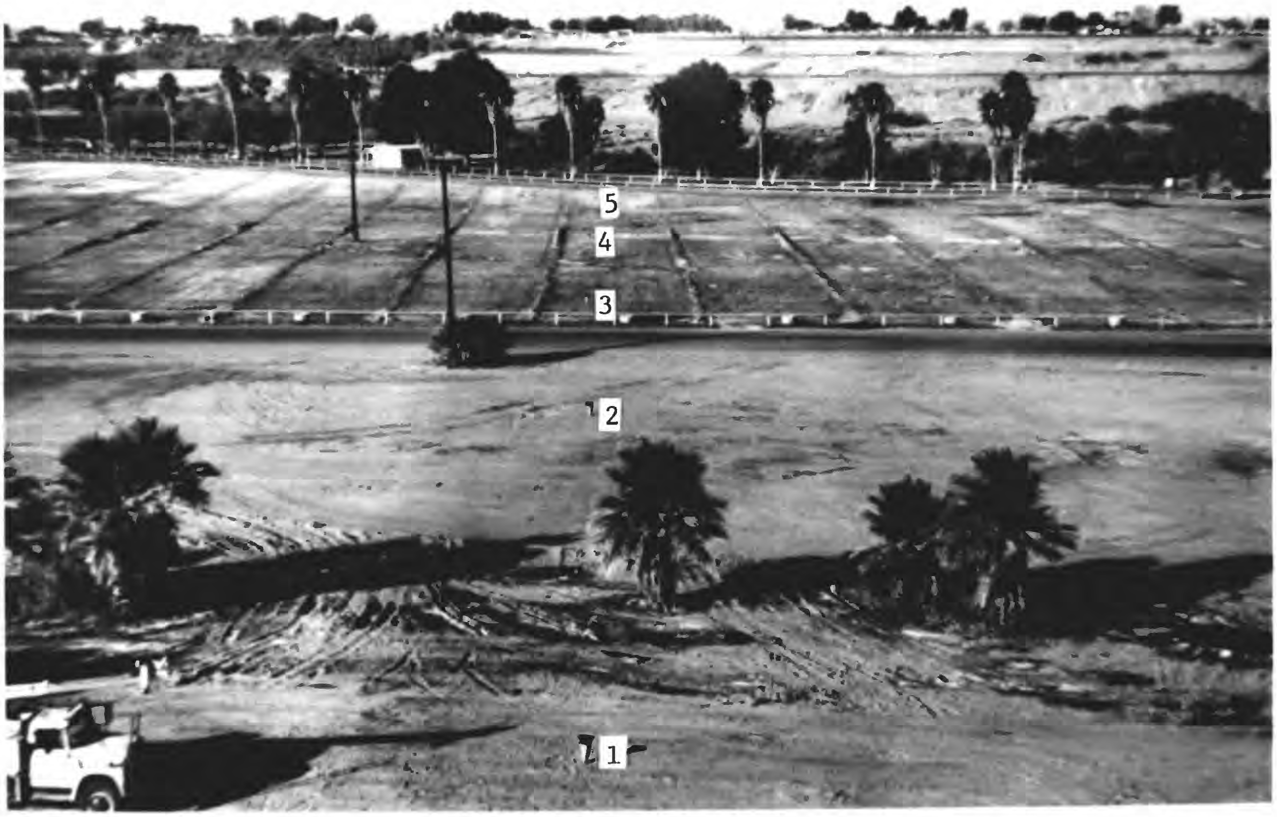


Figure 12. Numbers mark the location of holes on the flood plain at River Park (view looking west).

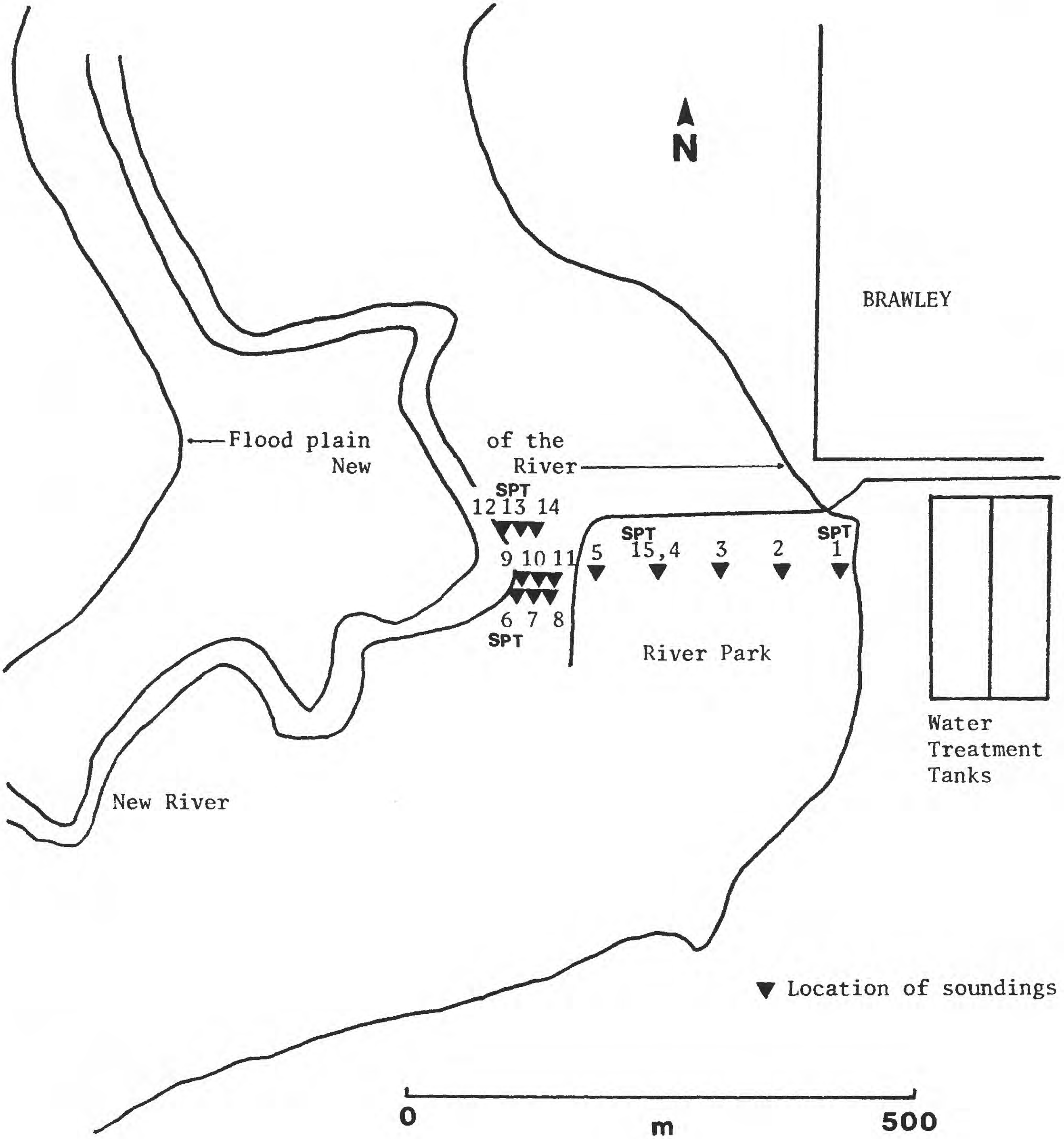


Figure 13. Location of tests at River Park site. Cone penetration tests were made at holes 1-15. Standard penetration tests (SPT) were made at holes 1, 6, 13, and 15. Disturbed samples were taken at holes 1, 4, 6, 8, 9, and 11.

Figure 14. View of River Park looking east. Location of holes is marked by numbers. Profiles of holes 1-5 are shown in figure 20. Profiles of holes 6-14 are shown in figure 21.

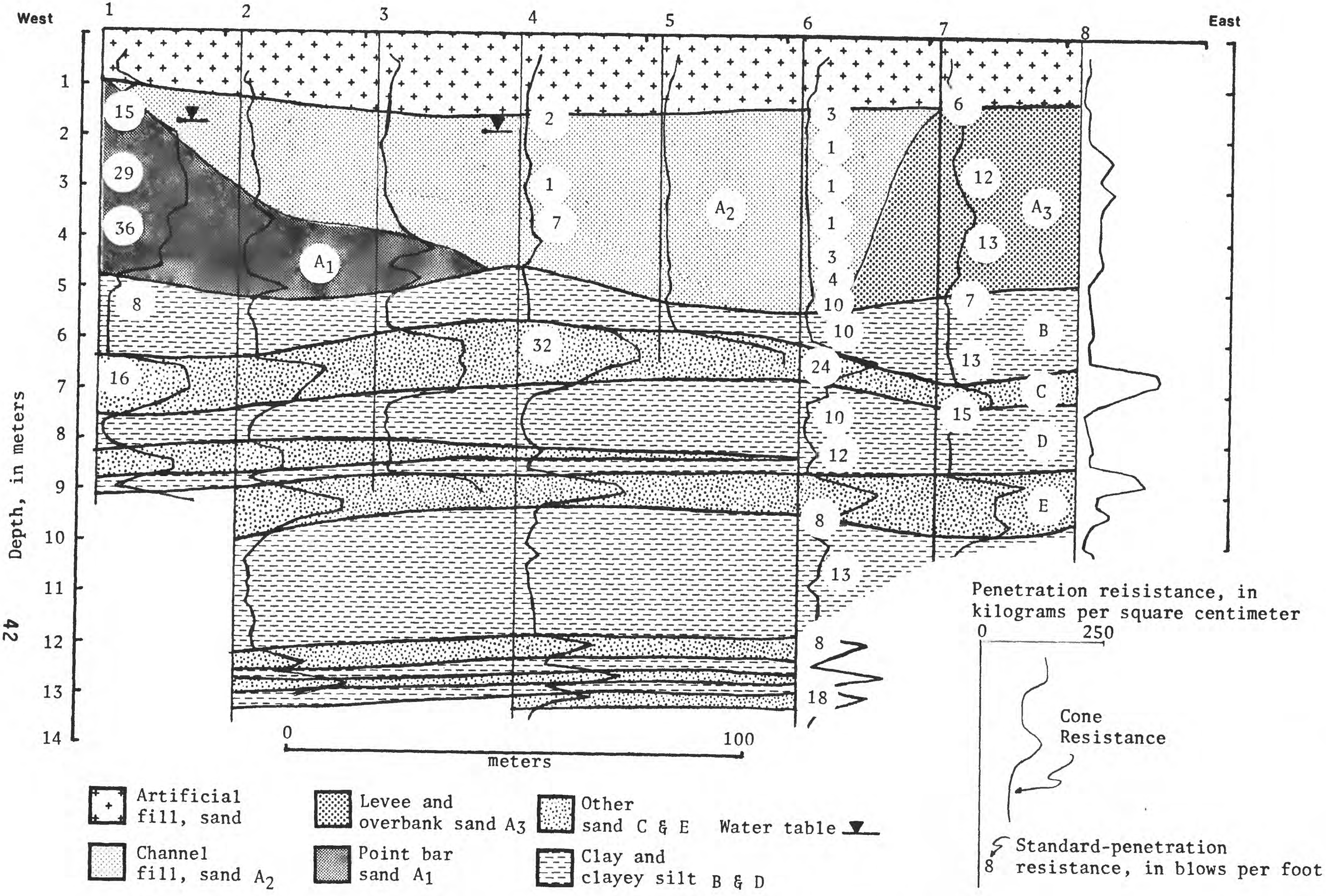


Figure 15. Profile of sediments at Heber Road site. Unit A_2 represents loose channel fill. Units A_1 and A_3 represent point bar deposits and overbank deposits, respectivly. Units B-F represent alternating stream channel and lacustrine deposits.

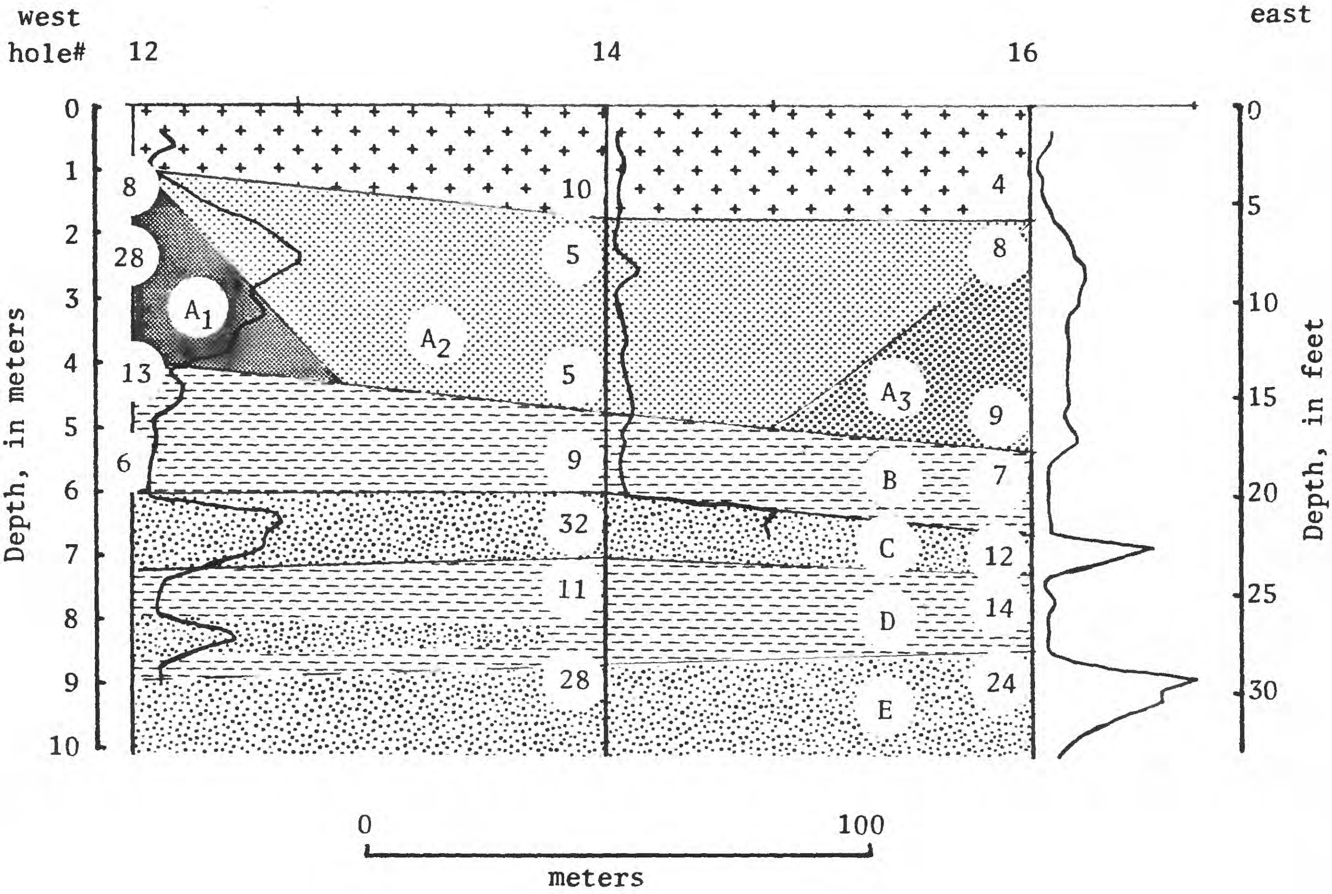


Figure 16. Profile of sediment on north side of Heber Road.

UNITS	$\bar{N}$	$\bar{q}_c$	$\bar{R}_f$	$\bar{D}_r$	approximate depth, in meters
Fill	5	22	3.0	52%	1.5
A_1- top * fine sand	12	75	3.40	80%	1.8
A_1- bottom * fine sand	31	160	2.87	119%	5
A_2- fine sand	4	20	2.76	23%	5
A_3- fine sand	11	49	2.46	69%	5
B- clay	8	22	3.36	-	6
C- fine sand	23	169	2.56	105%	7
D- clay	13	27	4.00	-	9
E- fine sand	26	138	2.53	88%	10
F- clayey silt	11	38	3.17	-	12

$\bar{N}$ = Average N, in blows per foot
$\bar{q}_c$= Average cone resistance, in kg/cm^2
$\bar{R}_f$= Average ratio, in percent
$\bar{D}_r$= Average relative density, in per cent

Mechanical cone values converted to electrical cone values (Schmertmann, 1978a, p. 59)

Relative density was calculated from:

$$D_r = 1/2.91*\ln(q_c/12.31*\sigma_v'^{0.71})*100\%$$

σ_v' = effective vertical stress (from Schmertmann, 1978a, p. 40)

* The top part of unit A_1 is characterized by ripple bedding and medium dense sand. The bottom part of the unit is characterized by horizontal bedding and dense sand.

Figure 17. Generalized characteristics of sediment at Heber Road site. Data include average; blows per foot (N), point resistance/friction ratio, and relative density (D_r).

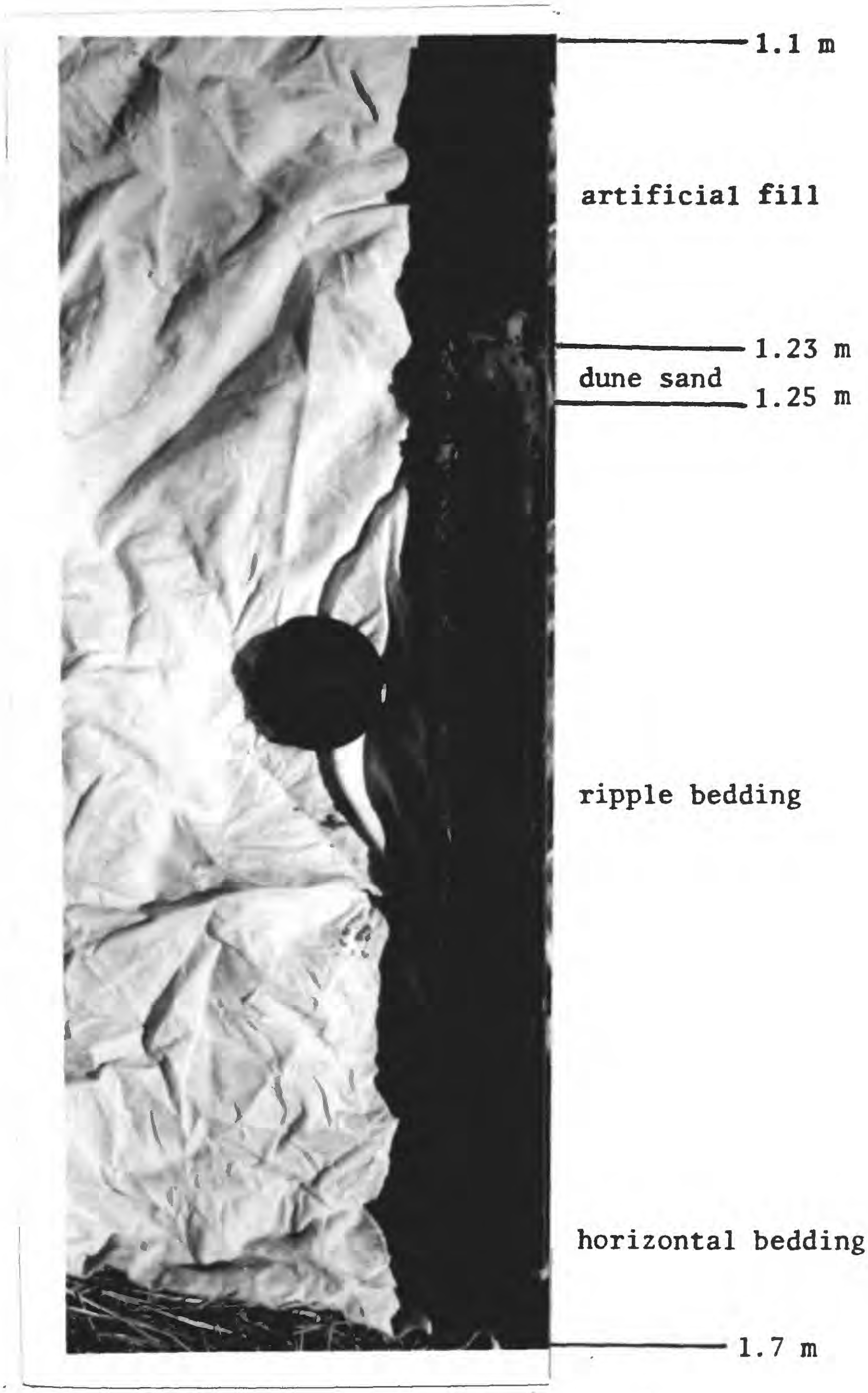


Figure 18. Standard penetration sample, 1.1-1.7 m, hole 1. 0-13 cm, artifical fill; 13-15 cm, thin layer of dune sand (?); 15-51 cm, ripple bedding from the upper portion of the point bar deposit. The change to horizontal bedding can be seen at the bottom of the sample.

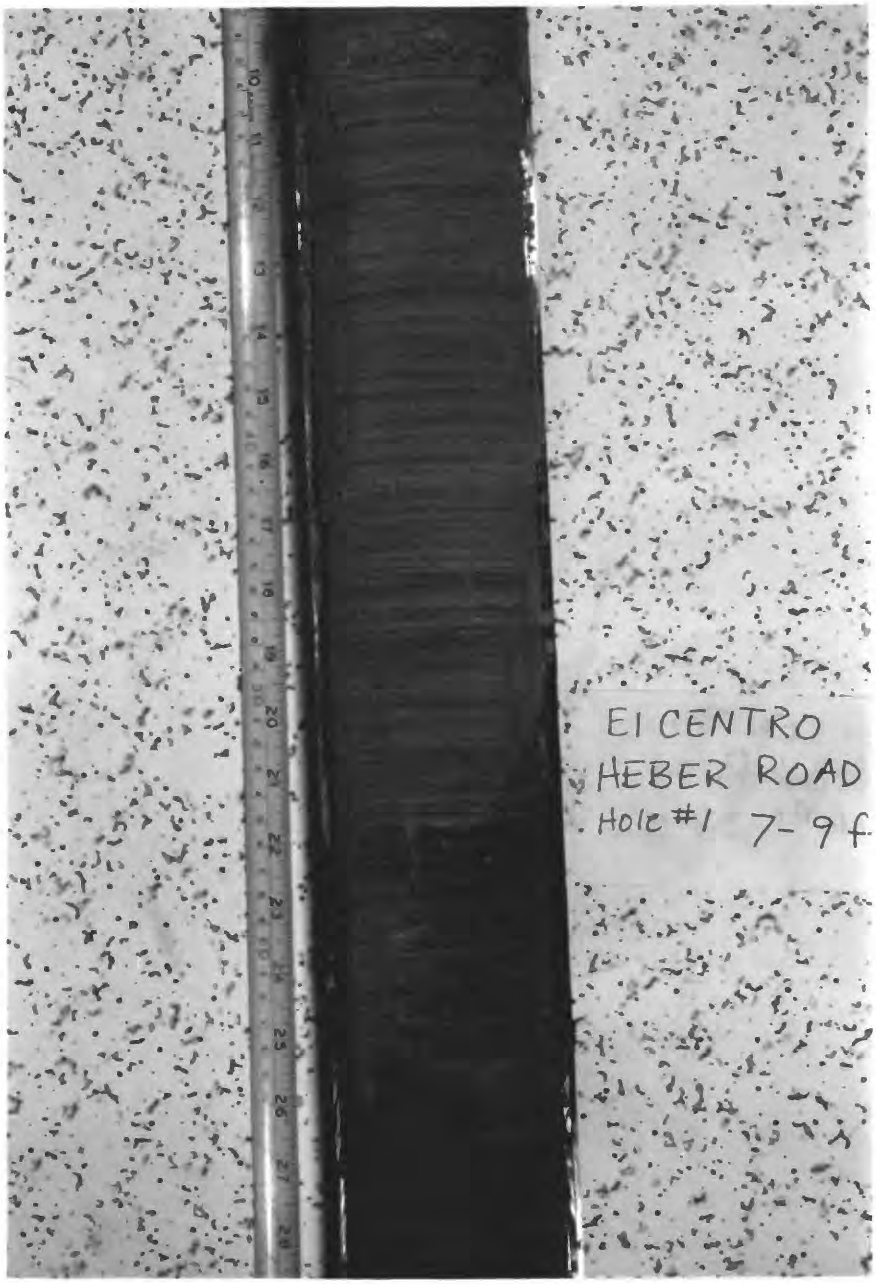


Figure 19. Tube sample, 2.1-2.7 m, hole 1. This sample contains 61 cm of undisturbed horizontal bedding from the point bar deposit.

Figure 20. Tube sample from the overbank deposit, 3.0-3.7 m, hole 7. The left hand sample is from 3.0-3.4 m, the right hand sample is from 3.4-3.7 m. The disturbed bedding at 3.2 m is probably from sampling disturbance.

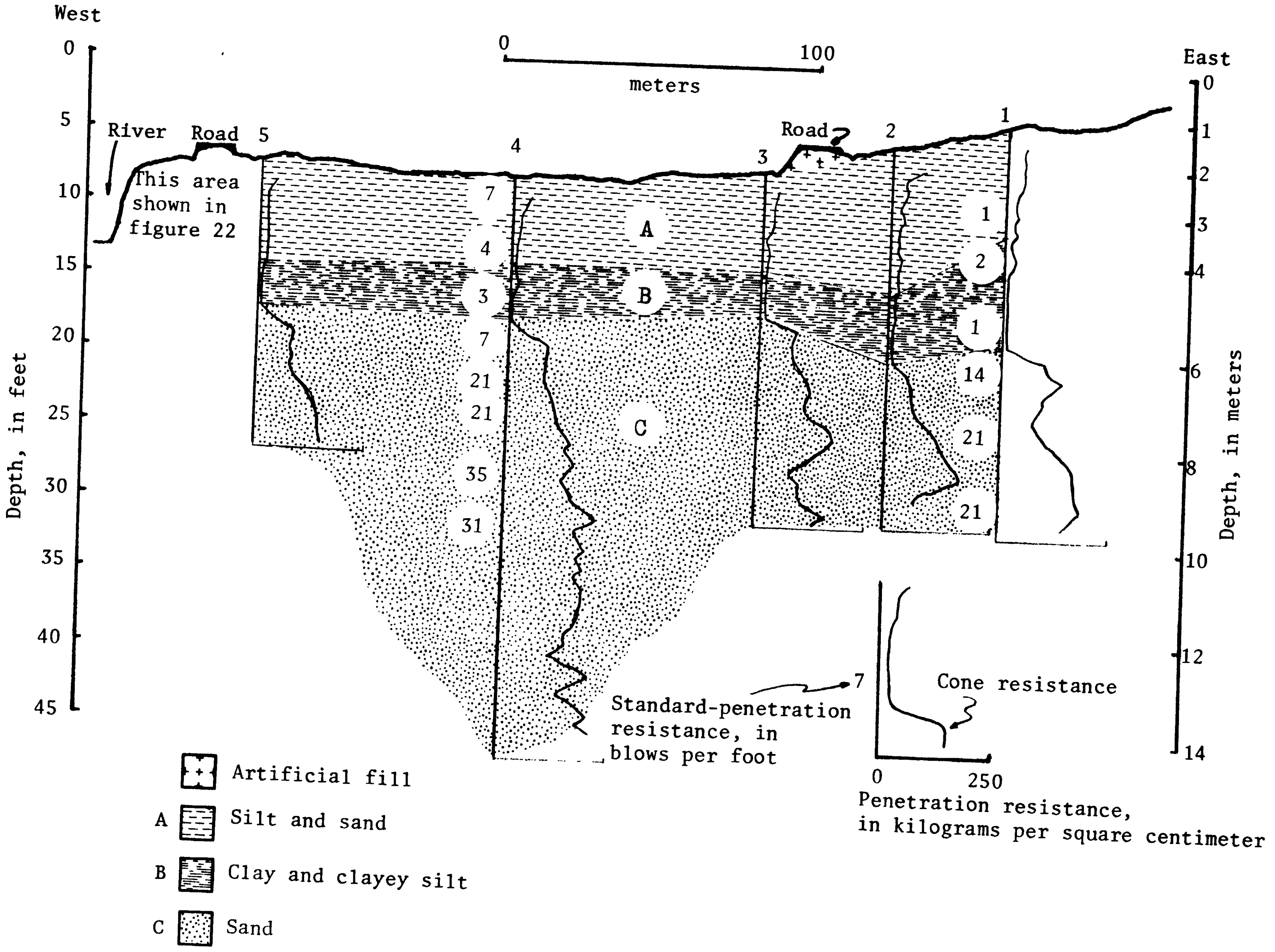


Figure 21. Profile of sediment units on River Park flood plain. Unit A represents overbank flood plain deposition. Unit B represents flood basin deposition. Unit C represents channel deposition, probably a point bar.

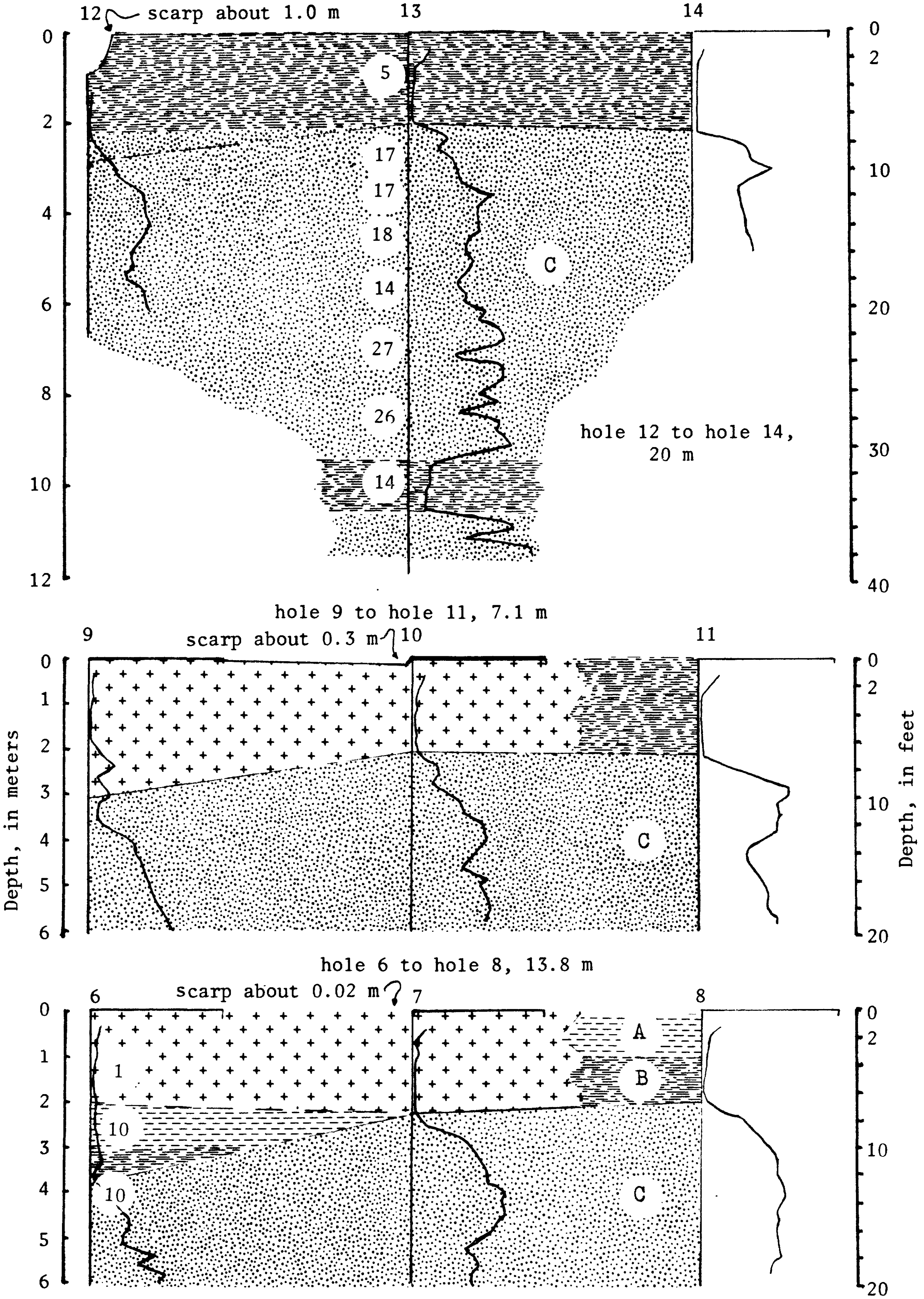


Figure 22. Profile of sediment units near slump area. In general, the units carry over from the flood plain. The most noticeable difference is the artificial fill near holes 6, 7, 9, and 10.

UNITS	$\bar{N}$	$\bar{q}_c$	$\bar{R}_f$	$\bar{D}_r$	approximate depth, in meters
Fill*	-	18	2.13	-	variable
A- clayey silt to silty sand	3	24	2.57	54%	2.0
B- clay to clayey silt	3	9	3.40	-	3.0
C top** fine to medium sand	7	69	2.28	80%	
C bottom** fine to medium sand	23	138	2.51	102%	
C all** fine to medium sand	21	117	2.41	99%	11.0

$\bar{N}$ = Average N, in blows per foot
$\bar{q}_c$= Average cone resistance, in kg/cm^2
$\bar{R}_f$= Average ratio, in per cent
$\bar{D}_r$= Average relative density, in per cent
Mechanical cone values converted to electrical cone values using Schmertmann, 1978a, p. 59. Relative density was calculated from:

$$D_r = 1/2.91*\ln(q_c/12.31*\sigma_v'^{\,0.71})*100\%$$

σ_v' = effective vertical stress (from Schmertmann, 1978a, p. 40)

* Fill replaces units A and B in holes 6 and 9 on the slump
** The top 1-m of unit C is medium dense sand, whereas the bottom of the unit is dense sand

Figure 23. Generalized characteristics of sediment at River Park site. Data include average; blows per foot (N), point resistance/friction ratio, and relative density (D_r).

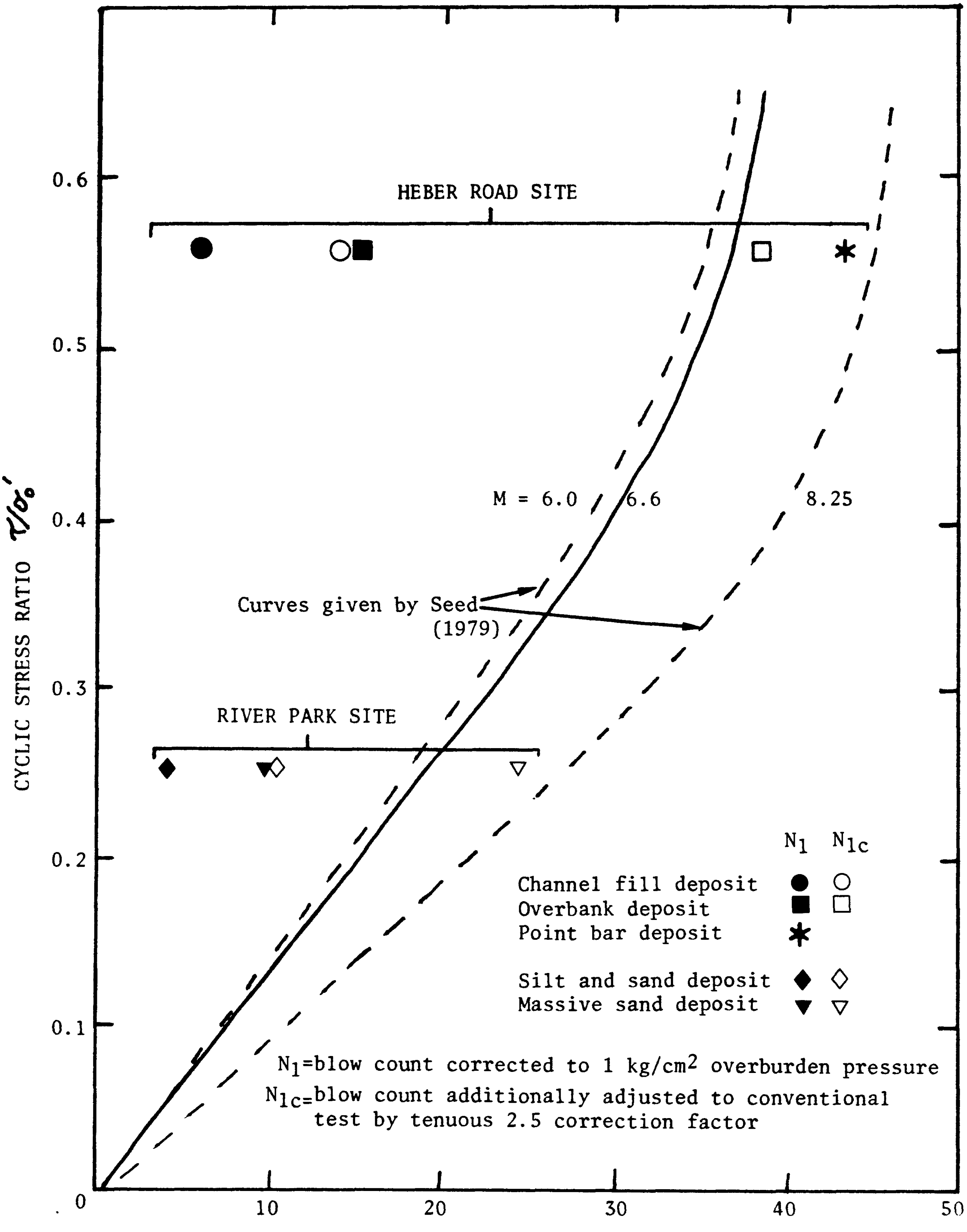
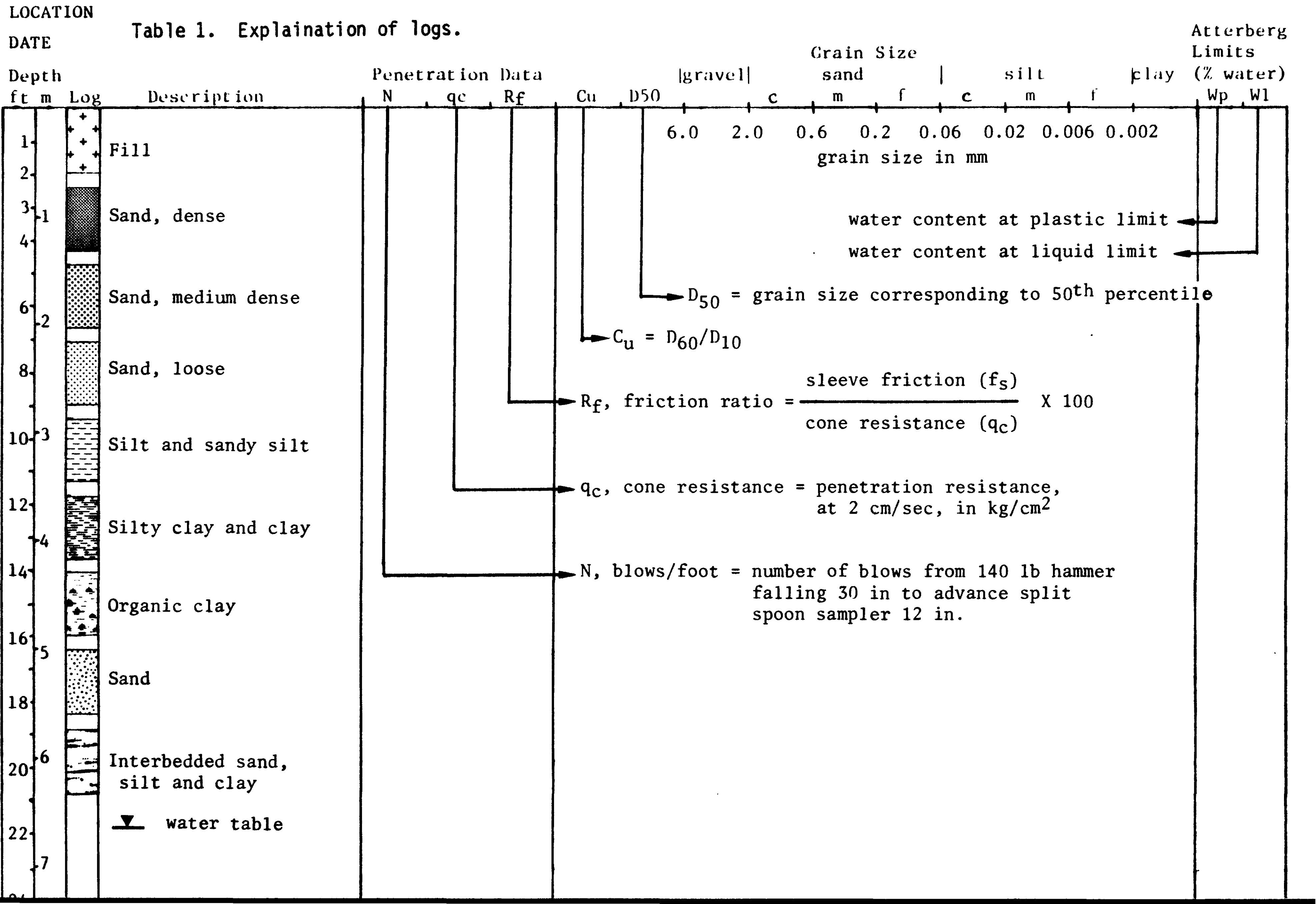


Figure 24. Liquefaction susceptibility from cyclic stress ratio and the corrected penetration resistance, following the procedure developed by Seed (1979).

Table 1. Explaination of logs.



water content at plastic limit

water content at liquid limit

D_{50} = grain size corresponding to 50th percentile

$C_u = D_{60}/D_{10}$

$$R_f\text{, friction ratio} = \frac{\text{sleeve friction } (f_s)}{\text{cone resistance } (q_c)} \times 100$$

q_c, cone resistance = penetration resistance, at 2 cm/sec, in kg/cm^2

N, blows/foot = number of blows from 140 lb hammer falling 30 in to advance split spoon sampler 12 in.

LOCATION EL CENTRO-

DATE December 1979

Table 2. Log of Heber Road 1.

Depth		Log	Description	Penetration Data			Cu	D50	gravel	Grain Size sand			silt			clay	Atterber Limits (% water	
ft	m			N	qc	Rf				c	m	f	c	m	f		Wp	Wl
1		+	fill, fine sand		52	1.8												
2					32	3.3												
					32	2.5												
3					88	2.1	2.8	.100	-	-	1	78	15	2	1	3		
	1	▓	(SP) fine sand, dark brown (7.5YR4/4), dense well sorted, abundant horizontal laminations		36	5.6												
4					70	2.7												
				15	84	4.0												
					130	2.1	2.7	.105	-	-	1	85	10	4				
6	2		▼		160	2.5												
					160	2.7	2.4	.110	-	-	1	84	13	2				
					166	3.2	2.4	.100	-	-	-	80		20				
8					160	2.7												
				29	180	2.2												
					180	2.4	2.3	.113	-	-	2	85	11	2				
10	3				176	2.3												
					176	3.6	2.0	.115	-	-	3	87		10				
					140	4.4	2.3	.116	-	-	5	84		11				
12					148	2.5												
				36	148	2.3												
	4				128	4.9	1.8	.120	-	-	4	88		8				
14					116	2.9												
					130	2.7	2.2	.120	-	-	6	84		10				
		=	(CL-ML) silt, dark brown (7.5YR4/3) very poorly sorted		36	3.0												
16					48	5.0												
	5			8	24	2.8	-	.021	-	-	-	8	43	24	9	16	20	24
		▒	(CL) silty clay, reddish brown (5YR4/3) reddish mottling, medium		24	2.8												
18					22	3.6												
					20	4.0												
	6				22	4.2	-	.003	-	-	-	4	9	27	22	38	25	47
20					24	5.0												
					24	11.1												
		░	(SP) sand, fine, med dense, mod-well sorted contains turret gastropods, dilatant		180	0.4												
22					190	2.1												
	7			16	190	2.5												
					160	1.3												
24					104	3.3	3.8	.130	-	-	15	65		20				
		▒	(CH) clay, reddish brown(5YR4/3) medium		18	4.4												
					14	3.8												
26	8				20	25.3												
					44	6.1	-	.001	-	-	-	-	1	13	25	62	28	66
		░	(SP) sand, fine, dark brown (7.5YR4/4) well sorted		160	2.0												
28					160	1.7	3.8	.135	-	-	15	71	6	2	2	4		
					80	3.8												
		=	clayey silt		30	24.4												
30	9	░	sand, dense		200	2.7	3.3	.140	-	-	13	73	11	3				
					260													
32																		
	10																	
34																		
36	11																	
38																		
	12																	
40																		
42																		
	13																	
44																		
46	14																	
48																		

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DATE December 1979

Table 3. Log of Heber Road 2.

Depth ft	m	Log	Description	Penetration Data N	qc	Rf	Cu	D50	Grain Size gravel	sand c	sand m	sand f	silt c	silt m	silt f	clay	Atterber Limits (% water Wp	Wl
1					24	0.0												
2					-	-												
					16	2.5												
3	1				10	6.7												
					30	3.6												
4					24	2.8												
					16	3.3												
					20	2.7												
6	2				32	1.7												
					34	3.5												
					24	2.8												
8					42	1.9												
					44	1.8												
					48	1.7												
10	3				36	3.3												
					40	3.3												
					80	2.8												
12					58	2.1												
					30	3.6												
	4				12	6.7												
14					10	2.7												
					18	3.0												
					20	2.0												
16					100	1.6												
	5				40	6.3												
					24	5.6												
18					24	2.2												
					36	3.7												
					36	4.4												
20	6				36	27.0												
					34	3.9												
					180	1.7												
22					154	3.0												
	7				130	3.3												
					116	2.4												
24					66	4.0												
					36	4.4												
					32	3.3												
26	8				24	3.3												
					88	1.8												
					92	1.4												
28					96	3.8												
					22	15.8												
					128	1.6												
30	9				220	2.6												
					210	3.3												
					116	2.8												
					68	3.3												
32					50	3.2												
	10				36	2.6												
34					18	4.4												
					30	2.7												
					24	3.9												
36	11				30	2.7												
					20	11.3												
					42	0.3												
38					48	4.2												
					30	3.1												
					40	4.0												
40	12				50	0.8												
					150	3.3												
					76	5.3												
					240	2.6												
42					116													
	13																	
44																		
46	14																	
48																		

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DATE December 1979

Table 4. Log of Heber Road 3.

Depth ft	Depth m	Log	Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterber Limits (% water Wp	Wl
1					24	2.2												
2					44	1.5												
					34	2.4												
3	1				24	3.3												
					26	2.6												
4					20	2.0												
					16	0.8												
					14	3.8												
6	2				16	1.7												
					8	1.7												
8					14	1.0												
					20	1.3												
					18	3.7												
					20	3.3												
10	3				20	1.3												
					30	2.7												
					44	3.0												
12					50	4.3												
					84	2.5												
	4				124	2.0												
14					46	7.8												
					26	4.1												
					92	0.9												
16					52	3.8												
	5				22	2.4												
					22	3.0												
18					20	4.0												
					26	5.1												
					180	1.1												
20	6				180	2.2												
					170	2.8												
					184	2.5												
22					170	1.6												
	7				160	2.7												
					36	5.9												
24					20	2.7												
					28	2.4												
					22	1.8												
26	8				36	3.7												
					28	0.5												
					38	3.9												
28					18	29.6												
					200	3.3												
					220													
30	9																	
32																		
	10																	
34																		
36	11																	
38																		
40	12																	
42																		
	13																	
44																		
46	14																	
48																		

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Table 5. Log of Heber Road 4.

Depth		Log	Description	Penetration Data			Cu	D50	gravel	Grain Size sand			silt			clay	Atterberg Limits (% water)	
ft	m			N	qc	R_f				c	m	f	c	m	f		Wp	Wl
1					40	2.0	-	.100	-	-	8	62	12	4	4	10		
2			fill, fine sand		32	2.1												
					26	2.6												
3	1				20	3.3	-	.080	-	-	4	52	12	10	7	15		
					12	4.4												
4					12	1.1												
			brownish	2	14	1.0	18	.110	-	-	8	67	10	6	3	6		
			▼ grayish		12	1.1												
6	2		dark grayish brown		10	1.3	-	.110	-	-	7	71	5	4	3	10		
			dark brown		10	4.0												
			(SM) silty sand and very fine sand, brown, very loose, moderately-poorly sorted		14	1.9												
8					24	1.1	3.7	.110	-	-	6	74	13	2	1	4		
				1	18	2.2	6.6	.100	-	-	4	70	16	3	3	4		
					8	5.0												
10	3				20	2.0												
					28	2.4												
					28	3.3	-	.020	-	-	4	38	8	6	13	31		
12				7	28	1.9	11	.112	-	-	13	63	12	4	4	4		
	4				46	1.4	-	.140	-	-	26	50	12	3	3	6		
			(SM) sand, poorly sorted		34	1.2												
14					28	4.8	-	.017	-	-	2	5	38	26	11	18	18	29
					8	1.7												
			(CL) clayey silt and silty clay, reddish brown (5YR4/3) with reddish mottling redder below 17.5'		18	3.7	-	.001	-	-	-	2	18	6	16	58		
16					16	1.7												
	5			7	18	3.0												
					22	4.8												
18					18	14.8												
					180	3.0												
	6		(SP) fine sand, brown well sorted, dilatant		220	2.4												
20					280	2.6												
				32	240	2.8												
			silty sand, poorly sorted at base		160	3.2	4.1	.130	-	-	13	76	2	1	2	6		
22					124	3.2												
	7				40	6.0	-	.082	-	-	6	61	16	5	4	8		
					20	2.7	-	.002	-	-	-	8	5	15	23	49	24	49
24			(CL) silty clay, reddish brown (5YR4/3), medium stiff,contains interbeds of silty sand		12	4.4												
					12	2.2												
					14	6.7												
26	8				20	8.7												
			(SM) silty sand, very poorly sorted		60	1.3	-	.100	-	-	5	63	7	5	6	14		
					20	6.7												
28					18	33.3												
			(SM) fine sand, poorly sorted		200	1.3												
	9				220	2.4	6.6	.150	-	-	22	66	3	3	2	4		
30					60	4.4												
			(SM) silty sand, very poorly sorted		36	3.3	-	.090	-	-	9	53	13	7	5	13		
					40	2.7												
32					28	5.7												
			clayey silt		20	0.7												
	10				46	4.9	-	.090	-	-	4	59	5	7	6	19		
					22	3.6												
34			clayey silt		24	4.4												
					24	5.0												
					38	2.1												
36	11				34	3.9												
					36	3.0												
					42	3.2												
38					46	2.9												
					160	3.2												
	12				76	5.3												
40					58	1.1												
					220	2.6												
					54	3.7												
42					160	2.7												
	13				50	2.7												
					34	2.4												
44					30	2.7												
					30	4.4												
					28	3.3												
46	14				110													
48																		
	15																	

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Table 6. Log of Heber Road 5.

Depth		Log	Description	Penetration Data			Cu	D50	Grain Size gravel	sand			silt			clay	Atterberg Limits (% water)	
ft	m			N	qc	R_f				c	m	f	c	m	f		Wp	Wl
1					32	1.7												
2					28	1.0												
					22	1.2												
3	1				14	3.8												
					10	5.3												
4					6	2.2												
					6	4.4												
					6	2.2												
6	2				10	2.7												
					8	3.3												
					4	6.7												
8					14	1.0												
					20	1.3												
					20	2.0												
10	3				12	3.3												
					10	2.7												
					14	1.9												
12					14	1.9												
	4				16	1.7												
					16	1.7												
14					22	1.8												
					14	2.9												
					24	2.2												
16	5				20	3.3												
					10	5.3												
					20	1.3												
18					28	14.3												
					40	6.7												
	6				180	2.2												
20					280	1.9												
					260													
22																		
	7																	
24																		
26	8																	
28																		
30	9																	
32																		
	10																	
34																		
36	11																	
38																		
40	12																	
42																		
	13																	
44																		
46	14																	
48																		
	15																	

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Table 7. Log of Heber Road 6.

Depth ft	m	Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterberg Limits (% water) Wp	Wl
1 2 3	1	fill, fine sand		50 28 26 28	2.7 2.9 5.1 3.8												
4 6	2		3	12 10 14 4 12	4.4 4.0 1.9 6.7 1.1	-	.110	-	-	9	67	4	4	4	12		
8		grayish – – – – – – – brownish (SM) very fine-fine sand, dark brown to reddish brown, very loose, dilatant, moderately sorted, abundant gastropod shells	1	12 10 8 10 14	2.2 4.0 3.3 4.0 1.9	2.7	.120	-	-	9	77		14				
10 12	3 4		1 3	10 14 12 16 18	4.0 2.9 2.2 2.5 2.2	2.6	.118	-	-	14	73		14				
14 16			4	16 20 24 22 30	3.3 3.3 2.2 1.8 1.8												
18	5 6	silty clay, dark reddish brown (5YR3/4)stiff	10 10	20 10 16 22 28	4.7 2.7 2.5 2.4 19.0	3.1	.132	-	-	25	61		14				
20 22	7	(SP) fine sand, brown, medium dense, well sorted, gastropods silty clay, dark reddish brown (5YR3/3), stiff	24 10	80 160 104 48 60	3.3 4.0 4.1 3.9 3.3	1.6 -	.150 .002	- -	- -	18 -	82 2	 6	 18	 24	 50		
24 26	8			14 20 10 12 28	3.8 3.3 6.7 2.2 1.0												
28	9	sand, dense, 6 ft of sand flowed into auger no samples	12	40 16 20 100 160	2.0 3.3 6.7 2.7 1.3	-	.003	-	-	1	2	7	23	23	44		
30 32	10	(ML) silt, clayey silt, and sand, reddish brown (5YR4/3.5), stiff moderately-poorly sorted, interbedded, beds 2-7 in thick	8	128 64 28 30 64	2.5 5.4 2.9 4.4 0.2	-	.025	-	-	3	38	10	9	13	27		
34 36	11		13	50 44 48 20 46	9.3 0.3 6.7 4.0 1.7	12.5	.020	-	-	-	2	48	33	6	11		
38	12	(SM) very fine sand dark brown, gastropods	8	46 40 38 34 144	5.8 3.0 3.9 3.9 1.7	-	.088	-	-	4	73	5	4	3	11		
40 42	13	(SM) sand and clayey silt, clayey silt is reddish brown (5YR4/3.5) sand is dark brown (7.5 YR4/4), sand is dense clayey silt is stiff		76 30 180 46 150	6.0 6.7 3.5 0.3 1.7												
44			18	76 34 22 76 90	4.0 3.9 10.9 2.6 2.7	-	.005	-	-	1	16	19	12	13	39		
46 48	14			116													

a, first SPT

b, second SPT

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Table 8. Log of Heber Road 7.

Depth				Penetration Data					gravel	Grain Size sand			silt			clay	Atterberg Limits (% water)	
ft	m	Log	Description	N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
1					22	3.6	-	.029	-	-	3	28	25	16	7	21		
2					22	3.6												
			fill, fine sand		12	2.2												
3	1				24	1.1												
					12	3.3												
4			brownish		34	0.8												
			grayish	6	46	1.2												
					44	0.6	12	.070	-	-	1	70	13	7	3	7		
6	2				44	0.3												
			(SM) silty sand and sand, (ML) silt near bottom, dark reddish brown (5YR3/4) at top, dark yellowish brown (10YR4/4) near bottom, loose-medium dense, well-poorly sorted		34	2.7	-	.060	-	-	-	50	30	8	4	8		
8					24	0.6												
					30	0.4	4.4	.094	-	-	1	69	22	3	2	3		
				12	36	1.9	-	.099	-	-	-	76	8	5	6	4		
					48	2.8												
10	3				56	2.1												
					72	2.0												
					74	2.5												
12					50	3.2	2.4	.095	-	-	2	78	15	2	1	1		
				13	44	3.0												
	4				40	2.0	4.5	.089	-	-	1	70	19	4	2	4		
14					38	2.1	3.2	.072	-	-	-	63	29	3	5			
					44	1.8												
					26	3.1												
16					14	5.7	3.5	.066	-	-	-	55	35	5	3	2		
	5			7	14	1.0												
					24	4.4												
18					22	1.8	-	.025	-	-	-	4	50	23	7	16		
					22	3.0												
					16	4.2	-	.001	-	-	-	1	3	11	23	62	25	73
20	6		(CH) clay, top reddish brown (5YR4/3), bottom half dark brown (10YR3/3)		22	3.0												
				13	28	1.9												
					30	25.8												
22					44	3.0												
	7		(SP) very fine sand dense, well sorted, coarsens downward		108	1.2	3.0	.120	-	-	9	76	15					
					112	3.5												
24				15	26	2.1												
			silty clay, reddish brown (5YR3.5/3), stiff carbon-rich zone at 7.6 m		40	2.3	-	.002	-	-	-	16	10	12	14	48		
					22	3.0												
26	8				32	1.7												
					32	1.3	-	.002	-	-	-	2	3	14	26	55		
					34	2.0												
28					20	3.3												
					180	2.0												
	9		(SM) silty sand, poorly sorted, dense, interbedded clayey silt 2-3 cm thick		116	2.8	17	.125	-	-	16	63	8	4	3	6		
30					116	2.8	-	.090	-	-	8	62	14	4	4	8		
					120	2.2												
					150	2.0												
32					116	3.0												
					48	2.8												
	10				36													
34																		
36	11																	
38																		
40	12																	
42																		
	13																	
44																		
46	14																	
48																		
	15																	

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Table 9. Log of Heber Road 8.

Depth		Log	Description	Penetration Data			Cu	D50	Grain Size gravel	sand			silt			clay	Atterberg Limits (% water)	
ft	m			N	qc	Rf				c	m	f	c	m	f		Wp	Wl
1					18	8.9												
2					20	5.3												
					10	6.7												
3	1				10	5.3												
4					6	2.2												
					18	0.7												
					16	2.5												
					16	5.0												
6	2				20	3.3												
					46	1.4												
					66	2.0												
8					56	2.4												
					38	3.5												
					68	1.4												
10	3				58	3.4												
					42	2.5												
					40	2.3												
12					46	2.3												
					38	2.8												
	4				38	2.8												
14					48	2.2												
					40	2.7												
					20	6.0												
16					20	4.7												
	5				24	3.3												
					28	1.9												
18					34	2.4												
					30	3.6												
	6				20	4.7												
20					24	3.3												
					26	7.7												
					160	0.8												
22					160	2.0												
	7				104	2.3												
					36	6.3												
24					10	6.7												
					16	3.3												
					24	2.8												
26	8				32	2.5												
					24	2.2												
					28	19.0												
					120	0.9												
28					140	2.3												
					40	4.7												
30	9				44	3.0												
					68	2.7												
					26	5.1												
32					20	6.0												
					16	0.8												
	10				38													
34																		
36	11																	
38																		
40	12																	
42	13																	
44																		
46	14																	
48																		
	15																	

LOCATION **El Centro-**

DATE December 1979

Table 10. Log of Heber Road 9.

Depth ft	Depth m	Log	Description	Penetration Data N	qc	R_f	Cu	D50	Grain Size gravel	sand c	sand m	sand f	silt c	silt m	silt f	clay	Atterberg Limits (% water) Wp	Wl
1					22	6.1												
2					16	4.2												
					20	1.3												
3					14	1.9												
	1				8	1.7												
4					8	1.7												
					8	1.7												
					6	2.2												
6	2				14	1.0												
					16	1.7												
8					6	2.2												
					16	0.8												
					16	1.7												
					20	2.0												
10	3				26	1.5												
					32	2.5												
					36	3.0												
12					40	2.7												
	4				40	2.7												
					44	2.1												
14					48	0.6												
					36	4.1												
					14	7.6												
16	5				30	1.8												
					24	2.2												
					34	2.7												
18					26	3.6												
					24	5.0												
	6				30	4.4												
20					34	4.3												
					30	6.7												
					160	1.3												
22					132	1.9												
	7				96	2.9												
					24	2.2												
24																		
26	8																	

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Table 11. Log of Heber Road 10.

Depth ft	Depth m	Log	Description	Penetration Data N	Penetration Data qc	Penetration Data Rf	Cu	D50	gravel	Grain Size sand c	Grain Size sand m	Grain Size sand f	Grain Size silt c	Grain Size silt m	Grain Size silt f	clay	Atterberg Limits (% water) Wp	Atterberg Limits (% water) Wl
1					32	3.8												
2					18	4.4												
					20	4.0												
3	1				14	1.9												
4					10	2.7												
					10	2.7												
					12	3.3												
6					8	3.3												
	2				12	4.4												
					24	1.1												
8					28	2.9												
					28	1.9												
					36	1.9												
	3				40	2.0												
10					44	2.7												
					60	2.0												
					42	2.5												
12					46	1.4												
	4				40	2.0												
					40	2.3												
14					44	1.2												
					38	3.9												
					20	0.7												
16	5				76	2.3												
					40	2.7												
					22	1.8												
18					42	2.9												
					22	3.6												
	6				32	2.5												
20					38	2.5												
					36	4.1												
					32	7.5												
22					160	1.4												
	7				156	2.3												
					40	1.3												
24																		
26	8																	

LOCATION El Centro-

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Table 12. Log of Heber Road 11.

Depth ft	m	Log	Description	N	qc	Rf	Cu	D50	gravel	sand c	sand m	sand f	silt c	silt m	silt f	clay	Wp	Wl
1			fill. loose. very fine, dry, sand		30	2.7												
2					40	3.0												
					38	2.1												
3	1				32	4.2												
			very fine, well sorted sand, reddish brown (5YR4.5/2) to dark brown (7.5YR4/4) ripple beds 1-1.4 m horizontal beds 1.4-3.8 dense		34	2.7												
4				8	32	3.8												
					20	12.7												
					86	3.1												
6	2				140	2.9	1.8	.102	-	-	1	89						
				28	170	2.4												
					180	2.2												
8					170	3.0												
					144	2.8												
					140	3.3												
10	3				160	2.9	4.0	.110	-	-	3	77						
					190	3.4												
					184	2.9												
12					180	3.2												
					190	1.8												
	4				140	3.3												
14			silt, dark reddish gray (5YR4.5/2), sharp upper contact	13	30	11.1	-		-	-	-	19						
					38	3.9												
					28	6.2												
16					18	3.7												
	5		clay, dark grayish brown, (10YR4/2), firm		22	3.6												
					22	3.6												
18				4	20	4.0												
					20	4.7												
					20	53.3												
20	6				40	5.0												
					240	2.2												
					240	2.2												
22					180	1.8												
	7				132	2.8												
					38	7.0												
24					20	4.7												
					24	3.9												
					24	2.8												
26					114	3.2												
	8				110	3.0												
					84	2.9												

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Table 13. Log of Heber Road 12.

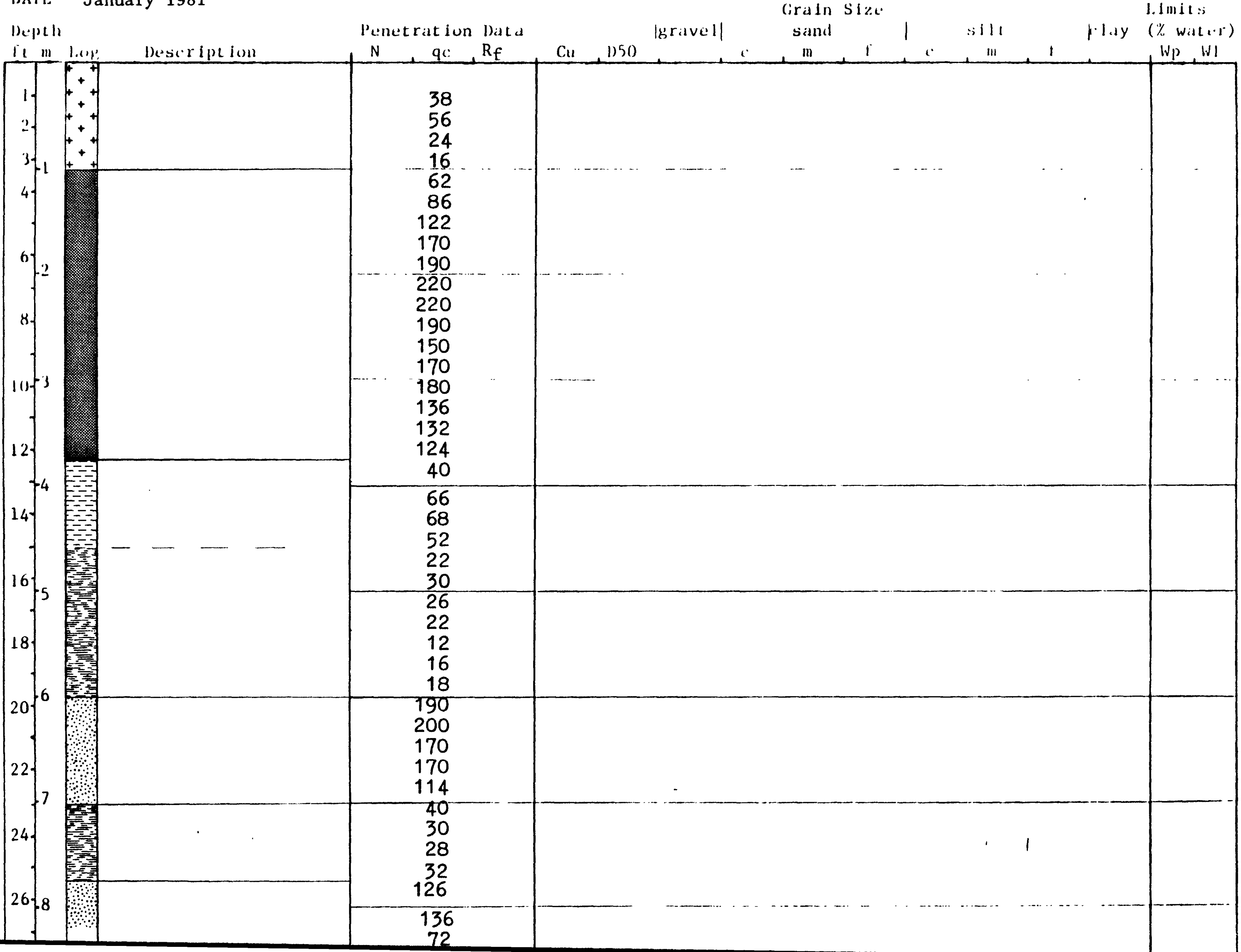

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Table 14. Log of Heber Road 13.

Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterber Limits (% water Wp	Wl
fill, moderately-poorly sorted, very fine sand reddish brown (5YR4/4)		34	6.7												
		8	13.3												
		24	3.9												
		24	4.4												
		22	3.6												
	10	18	3.0												
		22	3.6	10	.111	-	-	7	73						
		18	1.5												
		20	3.3												
sand, very fine to silty sand, reddish brown (5YR4/3) dilatant	5	20	1.3												
		16	3.3												
		16	1.7												
		18	3.0												
		18	3.7												
		20	3.3	7	.120	-	-	8	78						
		14	2.9												
		18	4.4												
		22	3.0												
		24	3.3												
		26	3.6												
		28	3.8												
	5	36	2.6	10	.140	-	-	12	72						
		22	7.3												
		10	2.7												
silty clay to clay dark reddish gray (5YR4/2)		24	2.8												
		12	6.7												
	9	14	4.8												
		24	13.9												
		30	11.1												
sand, very fine, uniform, no bedding		200	2.7												
	32	240	1.8												
		224	2.1												
		170	2.1												
		126													
silty clay to clay reddish brown (5YR4/3)	11														
sand, fine, well sorted	28														

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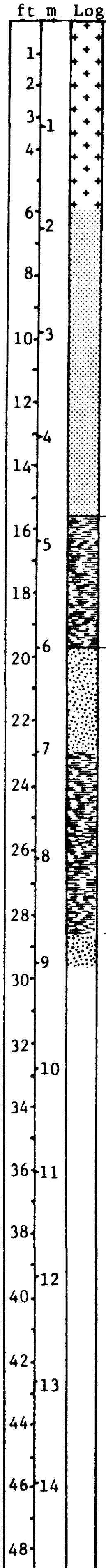
Table 15. Log of Heber Road 14.

Depth ft m Log Description



Penetration Data					Grain Size									Atterbe
					gravel	sand			silt			clay	Limits (% wate	
N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
	18													
	14													
	26													
	22													
	14													
	18													
	14													
	12													
	10													
	10													
	42													
	36													
	16													
	12													
	16													
	20													
	26													
	18													
	18													
	22													
	30													
	40													
	30													
	18													
	22													
	14													
	18													
	22													
	32													
	230													
	210													
	220													

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Table 16. Log of Heber Road 15.

Depth ft	m	Log	Description	Penetration Data N	qc	R_f	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterbe Limits (% wate Wp	Wl
1					34	2.7												
2					34	2.7												
			fill, fine sand, some silt, gastropod shells		34	3.5												
3	1				22	4.8												
4					26	2.1												
				4	16	1.7												
					12	3.3												
					16	2.5	-		-	-	1	19						
6	2				28	3.8												
				8	64	2.1												
					82	3.9												
8					66	3.2												
					96	2.1												
					76	3.2												
10	3		sand, fine, well sorted reddish brown (5YR4.5/3)		40	3.0												
					34	3.1												
					34	3.9	2.5	.112	-	-	2	89						
12					64	2.5												
					64	2.7												
	4				56	3.1												
14					54	2.7												
				9	50	2.9												
					42	3.8												
16					30	4.9												
	5				24	3.9												
			clayey silt at top dark brown (7.5YR4/2) to silty clay at bottom reddish brown (5YR4/3)		26	4.1												
18					28	2.9												
				7	28	2.9												
					26	3.1												
20	6				26	2.1												
					22	4.2												
					22	3.0												
22			sand, fine, uniform dark brown (7.5YR4/4)		170	1.6												
				12	88													
	7																	
24			silty clay with 5 mm beds of silt, dark grayish brown (10YR4/2)	14														
26	8																	
28			sand, fine, well sorted reddish brown (5YR4.5/3)	24														
	9																	
30																		
32																		
	10																	
34																		
36	11																	
38																		
	12																	
40																		
42																		
	13																	
44																		
46	14																	
48																		

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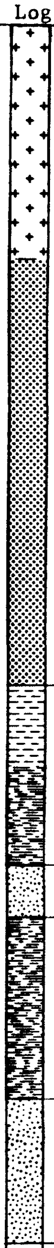
Table 17. Log of Heber Road 16.



Depth				Penetration Data					gravel	Grain Size sand			silt			clay	Atterber Limits (% water	
ft	m	Log	Description	N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
1					32													
2					26													
					10													
3	1				10													
					18													
4					18													
					28													
					36													
6	2				58													
					60													
					72													
8					78													
					66													
					68													
10	3				52													
					48													
					54													
12					50													
					48													
	4				48													
14					54													
					50													
					44													
16					64													
	5				68													
					30													
18					22													
					26													
					22													
20	6				20													
					24													
					28													
22					170													
	7				104													
					24													
24					18													
					32													
					22													
26	8				22													
					18													
					30													
28					68													
					220													
	9				170													
30					180													
					116													
					70													
					48													
32					30													
	10																	
34																		
36	11																	
38																		
	12																	
40																		
42																		
	13																	
44																		
46	14																	
48																		

LOCATION RIVER PARK

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Table 18. Log of River Park 1.

Depth ft	Depth m	Description	Penetration Data N	qc	Rf	Cu	D50	Grain Size gravel	sand c	sand m	sand f	silt c	silt m	silt f	clay	Atterberg Limits (% water) Wp	Wl
		▼ surface															
1		(ML) sandy silt, very dark grayish brown (2.5Y3/2), moderately sorted, very loose, moist, slightly plastic abundant roots		40	2.0												
2				34	3.5												
				38	2.8												
3	1			32	0.8												
4				36	1.5												
				22	1.8	-	.051	-	-	1	39	39	11	3	7		
			1	18	3.0												
6				22	0.6												
	2			14	2.9	-	.046	-	-	-	23	61	6	3	7		
				24	0.6												
8		(MH-ML) silty clay and silt interbedded, dark grayish brown (2.5Y3/2) soft		8	5.0	-	.004	-	-	-	2	21	20	21	36	26	65
				18	0.7												
			2	22	0.6												
	3			8	3.3	-	.026	-	-	-	12	47	25	7	9		
10		(MH-OH) clay, dark gray (5Y4/1), plant material very abundant, very soft		4	3.3												
				4	3.3												
				4	3.3												
12				4	3.3	-	.001	-	-	2	3	4	8	17	66	27	80
	4		1	4	3.3												
				2	13.3												
14				2	99.0												
		(SP) fine sand, well sorted, very dark grayish brown (10YR3/2), 15-18 ft, brown/dark brown (10YR4/3) 18-25', medium dense, gastropod shells present, dilatant near 17-21'		20	4.0	3.3	.165	-	-	36	53	7	1	1	2		
				92	2.0												
16				100	2.1												
	5		14	128	2.2	2.7	.180	-	1	39	51		9				
				108	2.5	4.8	.170	-	-	34	52		14				
18				90	2.2												
				86	2.6												
	6			70	2.9												
20				82	2.8												
			21	94	2.8	1.9	.115	-	-	10	83		7				
				114	2.1												
22				144	2.0												
	7			156	2.1												
				160	2.5												
24				160	2.5												
			21	160	2.3	2.0	.145	-	-	18	76		6				
				170	2.0												
26	8	*		160	2.5												
				140													

LOCATION RIVER PARK

DATE December 1979

Table 19. Log of River Park 2.

Depth ft	m	Log	Description	Penetration Data N	qc	R_f	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterberg Limits (% water) Wp	Wl
1					72	1.7												
2					30	1.3												
					34	1.2												
3	1				28	4.3												
					18	0.7												
4					28	1.9												
					18	1.5												
					20	1.3												
6	2				16	4.2												
					26	1.0												
					20	2.0												
8					16	1.7												
					22	1.8												
	3				10	5.3												
10					14	3.8												
					14	2.9												
					12	2.2												
12					6	4.4												
	4				8	3.3												
					6	31.1												
14					20	1.3												
					50	1.6												
					52	2.1												
16					54	2.5												
	5				60	2.2												
					64	2.3												
18					92	2.3												
					112	2.5												
	6				122	2.3												
20					128	1.9												
					144	2.3												
					170	2.1												
22					156	1.0												
	7				80	5.8												
					70													
24																		

LOCATION RIVER PARK

DATE December 1979

Table 20. Log of River Park 3.

Depth		Log	Description	Penetration Data					gravel	Grain Size sand			silt			clay	Atterberg Limits (% water)	
ft	m			N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
1					34	2.0												
2					24	0.6												
					24	1.1												
3	1				24	1.7												
4					16	3.3												
					8	8.3												
					16	3.3												
6					18	2.2												
	2				12	3.3												
					10	2.7												
8					10	1.3												
					12	1.1												
					10	1.3												
	3				10	2.7												
10					84	0.8												
					72	1.3												
					74	1.8												
12					74	2.9												
	4				80	3.3												
					104	1.9												
14					116	2.2												
					114	2.7												
					98	2.7												
16					124	2.5												
	5				160	2.1												
					170	2.0												
18					160	2.7												
					116	2.9												
	6				90	4.7												
20					72	3.5												
					98	2.7												
					92	5.5												
22					104	2.6												
	7				160	0.5												
					128													
24																		

LOCATION RIVER PARK

DATE December 1979

Table 21. Log of River Park 4.

Depth ft	m	Log ▼	Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterberg Limits (% water) Wp	Wl
1			(SM) silty sand, brown/ dark brown (7.5YR4/4), loose, dilatant, very moist, cohesive		40	1.7	8.0	.071	-	-	1	58	27	5	3	5		
2					40	2.0												
					30	1.3												
3	1		(ML) clayey silt, very silty at bottom, some sand, maybe thinnly interbedded, silt is dilatant		18	3.0												
					24	1.7												
4					8	6.7												
					10	1.3	-	.010	-	-	-	9	25	29	20	17		
					22	4.2												
6	2		(MH) clay, brown/dark brown (7.5YR4/2), yellow concretions, very firm		18	0.7												
					16	4.2	-	.001	-	-	-	-	-	4	22	72	27	74
					10	2.7												
8			(MH) clay, very dark grayish brown (loYR3/2) organics common, soft		12	2.2												
					8	1.7	-	.001	-	-	-	-	3	3	28	66	27	80
	3				6	13.3												
10			(SP) fine sand, well sorted to moderately sorted, brownish above 13', grayish below 13' dilatant between 10-20' gastropod shells at 13 to 15', drilling becomes harder at 16', better recoverey at 16-20'		76	1.4												
					88	1.7	3.5	.110	-	-	20	68	4	4	1	3		
					86	2.2	2.8	.120	-	-	7	80	7	3	1	2		
12					82	2.6												
	4				84	2.5	3.1	.135	-	-	11	77	6	2	1	2		
					88	2.3												
14					102	2.6												
					104	2.7	2.7	.140	-	-	11	78	7	2	1	1		
					112	3.2	2.6	.145	-	-	17	73	6	2	1	1		
16					120	2.7												
	5				132	2.8	2.7	.145	-	-	14	76		10				
					124	2.8	3.6	.145	-	-	17	70	5	4	1	3		
18					132	2.5												
					120	3.2	6.5	.140	-	-	15	67	8	4	2	4		
	6				122	3.4	6.0	.135	-	-	13	63	15	3	2	4		
20					138	2.4												
					150	2.7												
					160	2.0												
22					156	2.7												
	7				156	2.6												
					160	2.5												
24					160	2.3												
					156	2.6												
					156	2.2												
26	8				180	2.2												

LOCATION RIVER PARK

Table 22. Log of River Park 5.

DATE December 1979

Depth ft	Depth m	Log	Description	Penetration Data N	Penetration Data qc	Penetration Data Rf	Cu	D50	gravel	Grain Size sand c	sand m	sand f	silt c	silt m	silt f	clay	Atterberg Limits (% water) Wp	Wl
1					40	0.3												
2					26	4.1												
					12	1.1												
3	1				18	0.7												
4					22	0.6												
					22	2.4												
					18	0.7												
6					20	3.3												
	2				20	2.0												
					12	2.2												
8					12	2.2												
					14	2.9												
					12	5.6												
10	3				10	5.3												
					36	1.5												
					84	1.6												
					76	2.5												
12					82	2.4												
					76	2.8												
	4				72	2.8												
14					88	2.6												
					114	3.0												
					128	2.9												
16					140	2.5												
	5				144	2.4												
					140	2.5												
18					144	2.2												
					152													
20	6																	
22																		
	7																	
24																		

LOCATION RIVER PARK

DATE December 1979

Table 23. Log of River Park 6.

Depth		Log	Description	Penetration Data			Cu	D50	gravel	Grain Size sand			silt			clay	Atterberg Limits (% water)	
ft	m			N	qc	Rf				c	m	f	c	m	f		Wp	Wl
			(ML) sandy silt, dark brown (7.5YR3.5/4), very poorly sorted				-	.044	5	1	4	21	40	9	3	17		
1					22	2.4												
2					14	1.0												
			(SM) gravelly silty sand and coarse sandy silt, very dark brown (10YR2/2 and reddish brown (5YR 4/3), very poorly sorted dry, loose, BLACKTOP artificial fill		16	1.7												
3	1				16	1.7												
4					10	2.7												
				1	10	2.7	-	.210	24	12	14	14	14	10	6	6		
					4	3.3												
6					4	3.3												
	2				14	1.0	-	.035	8	6	8	12	29	15	7	15		
			(ML) sand, silt, and clayey silt, mixed, probably interbedded dark brown (10YR3/3) and dark grayish brown		10	1.3	-	.033	-	2	4	15	41	16	6	16		
8					6	2.2												
				10	8	1.7												
					16	1.7												
	3				18	1.5												
10			(CL) clayey silt and sandy silt, black (7.5YR2/0)		28	1.0	-	.044	-	-	-	27	46	11	5	11		
					22	1.8												
					6	2.2	-	.010	-	-	-	5	26	26	15	28		
12					6	2.2												
	4		(SM) silty sand, brown/dark brown (7.5YR4/2) moderately to poorly sorted *	10	40	1.7												
					52	2.1	-	.090	-	-	2	64	22	4	4	4		
14					56	2.4												
					76	2.5	-	.095	-	-	3	69	10	6	5	7		
					80	2.5												
16	5				66	2.7												
					60	2.7												
					130	3.7												
18					88	3.5												
					144	1.5												
	6				134													
20																		
22																		
	7																	
24																		

LOCATION RIVER PARK

Table 24. Log of River Park 7.

DATE December 1979

Depth				Penetration Data						Grain Size							Atterberg Limits (% water)	
									gravel	sand			silt			clay		
ft	m	Log	Description	N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
1					28	1.9												
2					14	1.0												
					8	1.7												
3	1				16	0.8												
4					6	2.2												
					4	3.3												
					6	2.2												
					4	3.3												
6	2				6	2.2												
					6	4.4												
8					24	3.3												
					44	2.4												
					104	2.8												
					116	2.9												
10	3				130	2.6												
					140	2.7												
					144	2.8												
12					144	2.8												
					180	2.4												
	4				170	2.4												
14					180	2.6												
					160	2.4												
					152	3.2												
16					128	4.0												
	5				104	2.9												
					124	2.7												
18					130	2.3												
					114	2.5												
					116													
20	6																	
22																		
	7																	
24																		

LOCATION RIVER PARK

DATE December 1979

Table 25. Log of River Park 8.

Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	m	f	silt c	m	f	clay	Atterberg Limits (% water) Wp	Wl
(CL) sandy silt, brown/ dark brown (7.5YR4/4), poorly sorted, may represent interbedded clayey silt and sand		34	3.1												
		14	2.9												
		14	2.9	-	.045	-	-	-	25	47	10	8	10	17	28
		10	4.0												
(MH) clay, brown, dark brown (7.5YR4/4), firm		10	4.0												
		6	2.2												
		4	6.7	-	.001	-	-	-	1	5	4	20	70	24	77
		6	4.4												
		10	8.0	7.0	.130	-	-	12	69	9	3	2	5		
(SP) fine sand, brownish between 5 to 8 ft, grayer bewteen 8 to 15 ' well sorted, very poor recoverey between 5 to 7 ft.		40	2.0												
		94	1.8												
		94	2.0	7.5	.140	-	-	14	73	3	3	3	4		
		108	2.8												
		120	2.7												
		140	2.7	3.1	.140	-	-	15	73	6	2	1	3		
		144	2.4												
		144	2.5												
		156	2.6												
		158	2.1	1.9	.150	-	-	15	80		5				
		150	2.8												
		140	2.5	1.9	.150	-	-	19	75	2	2	2	-		
		148	2.5												
		140	2.7												
		144	2.4												
		144	2.4												
		152	2.5												
		128	2.9												
		124													

Depth ft: 1 2 3 4 6 8 10 12 14 16 18 20 22 24

Depth m: 1 2 3 4 5 6 7

LOCATION RIVER PARK

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Table 26. Log of River Park 9.

Depth ft	Depth m	Log	Description	Penetration Data N	qc	Rf	Cu	D50	gravel	Grain Size sand c	sand m	sand f	silt c	silt m	silt f	clay	Atterberg Limits (% water) Wp	Wl
1		+	(ML, CL) silt, clay, and sand, best described as silt with abundant clay and sand, uniform, not interbedded, brown/dark brown (7.5YR4/4), very poorly sorted ,loose		10	1.3												
2		+			8	3.3	–	.034	–	–	1	22	42	11	8	16		
		+			14	1.9												
3	1	+			6	2.2												
4		+			4	3.3												
		+			4	3.3	–	.030	–	–	1	26	32	14	8	19		
		+			4	3.3												
6		+	(SM) gravel, sand, silt and clay, extremely poorly sorted, BLACKTOP artificial fill, black (10YR2/1)		10	5.3												
	2	+			16	0.8	–	.085	20	11	10	15	17	11	6	10		
		+			40	0.3	–	.140	15	11	18	18		38				
8		+			56	1.0												
		+			20	10.0												
		+			26	1.0	–	.325	29	12	17	14		28				
	3	+	▼		48	1.1												
10		∴	(SP, SM) sand and silty sand, well to poorly sorted, 10 to 14' very poor recoverey, mixture of brownish and grayish sand, 14 to 20' grayish sand and silty sand dense		20	2.0												
		∴			14	2.9												
		∴			20	8.0												
12		∴			48	2.2												
	4	∴			88	2.1												
		∴			88	2.1												
14		∴			102	2.5												
		∴			102	2.6	2.9	.160	–	1	29	60	3	2	1	4		
		∴			116	2.3												
16		∴			116	3.7												
	5	∴			126	3.2												
		∴			130	2.7	5.7	.180	10	10	30	42	6	4	2	2		
18		∴			144	2.4												
		∴			148	2.3	–	.080	11	6	13	27	23	8	3	9		
	6	∴			170	2.4												
20			+		156	2.0												
					170	2.0												
					170	2.0												
22					152													
	7																	
24																		

LOCATION RIVER PARK
DATE December 1979

Table 27. Log of River Park 10.

Depth ft	Depth m	Log	Description	Penetration Data N	Penetration Data qc	Penetration Data R_f	Cu	D50	Grain Size gravel	Grain Size sand c	Grain Size sand m	Grain Size sand f	Grain Size silt c	Grain Size silt m	Grain Size silt f	Grain Size clay	Atterberg Limits (% water) Wp	Atterberg Limits (% water) Wl
1					24	2.2												
2					16	2.5												
					10	4.0												
3	1				12	5.6												
					6	2.2												
4					6	8.9												
					12	2.2												
					6	2.2												
6	2				14	1.0												
					24	0.6												
					56	0.7												
8					50	5.3												
					36	3.0												
10	3				80	2.2												
					96	2.4												
					100	1.1												
12					138	2.6												
					136	2.9												
	4				140	2.7												
					124	2.4												
14					104	3.6												
					92	3.8												
					138	3.0												
16					128	3.1												
	5				140	2.9												
					144	2.8												
18					140	2.7												
					136													
20	6																	
22																		
	7																	
24																		

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Table 28. Log of River Park 11.

Depth		Log	Description	Penetration Data			Cu	D50	Grain Size								Atterberg Limits (% water)	
									gravel	sand			silt			clay		
ft	m			N	qc	R_f				c	m	f	c	m	f		Wp	Wl
1			(CH) clay, reddish brown firm, roots very abundant		38	3.5	-	.002	-	-	-	1	4	19	27	49	32	56
2					20	3.3												
					10	5.3												
3	1				4	3.3												
4					6	8.9												
					4	10.0												
			▼		6	11.1	-	.001	-	-	-	1	2	8	20	69	31	67
					8	3.3												
6	2		(ML) silt, moderately to poorly sorted, maybe graded sandy to clayey		10	1.3												
					18	4.4	-	.042	-	-	-	14	65	8	4	9		
8					76	4.0												
			(SP) fine sand, well sorted, brownish between 8 and 13', grayish between 13 and 20' gastropod shells in upper half unit fines upward		124	2.2	4.1	.128	-	-	11	76	5	3	2	3		
					170	2.0												
	3				170	2.6	2.5	.145	-	-	16	74	7	2	1	-		
10					144	3.0												
					156	2.6	1.8	.170	-	-	26	70	4					
					144	3.7												
12					140	2.5												
	4				108	2.7												
					88	2.9	1.8	.155	-	-	20	76	4					
14					88	3.2												
					98	2.9												
					114	3.0	1.8	.158	-	-	26	70	3	1				
16	5				128	3.0												
					132	3.1	1.9	.165	-	-	26	69	5					
					128	2.9	2.1	.188	-	-	44	52	4					
18					144	2.9												
					148		2.2	.195	-	2	46	49	3					
	6						2.4	.210	-	-	55	41	4					
20			*															
22																		
	7																	
24																		

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Table 29. Log of River Park 12.

Depth ft	Depth m	Log	Description	Penetration Data N	Penetration Data qc	Penetration Data Rf	Cu	D50	gravel	Grain Size sand c	Grain Size sand m	Grain Size sand f	silt c	silt m	silt f	clay	Atterberg Limits (% water) Wp	Atterberg Limits (% water) Wl
1					6	1.1												
2					4	0.0												
					0	99.0												
3	1				2	6.7												
4					4	10.0												
					10	5.3												
					24	3.9												
					36	3.3												
6	2				56	2.1												
					60	2.7												
					84	2.4												
8					110	2.7												
					112	2.7												
					114	2.6												
10	3				120	3.3												
					110	3.2												
					100	2.7												
12					88	2.9												
					82	2.6												
	4				92	1.3												
14					68	4.7												
					88	2.1												
					110	2.2												
16					110	2.4												
	5				120													
18																		
20	6																	
22																		
	7																	
24																		

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Table 30. Log of River Park 13.

Depth				Penetration Data						Grain Size sand			silt				Atterber Limits (% water	
ft	m	Log	Description	N	qc	R_f	Cu	D50	gravel	c	m	f	c	m	f	clay	Wp	Wl
1		▓	silty clay, dark brown (7.5YR4/2)		40	3.0												
2					30	3.1												
					10	4.0												
3	1				10	2.7												
4					6	8.9												
					8	5.0												
				5	6	4.4												
					4	53.3												
6	2				8	5.0												
		░	sand, fine to coarse, well sorted, dark brown to grayish brown (10YR4/3) to (10YR5/2) coarsens downward, gastropod shells are common		62	1.5												
					74	2.7												
8				17	54	3.2												
					84	2.7												
					88	2.6												
10	3				100	3.3												
				17	110	0.2												
					156	2.5												
12					132	3.0												
					124	3.0												
	4				134	2.4												
14					132	2.7												
				18	114	3.2												
					106	3.1												
16					120	2.7												
	5				116	2.6												
					100	2.4												
18					88	2.4												
				14	108	2.7												
	6				102	2.4												
20					144	1.4												
					130	2.6												
					170	1.7												
22					180	2.0												
	7			27	156	2.4												
					88	2.7												
24					180	1.9												
					180	2.1												
					160	1.5												
26	8				108	2.0												
					164	1.4												
					94	2.3												
28				26	168	2.4												
					160	3.8												
	9				180	1.8												
30					196	2.7												
					82	4.4												
		▓	silty clay, dark brown (7.5YR4/2)		36	6.3												
32					36	3.7												
	10				36	2.2												
				14	30	3.6												
34					28	3.3												
					30	6.7												
		░			170	2.4												
36	11				200	3.8												
					96	4.9												
					230	2.5												
38					224													
40	12																	
42																		
	13																	
44																		
46	14																	
48																		
	15																	

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Table 31. Log of River Park 14.

Depth ft	Depth m	Log	Description	Penetration Data N	Penetration Data qc	Penetration Data Rf	Cu	D50	Grain Size gravel	Grain Size sand c	Grain Size sand m	Grain Size sand f	Grain Size silt c	Grain Size silt m	Grain Size silt f	Grain Size clay	Atterberg Limits (% water) Wp	Atterberg Limits (% water) Wl
1					18	3.0												
2					8	3.3												
3					4	3.3												
	1				4	3.3												
4					6	4.4												
					6	4.4												
					6	6.7												
					8	5.0												
6	2				8	3.3												
					8	5.0												
8					88	1.5												
					106	3.8												
					100	2.0												
					146	2.7												
10	3				110	3.3												
					80	3.5												
					84	3.0												
12					90	3.3												
					88	3.5												
	4				98	3.5												
14					100	4.0												
					110	2.9												
					112													
16	5																	
18																		
20	6																	
22																		
	7																	
24																		

LOCATION **River Park**

DATE January 1981

Table 32. Log of River Park 15.

Depth				Penetration Data					gravel	Grain Size sand			silt			clay	Atterber Limits (% water)	
ft	m	Log	Description	N	qc	Rf	Cu	D50		c	m	f	c	m	f		Wp	Wl
1		░	sand, fine, and sandy silt. dark brown (7.5YR4/4)		42	1.9												
2				7	32	3.3	-		-	-	-	21						
					20	2.7												
3	1				20	2.0												
		▤	clayey silt and alternating thin beds (1 cm) of clayey silt and fine sand, dark grayish brown (10YR4/2)		14	2.9												
4					12	2.2												
				4	14	2.9	-		-	-	-	2						
					10	1.3	-		-	-	-	13						
6	2				12	0.6												
					18	1.5												
		▓	clay, alternating bands of brown, gray and green, soft, organics		6	4.4												
8				3	6	4.4	-		-	-	-	1						
					6	4.4												
					6	44.4												
10	3	░	sand, fine, well to moderately sorted, dark brown (10YR4/3) below 5 m dark grayish brown (10YR4/2)		40	2.0												
				7	88	2.3	1.1	.170	-	-	31	66						
					86	2.6	1.6	.149	-	-	12	85						
12					80	2.8												
					78	2.6												
	4			21	80	3.0	2.0	.147	-	-	16	78						
14					100	2.8												
					104	2.7												
					110	2.9												
16				21	112	3.0	-	.138	-	-	14	67						
	5				130	2.8												
					142	2.8												
18					130	2.6												
					150	2.5												
	6				140	2.4												
20				35	120	2.8												
					146	2.6												
					152	2.4												
22					190	2.5												
	7				200	2.7												
					154	2.6												
24				31	164	2.4	2.2	.210	-	-	54	44						
					180	2.6												
					160	2.3												
26	8				180	2.2												
					156	2.3												
					176	2.4												
28					180	2.4												
					168	2.8												
					160	2.6												
30	9				158	1.7												
					140	3.6												
					144	2.2												
					100	3.3												
32					160	2.7												
	10				196	2.0												
34					152	3.2												
					126	3.2												
					164	3.0												
36	11				196	3.4												
					164	3.4												
					200	3.0												
38					270													
40	12																	
42																		
	13																	
44																		
46	14																	
48																		