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PLAN FOR SURFACE STORAGE OF SALT TATUM DOME, LAMAR COUNTY, MISSISSIPPI

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

July 1962

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CORPS OF ENGINEERS
Vicksburg, Mississippi

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PREFACE

This study was requested in a letter dated 6 February 1962 from the Bureau of Mines, and was authorized by Comment No. 2 from Office, Chief of Engineers, dated 5 March 1962, to U. S. Army Engineer Waterways Experiment Station's Disposition Form, subject, "Request for Project Authorization," dated 27 February 1962.

The report was written by Dr. Charles R. Kolb and Mr. W. B. Steinriede. Field work was accomplished and plates and figures in the report were prepared by Messrs. Steinriede and Richard W. Hunt, Geology Branch, Waterways Experiment Station (WES). Field explorations were made by the Inspection and Exploration Section, WES, under the supervision of Mr. T. B. Goode. Analyses of laboratory test results were the responsibility of Mr. Walter C. Sherman, Jr. Thanks are due to personnel of the U. S. Geological Survey, Hattiesburg, Mississippi, who furnished data for use in the project, and also to Messrs. C. H. Riggs and L. J. Heath, Bureau of Mines Petroleum Research Center, Bartlesville, Oklahoma, with whom close liaison was maintained during the conduct of the project. All phases of the study were under the direct supervision of Dr. Kolb, Chief, Geology Branch, and the general supervision of Messrs. W. J. Turnbull and W. G. Shockley, Chief and Assistant Chief, respectively, of the Soils Division, WES.

Director of the Waterways Experiment Station during the conduct of this study and the preparation of this report was Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

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SUMMARY

The U. S. Atomic Energy Commission has leased a 1400-acre plot in southern Mississippi which is underlain at about 1200 feet by the Tatum Salt Dome, and plans to form cavities in the salt for a series of test blasts. Approximately 1,400,000 tons of rock salt will be mined in forming the cavities and must be disposed of. Sale of the salt for commercial purposes is not feasible, and disposal into streams or into the Gulf of Mexico is uneconomical or impractical. The salt could eventually be disposed of by injection as brine into saline, permeable horizons, but the salt might be stored on the surface for a period of ten years. The problem, therefore, was to locate the most practical storage site and to devise a plan for surface storage of the salt.

This report describes (a) the requirements for salt storage and the limitations placed on site selection; (b) geological and terrain considerations affecting the design of the salt-storage area; and (c) the recommended plan of storage.

The recommended plan provides for the following: (a) a drainage ditch on the upslope side of the site near the Pleistocene sand-Miocene clay contact; (b) a retention dike on the downslope side of the site; (c) a water-storage area ponded by the retention dike; and (d) a salt-storage area on the slope above the ponded area. This plan uses to advantage the surface topography and near-surface occurrence of clay in the Tatum Salt Dome area and will provide maximum assurance against seepage of salt effluent from the storage area. This plan, along with one or two permanent brine disposal wells, each with 15,000-barrels-per-day capacity, will effectively contain the salt and all salt effluent for at least ten years. The cost of construction for the recommended plan is estimated at $185,750. An additional cost of $98,000 is estimated for forming the salt pile after delivery of the salt to the storage site.

PLAN FOR SURFACE STORAGE OF SALT

TATUM DOME, LAMAR COUNTY, MISSISSIPPI

PART I: INTRODUCTION

The Problem

1. The U. S. Atomic Energy Commission has leased an area in southern Mississippi, underlain at 1200 feet by the Tatum Salt Dome, for use in blast tests. Present plans call for construction of a shaft over the approximate center of the dome and formation of cavities within the salt at a depth of about 2500 feet. This will entail mining about 1,400,000 tons of rock salt from the salt dome. Means of disposing of this salt have been investigated by the Bureau of Mines.* Sale of the salt for commercial purposes is not feasible, and disposal into streams or into the Gulf of Mexico would be uneconomical or impractical. The salt could be disposed of by injection as brine into saline, permeable horizons, but the salt might be stored on the surface for a period of ten years. The problem, therefore, was to locate the most practical storage site and to devise a plan for surface storage of the salt.

2. Of paramount importance was the fact that the plan devised be capable of totally containing the salt and any resulting brine or salt effluent. Locating the storage area on naturally occurring clay or on an artificially placed clay pad offers the most practical and economically feasible solution to the problem.

Method of Investigation

3. Sources of data examined as a preliminary step in locating a suitable storage area included published and unpublished maps compiled by the Soil Conservation Service, U. S. Department of Agriculture, published bulletins of the Mississippi Geological Survey, and available topographic maps of the salt-dome area. Of these, only the unpublished maps of the

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* Bureau of Mines, Investigation of Salt Disposal, Tatum Dome, Project DRIBBLE, June 1961. (Special report to Atomic Energy Commission.)

Soil Conservation Service proved to be sufficiently detailed to be of use in the project. An analysis of the logs of shallow borings made by Humble Oil Company, seismic shot-hole data, and particularly borings made by the U. S. Geological Survey (USGS) permitted a crude determination of geologic and soil conditions in the Tatum Salt Dome area. Less favorable sites were eliminated, until two were finally selected for detailed investigation. These were explored with 65 machine and hand-auger borings. Laboratory tests were made to determine compaction, permeability, plasticity, water content, and grain-size characteristics of selected soil samples.

Scope of Report

4. The paragraphs which follow describe (a) the requirements for salt storage and the limitations placed on site selection; (b) geological and terrain considerations affecting the design of the salt-storage area; and (c) the recommended plan of storage.

PART II: STORAGE AND SITE SELECTION REQUIREMENTS

Area Considered

5. The area investigated lies approximately 20 miles southwest of Hattiesburg, in Lamar County, Mississippi, and is underlain by the Tatum Salt Dome, a piercement-type dome which reaches to within 1200 feet of the surface. Fig. 1 shows the proposed location of the shaft (labeled "Ground Zero") which will be near the center of a 1400-acre plot now under lease to the U. S. Atomic Energy Commission. The boundaries of the lease acreage are also shown in fig. 1. One of the considerations in selecting the salt-storage site was that it be located within this lease acreage if possible. However, because this was not an explicit requirement, the preliminary survey considered an area within roughly a 2-mile radius of the center of the dome.

6. It was also desired that the storage site be located south, southeast, or southwest of the dome in order to take advantage of the greater disposal potentialities of the Camerina limestone. This limestone lies at a depth of about 2600 feet and is considered the most favorable horizon for the final disposition of salt effluent from the storage area. The limestone apparently thickens and becomes more porous south of the dome, and thus its capacity for accepting salt effluent through disposal wells increases. At the present time one or two disposal wells are contemplated. In order to permit gravity flow from the surface storage area to such disposal wells, location of the storage area at some elevation above a nearby site for the disposal wells was also considered desirable.

7. Other considerations in site selection included the accessibility of the storage site from the shaft, the possible effect of blast damage on the storage area, and the proximity of roads and inhabited areas. That the site should be located within a short haul distance of the shaft from which the salt will be mined is obvious; however, test equipment, housing facilities, and similar features will preempt much of the area in the immediate vicinity of the shaft. Another important consideration is the effect a subsurface blast might have on a clay pad or other impermeable membrane forming part of the storage area. Heaving of the ground might

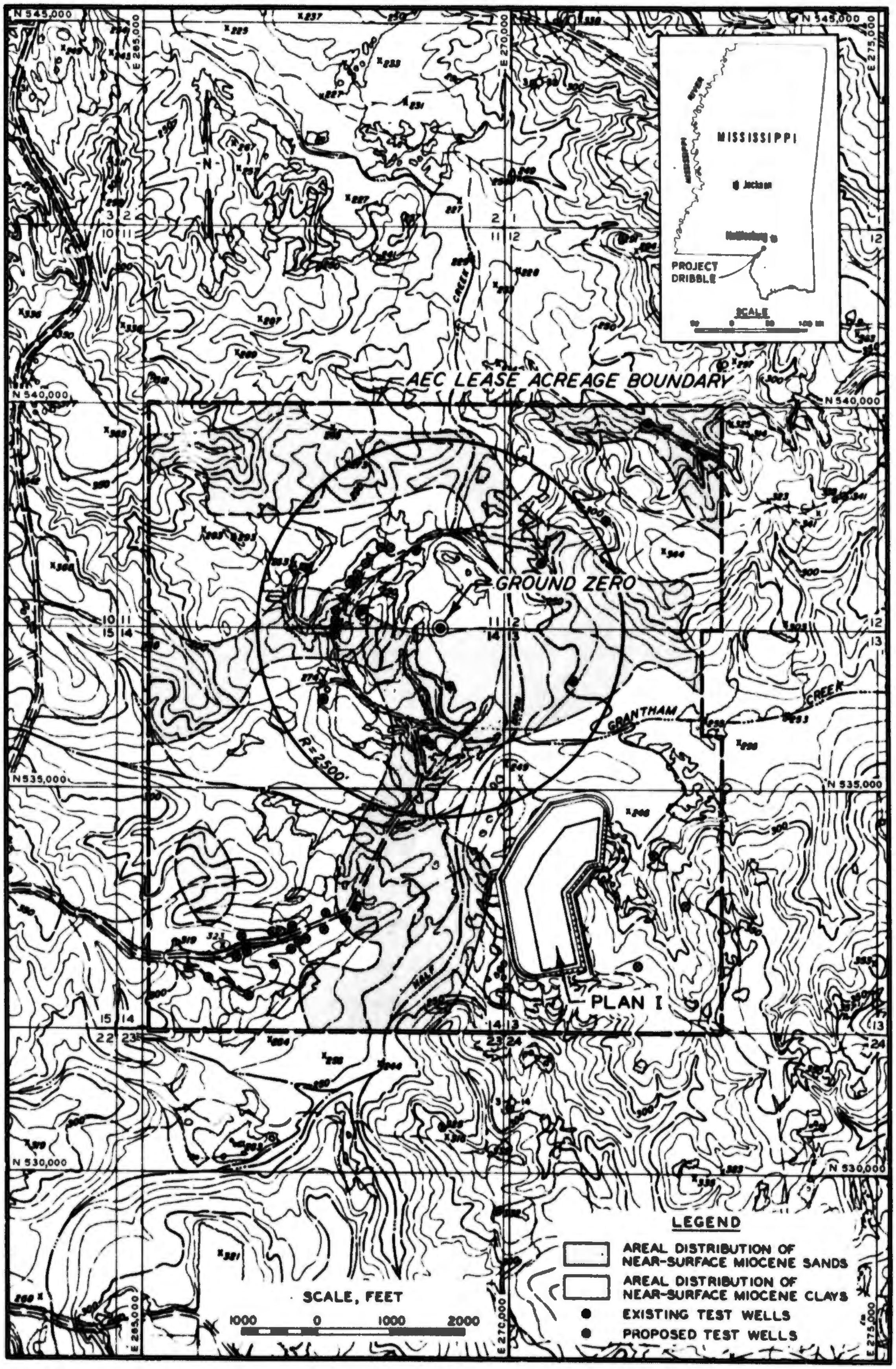

Fig. 1. Subsurface distribution of Miocene sands and clays within Tatum lease

disrupt such an impermeable seal, thereby permitting escape of salt effluent. Thus, no sites less than 2500 feet from the proposed shaft were considered. A circle with a 2500-foot radius centered at the shaft is shown in fig. 1.

8. A final consideration was that the site be located in a sparsely populated or uninhabited area where the salt pile would not be visible from a public roadway. An arbitrary distance of 1/4 mile from the nearest house or road was used for selection purposes.

Salt Storage

9. The salt is to be stored in a rectangular pile averaging 36 feet in height. The center of the pile will be slightly higher than the edges to provide for adequate drainage. Since an estimated 1,400,000 tons of salt will be stored, an area should be provided for about 1,150,000 cubic yards of salt. With the salt pile averaging 36 feet in height, an area of about 20 acres will be required.

10. The mined salt will be delivered to the site in a dry, loose condition with particle sizes not exceeding 8 inches in diameter. The salt may be hauled to the site by truck or by conveyor belt. Formation of the storage pile will be contingent upon the method of salt delivery to the storage area. Normal stockpiling operations will be followed, with the salt being spread in 2-foot lifts and compacted by means of controlled operation of hauling and/or spreading equipment. Additional compaction by other than the use of spreading and hauling equipment is not believed necessary for stability of the salt pile. Early planning had anticipated the need for some sort of cover for the salt, such as a polyethylene blanket. The cover was thought necessary (a) to prevent the salt from being rapidly eroded by rainfall, and/or (b) to prevent powdered surficial salt from being blown outside the storage area by the wind, possibly contaminating streams or blighting vegetation. However, it is now believed that neither of these conditions will cause problems. Experience at other areas where salt has been stored indicates that the salt normally absorbs moisture at the surface and forms a hard, durable crust that is relatively unaffected by wind and water erosion.

Surface-Water Storage

11. All water which becomes saline through contact with the salt pile must be contained until it can be injected into deep subsurface horizons. Determination of the amount of surface-water storage required for the project was based on a survey of meteorological data by the U. S. Army Engineer District, Mobile. The survey considered the maximum amount of storage that must be provided for precipitation within a 50-acre plot in the Hattiesburg area. As shown in the tabulation below, storage values

Maximum recorded rainfall				Well capacity, acre-feet per duration		Required water storage acre-feet		Time to empty water storage, days	
Record period years	Duration hours	inches	acre-feet	1 Well	2 Wells	1 Well	2 Wells	1 Well	2 Wells
25	24	8.6	35.83	1.93	3.86	33.90	31.97	18	9
50	24	9.7	40.42	1.93	3.86	38.49	36.56	20	10
100	24	11.0	45.83	1.93	3.86	43.90	41.97	23	11
25+100*	144	19.6	81.67	11.58	23.16	70.09	58.52	37	16
100**	96	44.0	183.33	7.72	15.44	175.61	167.89	91	44
PMP†	48	43.2	180.00	3.86	7.72	176.14	172.28	92	45

* Assumed as two 24-hour rainfalls occurring 5 days apart.
** Assumed as occurring on 4 successive days.
† Probable maximum precipitation.

were based on the maximum 24-hour precipitation for 25-, 50-, and 100-year periods of record; on the 25- and 100-year maximum precipitations occurring 5 days apart; on the 100-year maximum precipitation occurring on 4 successive days; and on what is called the "probable maximum precipitation" for a rainfall of 48-hour duration. These computations are based on the operation of either one or two disposal wells, each with a capacity of 15,000 barrels per day. It is also assumed in these computations that no runoff would enter the ponded area other than that caused by precipitation within a 50-acre tract, and that the effect of infiltration, evaporation, and transpiration would be negligible. Note that the values obtained for the last two above-listed conditions (bottom two lines of tabulation) are similar. These values are probably higher than any rainfall and resulting water storage that will occur during the life of the project; however, consideration of the probable occurrence of such great amounts of rainfall at closely spaced intervals provides a desirable factor of safety. This is important since (a) infiltration may introduce a nominal amount of water into the ponded area (see paragraph 29), and (b) siltation may decrease the size of the ponded area over a long period of time. Therefore, design of the water-storage area was based on containment of approximately 180 acre-feet of water.

12. It is pointed out that the mean annual precipitation at Hattiesburg is 59.94 inches and that one well would be required to operate on the average of 129 days during the year to dispose of the resulting runoff. During 1961, the wettest year of record, 90.71 inches of rain fell, and one well would be required to operate on a 24-hour basis for 196 days to dispose of the resulting runoff. In computing well capacity, a barrel was taken as 42 gallons. Based on this criterion one well would have a capability of disposing of 1.93 acre-feet of water per day.

Criteria for Site Selection

13. The criteria for storage and site selection are summarized as follows:

- a. The salt and salt effluent must be totally contained so as not to contaminate streams or groundwater aquifers. An artificially placed, or naturally occurring impermeable material must underlie the storage area to prevent escape of brine for a period of at least ten years.
- b. The storage area should be located within a reasonably convenient distance from the shaft from which the salt will be mined.
- c. It is desirable that the storage area be located on Tatum property presently under lease to the Government.
- d. The storage area should be located at least 2500 feet from ground zero of the proposed shot to prevent rupturing of any impermeable pad by ground heave resulting from the blast.
- e. The storage area should be located south of the dome to take advantage of the greater permeability of the Camerina limestone which will be utilized for brine disposal.
- f. The storage area should be located at sufficient elevation to permit gravity flow from the surface storage pond to a disposal well or wells.

g. The storage area should be located in a spot sufficiently remote so as not to be visible from a public road, and at least 1/4 mile from the nearest habitation.

h. Approximately 20 acres for salt storage, and an additional area capable of containing 180 acre-feet of salt effluent, should be provided.

PART III: GENERAL GEOLOGY

Physiography

14. The area under consideration consists of fairly well dissected terrain with narrow, flat-topped ridges rising about 100 feet above intervening valleys. The area is forested principally with pine and some scrub oak, with dense stands of deciduous trees in the bottomlands. The hills are well drained, but the bottomlands are usually wet during most of the year. Open areas of dense, water-tolerant grasses are typical along the lower slopes. Principal streams in the area are Half Moon and Grantham Creeks which flow in a northerly direction and enter Lower Little Creek about a mile north of the lease acreage. Although it is centered over a structural dome, the central portion of the lease acreage is marked by a topographic low. Elevations of 250 feet* characterize the central portions of the lease acreage, and elevations ranging from 300 to 350 are common in the hills along the lease border.

Surface Deposits

15. Surface and near-surface deposits in the area can be conveniently divided into ancient Miocene clays and sands, Pleistocene sandy materials, and Recent alluvium and slope wash (colluvium). Although the effects of domal upwarping are apparent in strata penetrated by deep borings, the near-surface strata appear to have been unaffected by structural activity.

Miocene

16. Primary deposits of Miocene age underlie the lease acreage at relatively shallow depths. These deposits, as indicated in scattered outcrops outside the lease boundaries and in borings, consist principally of fat, varicolored clays and thinner lenses of fine, micaceous sand. Occasional silts and siltstones are also found. Insufficient data are available to delineate individual strata within the Miocene; however,

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* All elevations are in feet above mean sea level.

several borings encountered individual clay strata more than 30 feet thick. Based on scattered borings made by the USGS throughout the lease acreage, a rough delineation of those areas underlain by Miocene sands and those underlain by Miocene clays is shown in fig. 1.

Pleistocene

17. Pleistocene deposits overlie an eroded Miocene surface. They blanket most of the lease acreage, forming the ridges and some of the lower-lying areas. The deposits consist of clayey to silty sands, sands, and occasional gravels. Although outcrops of Pleistocene deposits short distances from the lease acreage expose considerable amounts of gravel, no appreciable amounts of gravel-bearing deposits were encountered in borings on the lease acreage. Finer materials ordinarily form the surface, with the coarsest materials occurring near the base of the deposits. Thicknesses vary from thin veneers up to 60 feet or more.

Recent

18. Recent deposits of varying thickness blanket the lower slopes of the ridges and occupy the stream bottoms. Indications are that within the study area the Recent deposits consist predominantly of silty and clayey sands. The thickness of the Recent deposits in the stream bottoms may reach 25 feet or more. These deposits are normally saturated and often form spongy swamps at the lowest elevations.

Groundwater

19. Little is known of the groundwater conditions within the Miocene sediments at the site. The only reported use of water from the Miocene is the town well at Baxterville, 3 to 4 miles south of the dome. There is no indication that this Miocene aquifer outcrops within the lease acreage, or that it occurs at depths shallow enough to be affected by leakage from the salt-storage area.

20. The principal groundwater aquifer in the area is the sandy Pleistocene. Many of the dwellings near the lease acreage utilize water from shallow wells in this horizon. Water tables are highest beneath the ridge crests and slope toward the valleys. A seasonal fluctuation in the water table commonly occurs, with the water levels rising in the wet winter

and spring months and falling during summer and fall. Water is held up by Miocene clay deposits. In many areas within the lease acreage the contact between Miocene clays and Pleistocene sands occurs about two-thirds of the distance down the hill slopes. Water seeps from this contact during most of the year, wetting the lower slopes.

21. Creeks in the valley bottoms are fed by local rainfall and moderate quantities of water seeping from the Pleistocene sands. Because of the impervious nature of the Miocene clays which form the lower slopes and underlie the valleys in much of the lease acreage, water stands at relatively high levels in the bottoms throughout the year. Most of the investigation reported herein was done during the wet months, and the swampy nature of the lower slopes and bottomlands during the wet season can be unequivocably confirmed. Local residents questioned revealed that even during dry seasons seepage occurs along some of the lower slopes.

PART IV: STORAGE PLANS CONSIDERED

22. As summarized in paragraph 13, eight factors were considered in selecting the salt-storage site. A general survey of the area within a 2-mile radius of the proposed shaft at the center of the dome indicated that there would be no advantage in locating the storage site outside the lease acreage. Detailed investigations were therefore concentrated within the 1400-acre Tatum Plot.

23. The distribution of Miocene clay strata, as shown in fig. 1, and the desirability of locating the storage site south of the dome (paragraph 13e) limited site selection to the southwest and southeast corners of the Tatum Plot. A site in the southwest corner would have to contend with a number of USGS observation and test wells, the occurrence of a sandy Miocene deposit which would complicate design of the storage area, the relocation of an access road, and undesirable topographic and stratigraphic features. Therefore, a detailed investigation, including approximately 65 machine and hand-auger borings, was made of the area in the southeast corner of the Tatum Plot.

24. Locations of borings made in the southeast corner of the lease acreage are shown in plate 1. Logs of these borings are shown in plates 2-5. Contours shown in plate 1 are based on mapping done by Holmes and Narver, Inc., with modifications by USGS. These contours have been further corrected based on surveyed elevations of the borings made within the lease acreage. The resulting contours, although sufficiently accurate for planning purposes, are not exact, and calculations of required excavation volumes based on them could be subject to as much as 20 percent error. Estimates of fill volumes would be subject to less error.

25. As shown in fig. 1 and plate 1, the southeast corner of the lease acreage consists of the nose of a ridge which reaches elevation 350. The ridge slopes downward toward the north and west with Half Moon Creek skirting its western edge. Section A-A', plate 2, shows the soil conditions prevalent in the area. Silty sands and sands of Pleistocene age form the ridge crest and extend to depths of more than 50 feet. These overlie Miocene clays which form an uneven, eroded surface at an average elevation of 275. Groundwater in the coarse Pleistocene materials usually

seeps from the Miocene-Pleistocene contact and wets the lower slopes. These slopes consist of sandy colluvial wash from the upslope areas, but the colluvial wash is underlain at shallow depths by Miocene clays. At the base of the slopes the colluvial wash increases in thickness and merges with sandy alluvium from the valley bottoms.

Ridgetop and Upper-Slope Storage

26. Two plans for storing salt on the ridgetop and its upper slopes and two plans for storage on the lower slopes were investigated. A most important consideration, of course, was that no salt effluent be permitted to escape from the storage area. Thus, the plans for storage on the ridgetop were based on isolating the Pleistocene sand aquifer which forms the ridge by cutting a trench across narrow necks of land either (a) along a line running through borings A-9 and Y-4, or (b) along a generally parallel line (i.e., parallel to the line just mentioned) running through boring A-13 (see plate 1). If this could be done economically, a small drainage channel could be cut at the clay-sand contact at about elevation 275, and runoff and seepage from the area could be channeled to a conveniently located surface storage pond. The borings made at the narrow necks of land, however, indicated a considerable thickness of Pleistocene sandy material. An open cut extending to Miocene clay would necessitate large volumes of excavation and would be prohibitively costly. A possible alternative considered was the use of trenching and backfilling equipment, such as is used in the patented Cronese process, to construct a narrow, impermeable soil core to the Miocene clay. However, construction costs would be prohibitive. Consequently, use of the hillcrest and upper slopes for a storage area was abandoned in favor of the lower slopes where clay occurs at shallow depths.

Lower-Slope Storage

27. Two plans, I and II, were explored utilizing the lower slopes for salt and water storage. Plan II was located in the ravine along the northern slope of the ridge. The area was explored with a number of

machine and hand-auger borings (see plate 1 for locations, and plate 5 for logs of these borings), and although the plan is feasible, the cost of storage would be considerably greater than that for storage according to Plan I. For Plan II a retention dike about 30 feet high would be required roughly between borings C-3 and H-5; a compacted clay pad would be necessary beneath the water-storage area and beneath the higher portions of the salt-storage area; and a fairly elaborate system of diversion ditches would be required for diversion of surface runoff. Fairly detailed cost estimates were made, and costs for Plan II exceeded those for Plan I by approximately 50 percent. Plan I, which called for salt and water storage along the western slope of the ridge, was therefore chosen for more detailed study. This plan is recommended for construction, and is discussed in detail in the following part.

PART V: RECOMMENDED PLAN OF STORAGE

28. Plan I, shown in plates 1-4, provides for the following: (a) a drainage ditch on the upslope side of the site; (b) a retention dike on the downslope side of the site; (c) a water-storage area ponded by the retention dike; and (d) a salt-storage area on the slope above the ponded area. The relative positions of these features are shown in profile in fig. 2.

Drainage Ditch

29. The drainage ditch on the upslope side of the site will be cut into clay to approximately elevation 280 (see section C-C', plate 3, for detail). This ditch will intercept groundwater from the sandy Pleistocene aquifer, which lies uphill from the ditch, and channel it into the water-storage area. A 30-foot-wide space will be provided between the toe of the salt pile and the ditch. Water draining off or from beneath the salt pile will also be intercepted by this ditch and channeled to the ponded area, preventing any possible brine contamination of the Pleistocene aquifer. A deflection dike about 5 feet high will be constructed of spoil from the ditch on the uphill side of the cut to divert surface runoff around the storage area. Estimates of the amount of flow from the Pleistocene sands into this ditch are 10 to 12 grams per minute. The plan provides for a ditch 20 feet wide at its base. Specifications should require excavation at least 2 feet into the clay in all instances along the uphill side of this ditch.

Retention Dike

30. The retention dike, averaging 20 feet in height, will extend to elevation 270 along the downslope border of the storage area. The outer slopes of this dike are to be constructed of random fill; the core will consist of clay. The clay core will be tied into a 5-foot-thick clay pad with which the bottom of the water-storage area will be lined, forming a continuous seal against seepage from the storage area (see fig. 2 and

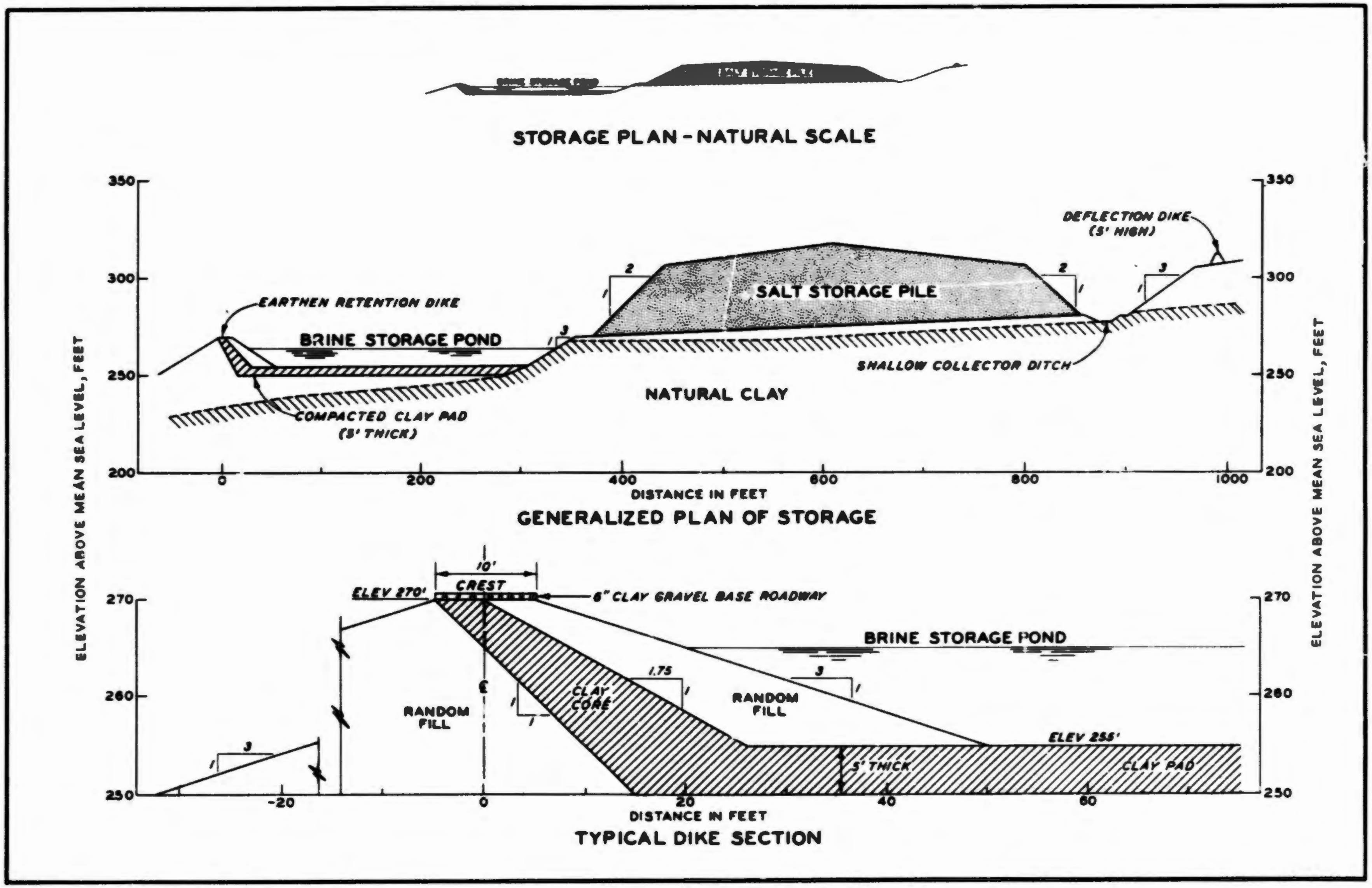


Fig. 2. Generalized plan of storage, Plan I

sections A-A' through F-F', plates 2-4). The purpose of placing the compacted clay inside the embankment rather than on its inner face is to prevent cracking of the clay. Since there will be long periods during which water levels within the ponded area will be very low, exposing the embankment to desiccation, unprotected clay surfaces would crack, possibly permitting small amounts of salty seepage through the embankment when water levels are high.

31. The dike will have a 10-foot crest width to provide for an inspection road. This road should consist of a 4-inch- to 6-inch-thick blanket of compacted clay gravel. All of the materials of which the retention dike will be constructed are available within the storage area except the clay gravel. No protection stone is considered necessary for the inner slope of the dike. Volumes for dike construction, based on a 20-foot height, 1-on-3 slopes, and a 10-foot crest width, are estimated at 250,000 cubic yards. This estimate is 20 percent in excess of measured volumes to allow for wastage and decrease in volume due to compaction. Random fill, of which the major portion of the dike will be constructed, can be obtained from the sandy and silty colluvial wash which blankets the underlying Miocene clays within the storage area. Material excavated from the drainage ditch in excess of requirements for the deflection dike can be used for this purpose. More than half of the retention dike volume can be obtained from the required excavation within the water-storage area. Additional fill can be obtained at random from the salt-storage area. The source of clays will be discussed in paragraph 35.

32. The general soil conditions beneath the retention dike are shown in section B-B', plate 2. Depths to the stiff Miocene clay (CH) are based on available borings. The elevation of this clay is contoured in fig. 3. The colluvial wash and alluvium overlying the clay beneath the retention dike consist chiefly of sandy clay and sandy silt (SC and SM). The water table is at or very near the surface. These materials should consolidate rapidly under the weight of the embankment, and no foundation problems are anticipated.

Water-Storage Area

33. As discussed in paragraph 11, at least 180 acre-feet must be

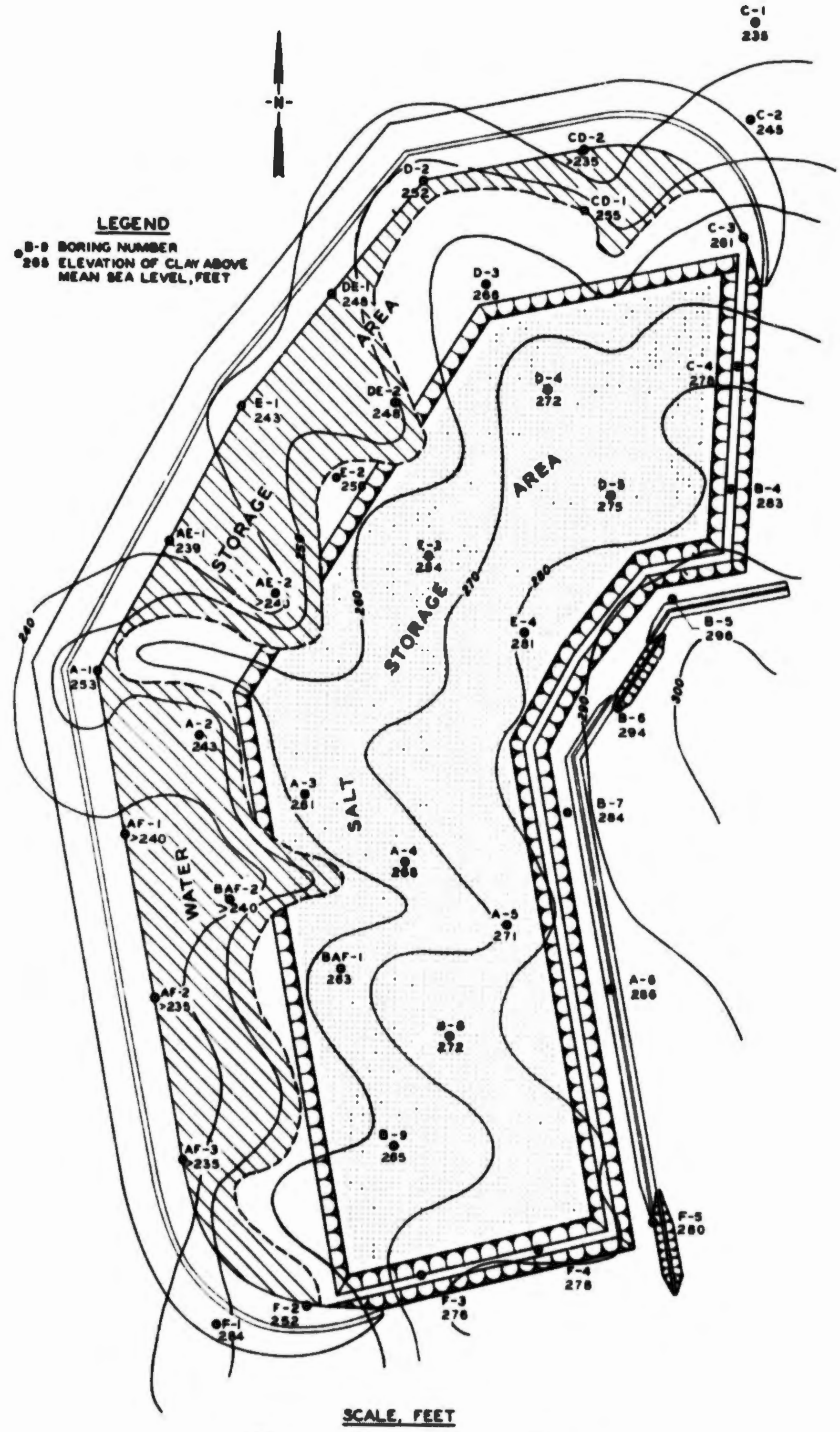


Fig. 3. Surface of Miocene clay in area of Plan I shown by contours in feet above mean sea level. Position of compacted clay pad shown by diagonal-line overprint

provided for water storage. Plan I permits approximately 195 acre-feet of storage. In addition, the plan includes an extra 5 feet of retention dike height for freeboard. This additional height will permit storage of about 300 acre-feet before overtopping of the dike will occur. The additional storage of about 105 acre-feet, besides providing assurance against overtopping, provides an added factor of safety against decrease in storage volume due to siltation or the formation of a salt cake within the ponded area. Because the plan must positively contain the salt and its effluent, no spillway was considered.

34. Since it is of prime importance that a continuous clay stratum be provided beneath the entire area so that no salt effluent can escape, the water-storage area will have an impervious bottom at elevation 255. This bottom will consist of natural clay, which borings show to be at least 10 feet thick, or a layer of compacted, artificially placed clay at least 5 feet thick. The results of laboratory permeability tests show that this thickness of clay will be sufficient to contain any salt effluent for a period of at least ten years. This is discussed further in paragraph 42. Based on contours of the natural clay surface, fig. 3 and plate 1 show the area in which a clay pad is believed necessary. Because of inaccuracies in presently available topographic maps and in the natural clay contours shown in fig. 3, minor variations in the upslope limits of the clay pad can be expected. Specifications should stipulate, therefore, that natural clay must be cut to elevation 255; that, wherever the natural clay lies at a greater depth, stripping of the overlying sandy materials must extend to elevation 250; and that this excavation must be filled with a compacted clay pad. Note that in plate 1 the compacted pad has been extended beneath the salt pile in several areas. These are topographic lows which form shallow reentrants where the Miocene clay has been removed by erosion to an elevation lower than 255.

35. Some clay for the compacted clay pad will be available from the excavations within the water-storage area and from within the drainage ditch. Additional clay can be obtained at shallow depths within the salt-storage area. Boring F-3 at the southern end of the salt-storage area and borings E-3 and B-4 in the northern part encountered Miocene clay within 2 feet of the surface. The thickness of the clay is at least

10 feet and, as indicated by boring F-3, is probably greater than 30 feet. See logs of these borings in plates 3 and 4.

36. The clay pad should not be subjected to long periods of desiccation which could cause shrinkage fissures to form in the clay that might provide paths for seepage. It is suggested, therefore, that a 1-foot depth of water be left in the pond at all times. Even during periods of extended drought this, together with natural seepage into the area (paragraph 29), should be sufficient to prevent complete evaporation of the water and desiccation of the underlying clay to the extent that deep cracks could form.

Salt-Storage Area

37. An area of 20.1 acres is provided in Plan I for salt storage. Salt-pile height may vary but should average 36 feet. Borings indicate that a natural clay, 10 feet thick or more, occurs throughout the area. As shown in plates 2-4, a variable thickness of sandy and silty colluvial wash lies above the clay in the salt-storage area. Materials may be borrowed at random from this area for construction of the retention dike.

38. Plan I provides for a saltfree zone, some 20 to 30 feet wide, around the salt pile and between it and the water-storage area or the drainage ditches. It is anticipated that the compacted salt pile will be relatively impervious. The outer surface should absorb enough moisture from the air to form a crust that will be moderately resistant to both water and wind erosion. Effluent emerging from the sandy material underlying the salt pile should be negligible.

39. Slopes of 1 on 2 are suggested for the sides of the salt pile. The only slope stability problem anticipated involves the downhill slope facing the water-storage area. Water at maximum storage elevation for an extended period (this should occur very rarely) might wet the salt sufficiently to cause some small slumpage. It is suggested, therefore, that fill material from the salt-storage area be taken from above elevation 265, the elevation of maximum water storage, and that low areas be built up to at least elevation 265 by using them for spoil disposal.

Construction Characteristics of Soils in Plan I Area

40. Laboratory tests were made on selected samples of both the colluvium and Miocene clays to obtain information for use in construction of Plan I. The results of the laboratory tests are summarized in table 1.

41. The Miocene clays range from lean (CL) to fat (CH) clays. The liquid limits range from 31 to 75. Sack samples of the lean clay and fat clay were obtained for compaction tests. Grain-size curves for the two sack samples are shown in fig. 4; compaction data are shown in fig. 5. Optimum water content of the fat clay was determined to be 21.5 percent. The natural water content of the fat clays ranges from about 20 to 27 percent, and it may be necessary to air-dry these soils by disking or other means to ensure effective compaction in the field. The natural water contents of the lean clays vary widely and generally exceed the optimum water content (12.2 percent). Additional compaction tests on intermediate types of soils will be necessary during construction in order to obtain adequate control of compaction.

42. A single permeability test on the sample of lean clay compacted at maximum density indicated a permeability in a vertical direction of 4.4×10^{-8} centimeters per second (0.0046 feet per year). The permeability in a horizontal direction may be somewhat greater; however, the compacted Miocene clays can be considered as relatively impervious, and a 5-foot-thick blanket thereof should prevent emergence of the salt effluent past the blanket for a period of at least ten years provided measures are taken to prevent the formation of shrinkage cracks in the blanket.

43. Grain-size curves for the colluvium are also shown in fig. 4. Samples from borings E-1 and AF-3 represent materials existing beneath the proposed retention dike, while samples from borings BAF-1 and C-4 represent materials to be used as random fill in the dike. These materials can be generally classified as silty sands (SM). Although no permeability tests were performed on these materials, experience indicates that they are relatively permeable. No difficulties should be encountered in compacting these materials for use as random fill in the dike. Furthermore, consolidation of the colluvium beneath the dike should occur fairly

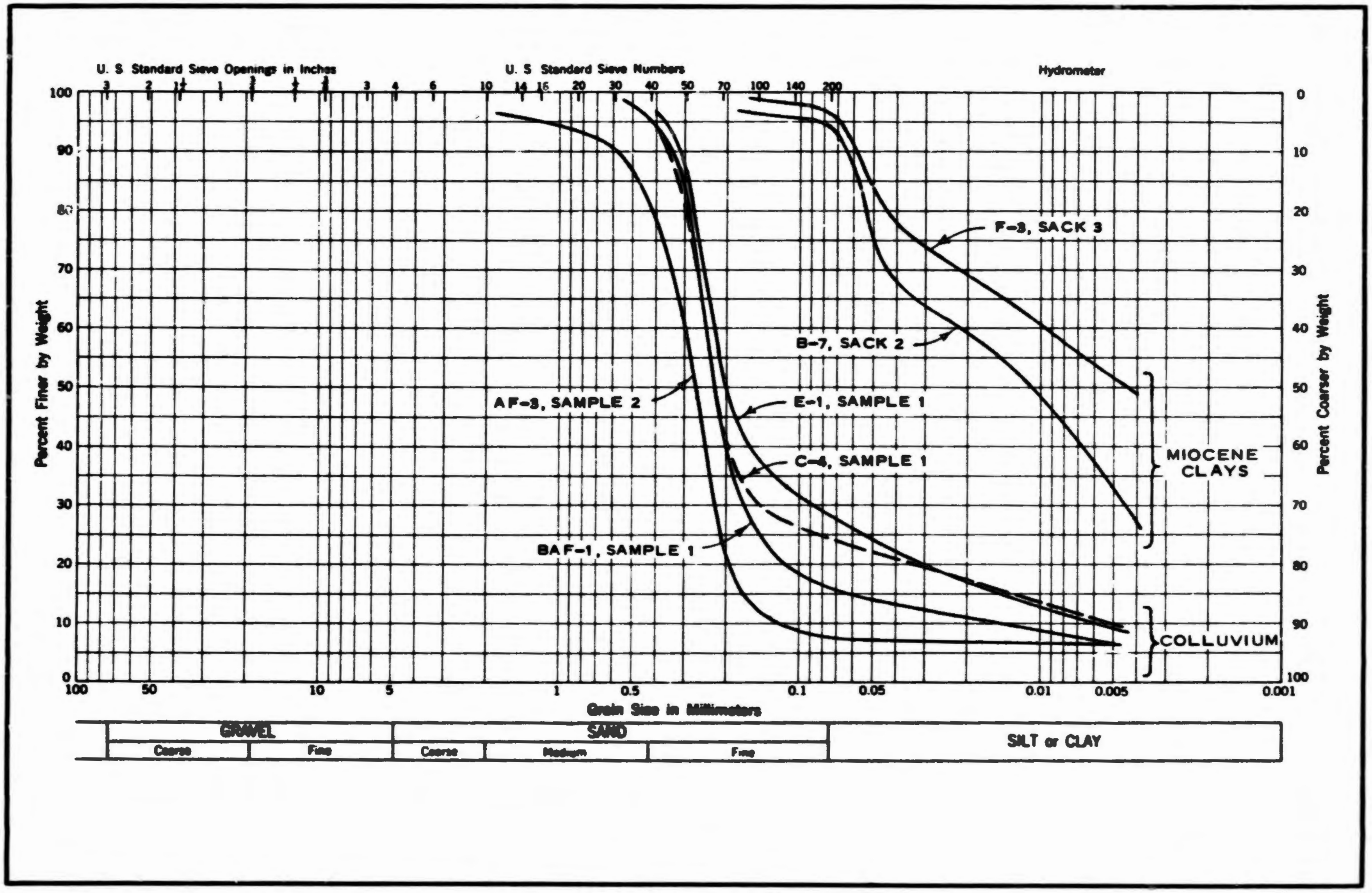
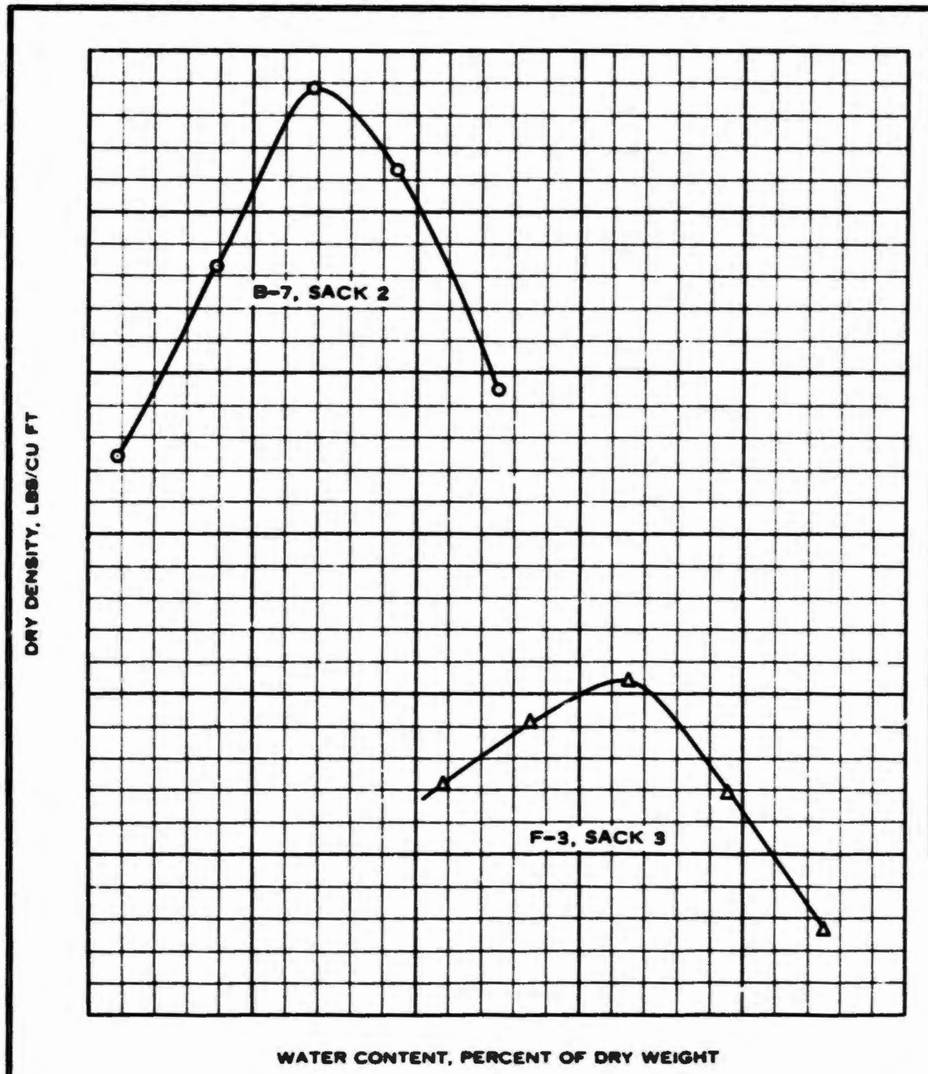
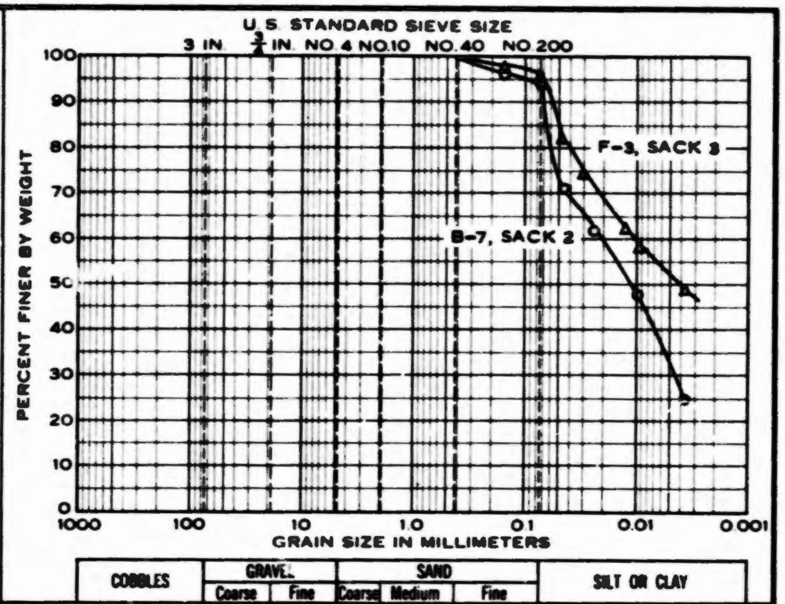


Fig. 4. Grain-size curves of boring samples





Sample No.	Elev or Depth	Classification	G	LL	PL
SACK 2		LEAN CLAY-CL	2.69*	31	13
SACK 3		FAT CLAY-CH	2.69*	66	17
		* ESTIMATED			

Sample No.		2	3		
Optimum Water Content	%	12.2	21.5	(STD COMP)	
Max Dry Density	Lbs/Cu Ft	118.9	100.4	(STD COMP)	
Optimum Water Content Corr for +	%				
Max Density Corr for +	Lbs/Cu Ft				

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Fig. 5. Compaction data on representative samples

rapidly, and only minor settlements of the dike are expected after completion of construction.

Other Considerations

44. Because of seepage along the lower slopes of the storage site, consideration must be given to draining this area prior to construction of the retention dike and water-storage area. One method of accomplishing this would be to excavate the drainage ditch as the first stage in construction. This ditch should effectively intercept seepage from the higher ridge areas which now causes the wet condition along the lower slopes.

45. Some consideration was given to methods for providing an impermeable blanket beneath the storage area other than by use of natural or artificially placed clay. However, use of a polyethylene membrane or bituminous surfacing was not considered feasible because of the high cost of such methods and/or their probable ineffectiveness in providing a positive seal for a ten-year period. A polyethylene cover for the salt pile was also suggested; however, it is believed that the only benefit of such a cover would be to prevent wind erosion of the salt pile (see paragraph 10). In any event, placing such a cover on the salt can be deferred until there is definite evidence that wind-borne salt is being carried from the storage area in significant quantities.

Cost Estimate

46. Costs for construction of Plan I and formation of the salt pile are estimated as follows:

Retention dike (250,000 cubic yards at 45¢ per yard)	$112,500
Gravel road on dike crest	1,500
Deflection dike (5000 cubic yards at 35¢ per yard)	1,750
Clay pad (100,000 cubic yards at 55¢ per yard)	55,000
Clearing and grubbing (40 acres at $200 per acre)	8,000
Stripping (20 acres at $100 per acre)	2,000
Stockpiling, minor grading beneath salt pile, etc.	5,000
Cost for construction of Plan I	$185,750
Formation of salt pile (truck haulage)	98,000
Total	$283,750

47. This estimate is based on costs for earth embankments for levees and dams where maximum haul distances are on the order of 1000 feet. Due to the limited quantities of material involved and the controls which will govern placement of the clay pad, 10¢ per cubic yard has been added to the normal costs for placing random fill, and 20¢ per cubic yard has been added to the normal costs for placing and compacting the clay pad. The estimate of quantities is 20 percent more than measured volumes to allow for wastage and decrease in volume due to compaction.

48. In arriving at an estimate for forming the salt pile, it was assumed that the salt will be delivered to the site in a dry, loose state with particle sizes not exceeding 8 inches in diameter; also, that the salt will be conveyed to the site in trucks or other comparable hauling equipment, with the cost of hauling from the shaft to the stockpile area being covered under a separate item. On this basis, it is further assumed that the same hauling equipment will be available to place the salt at its final location in the stockpile. This method of placing the material with the same equipment will eliminate the necessity of rehandling at the storage site and reduce the cost of stockpiling to a minimum. The cost for forming the stockpile in this manner is based on the additional length of haul required to place the salt (4¢ per ton) and the operational cost of the equipment used to spread the material (3¢ per ton) after it is dumped in the stockpile. A total cost of 7¢ per ton was used in arriving at the estimate for formation of the salt pile. While the method of forming the salt pile may differ should the salt be delivered to the site by conveyor belt or blowing equipment, it is estimated that the cost of forming the pile will be approximately the same.

49. Beyond the scope of this study and not included in the estimates are costs for the following: (a) construction of an access road or other means of conveying the salt from the shaft to the storage area; (b) transportation of the salt to the storage site; (c) a possible cover for the salt pile; (d) land acquisition; (e) construction of disposal wells and other disposal facilities; and (f) fencing, maintenance, etc.

PART VI: CONCLUSION

50. The most feasible area for the storage of the 1,400,000 tons of salt to be mined from Tatum Salt Dome is the southeast corner of the 1400-acre tract presently under lease to the Atomic Energy Commission. Clay of Miocene age underlies this area at shallow depths and can be readily utilized in the construction of suitable storage facilities. Of the several schemes considered for this area, the recommended plan, Plan I, is the most economical to construct and will provide maximum assurance against seepage of salt effluent from the storage area. Plan I uses to advantage the surface topography and near-surface occurrence of clay in the construction of a retention dike, a water-storage area, and a salt-storage area. This plan, along with one or two permanent brine disposal wells, each with 15,000-barrels-per-day capacity, will effectively contain the salt and all salt effluent for at least ten years. The cost of construction for the recommended plan is estimated at $185,750. An additional cost for the formation of the salt pile is estimated at $98,000.

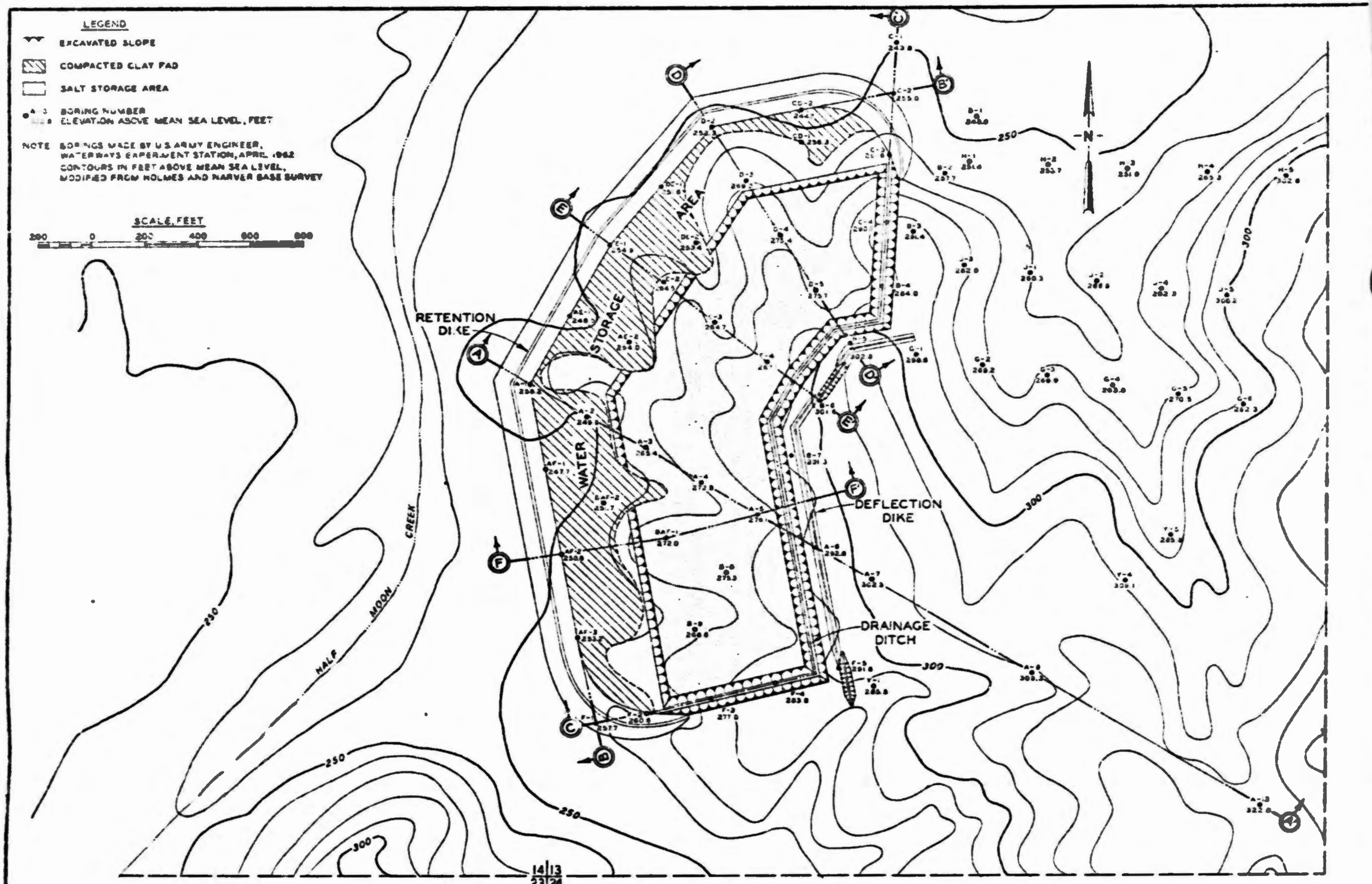
Table 1

Summary of Laboratory Test Data

Boring	Sample No.	Sample depth feet	Sample elevation feet mean sea level	USCS* soil classification	Natural water content percent dry weight	Atterberg limits LL	Atterberg limits PL	Atterberg limits PI	Percent of material finer than No. 200 sieve	Standard compaction test: Optimum water content, percent dry weight	Standard compaction test: Maximum dry density pounds per cubic foot	Permeability k_v centimeters per second
Colluvium												
E-1	1	2.5	252.4	SM	--	--	--	--	29	--	---	--
AF-3	2	6.0	247.2	SM-SP	--	--	--	--	8	--	---	--
BAF-1	1	2.0	270.0	SM	--	--	--	--	17	--	---	--
C-4	1	1.5	288.5	SM	--	--	--	--	25	--	---	--
Miocene Clays												
F-3	2	5.5	271.5	CH	23.1	66	16	50	--	--	---	--
C-4	3	14.5	276.0	CH	27.7	58	21	37	--	--	---	--
D-3	2	5.5	263.7	CH	19.7	51	14	37	--	--	---	--
A-4	2	6.5	266.3	CH	27.2	75	20	55	--	--	---	--
F-3	3**	1.0-5.0	277.0-272.0	CH	--	66	17	49	96	21.5	100.4	--
B-7	2**	5.0-7.5	286.3-283.8	CL	--	31	13	18	95	12.2	118.9	4.4×10^{-8}

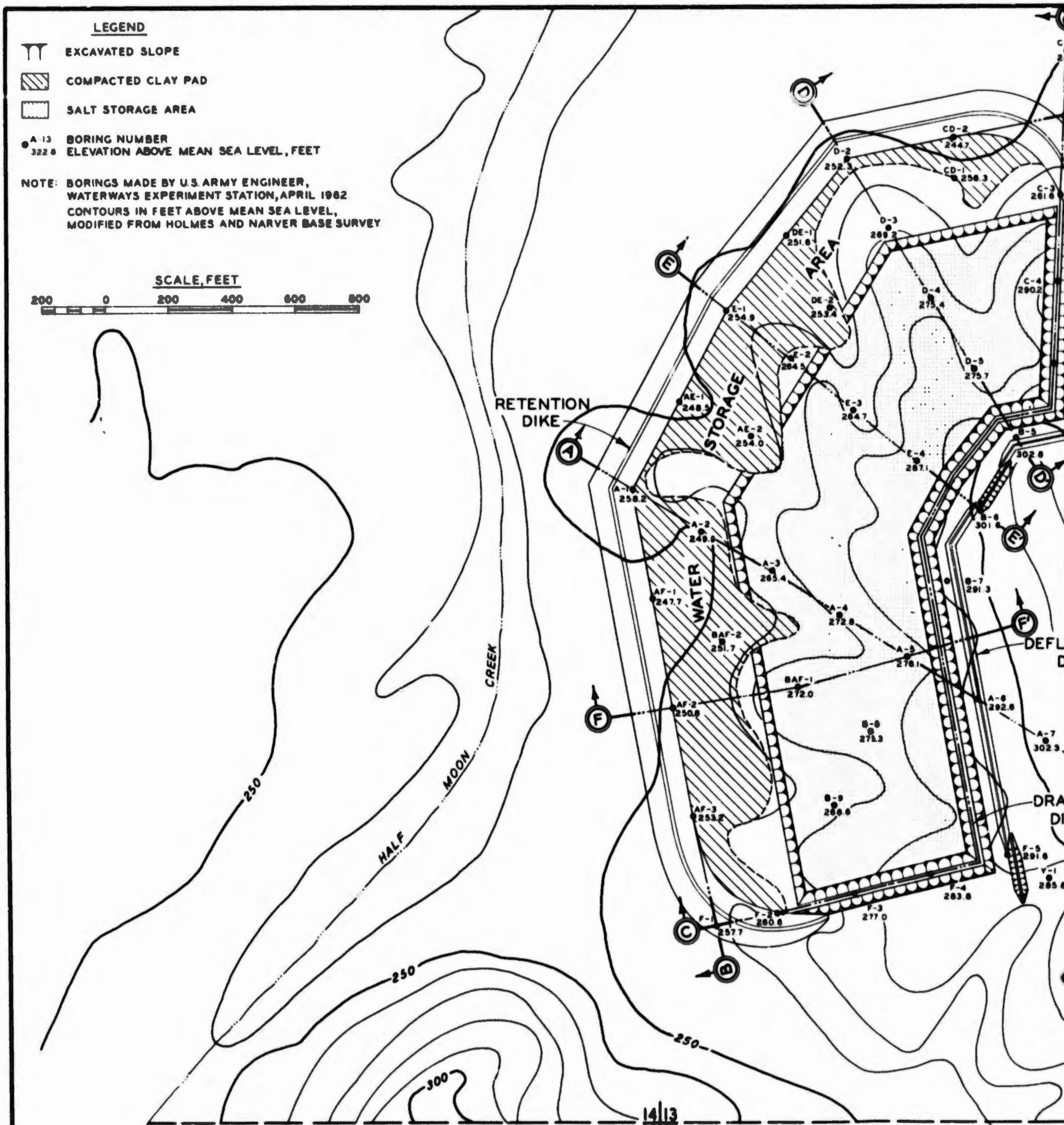
Note: LL, PL, PI = liquid limit, plastic limit, and plasticity index, respectively.
k_v = vertical permeability on compacted sample at maximum density.

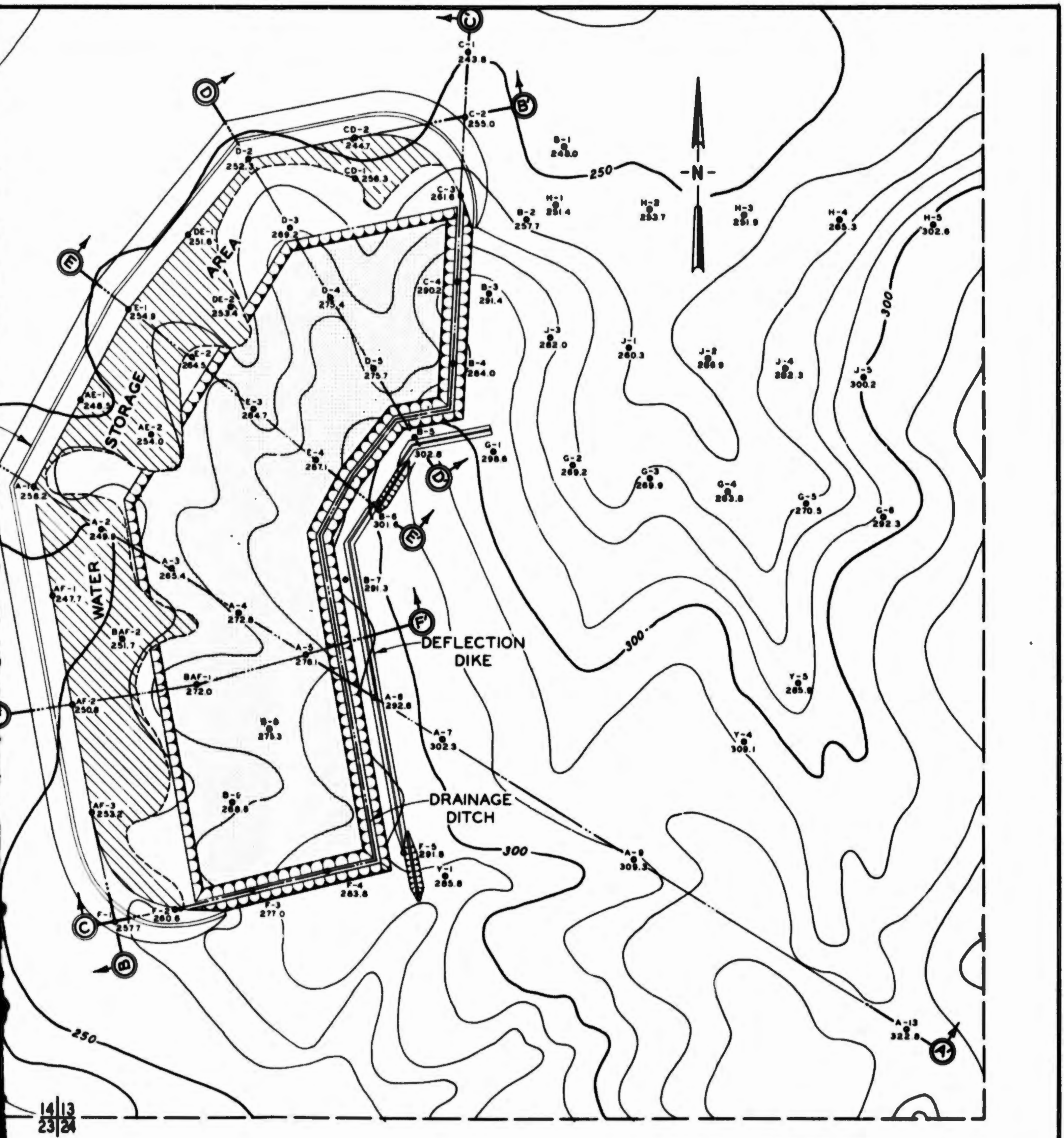
* Unified Soil Classification System.
** Sack samples.



SALT STORAGE AREA - PLAN I

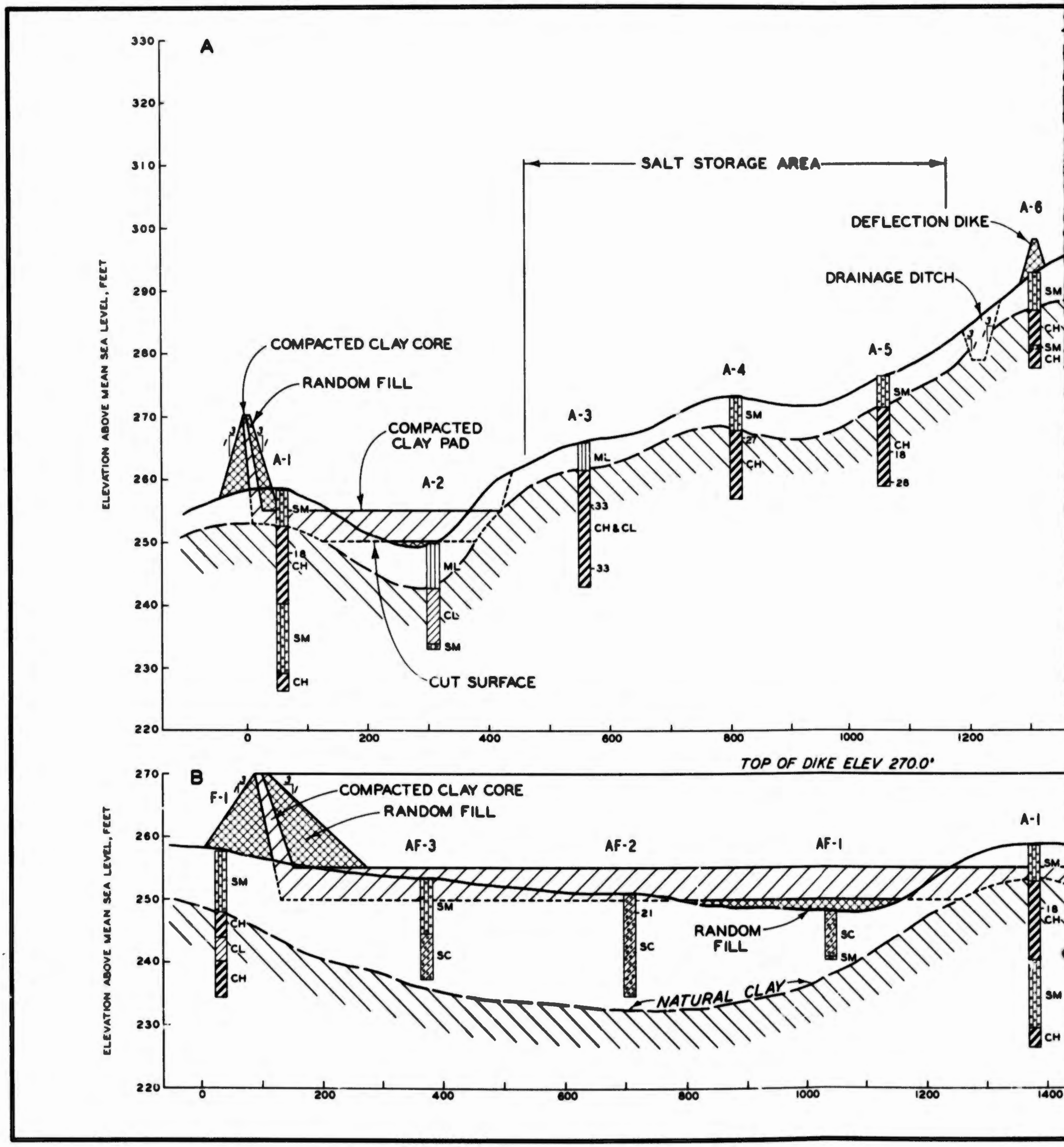
PLATE


LEGEND
EXCAVATED SLOPE
COMPACTED CLAY PAD
SALT STORAGE AREA
A 13 BORING NUMBER
322.8 ELEVATION ABOVE MEAN SEA LEVEL, FEET
NOTE: BORINGS MADE BY U.S. ARMY ENGINEER, WATERWAYS EXPERIMENT STATION, APRIL 1962
CONTOURS IN FEET ABOVE MEAN SEA LEVEL, MODIFIED FROM HOLMES AND NARVER BASE SURVEY
SCALE, FEET
200 0 200 400 600 800
RETENTION DIKE
WATER STORAGE AREA
HALF MOON CREEK
250
300
14|13
23|24

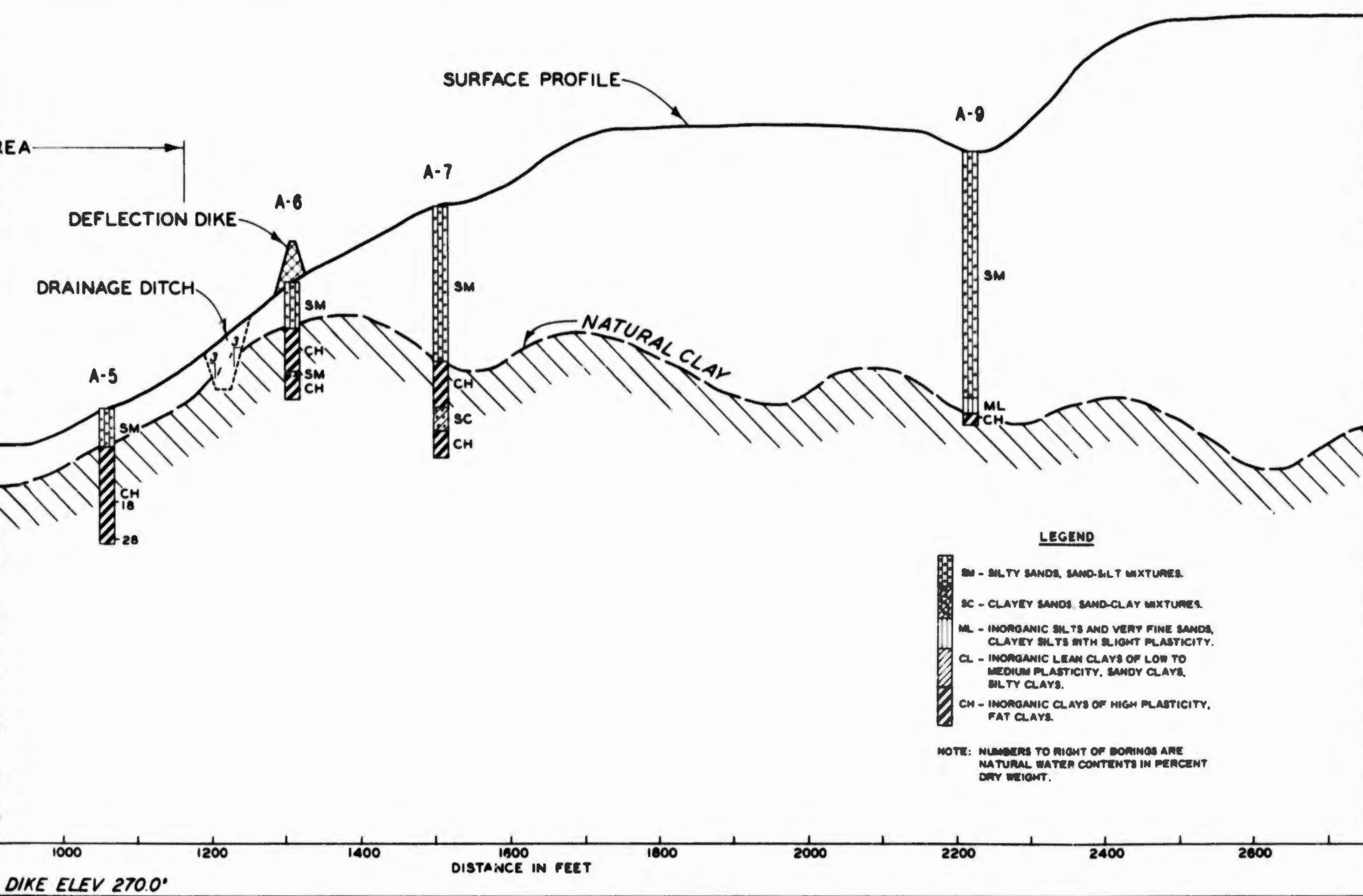


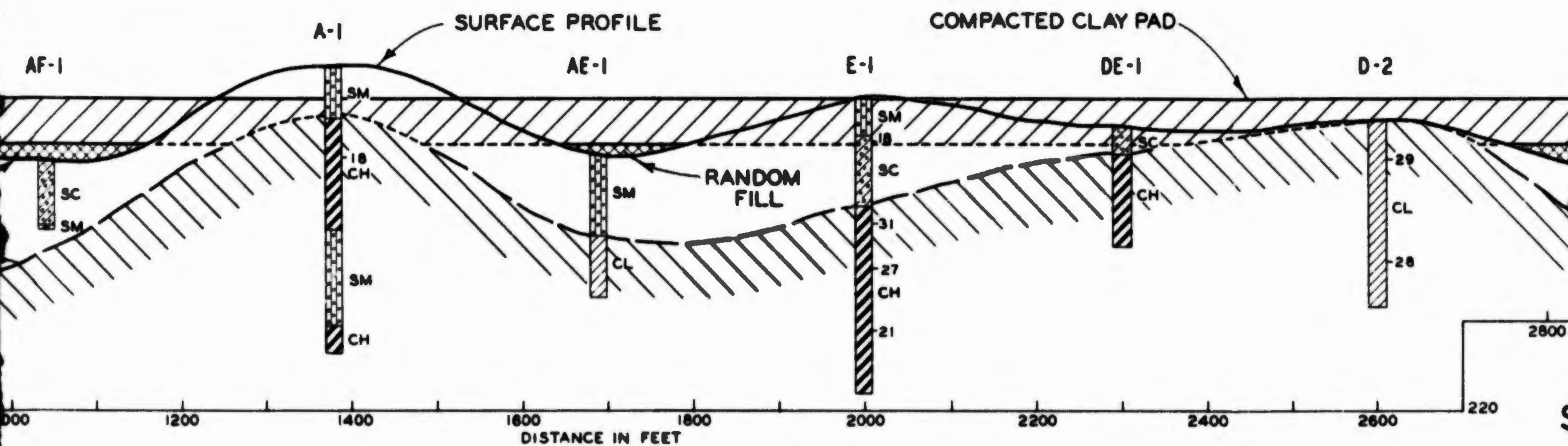
SALT STORAGE AREA - PLAN I

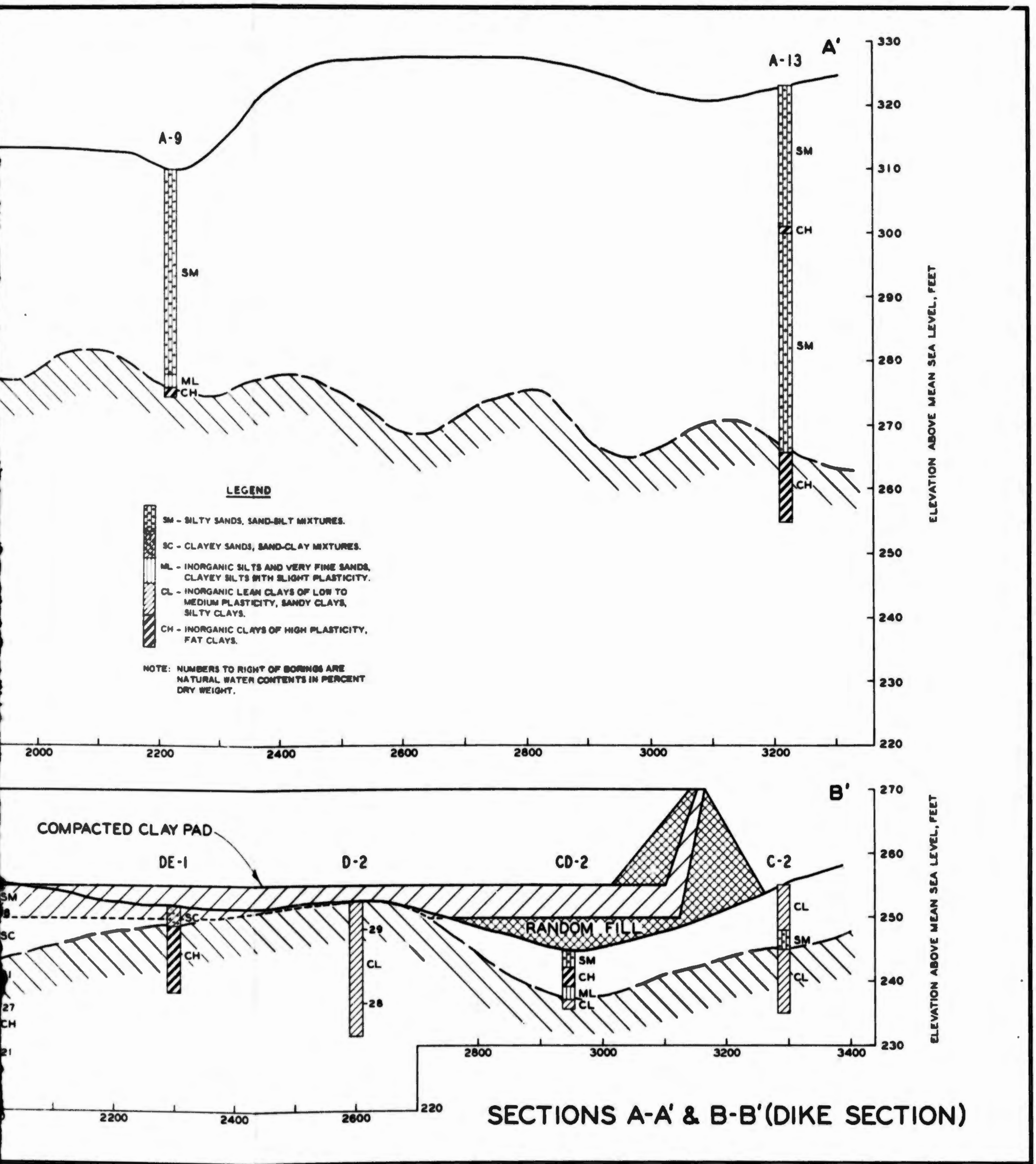
PLATE I



A
B
ELEVATION ABOVE MEAN SEA LEVEL, FEET
SALT STORAGE AREA
DEFLECTION DIKE
DRAINAGE DITCH
COMPACTED CLAY CORE
RANDOM FILL
COMPACTED CLAY PAD
CUT SURFACE
A-1
A-2
A-3
A-4
A-5
A-6
SM
CH
ML
CL
CH & CL
TOP OF DIKE ELEV 270.0'
F-1
AF-3
AF-2
AF-1
SC
NATURAL CLAY
RANDOM FILL

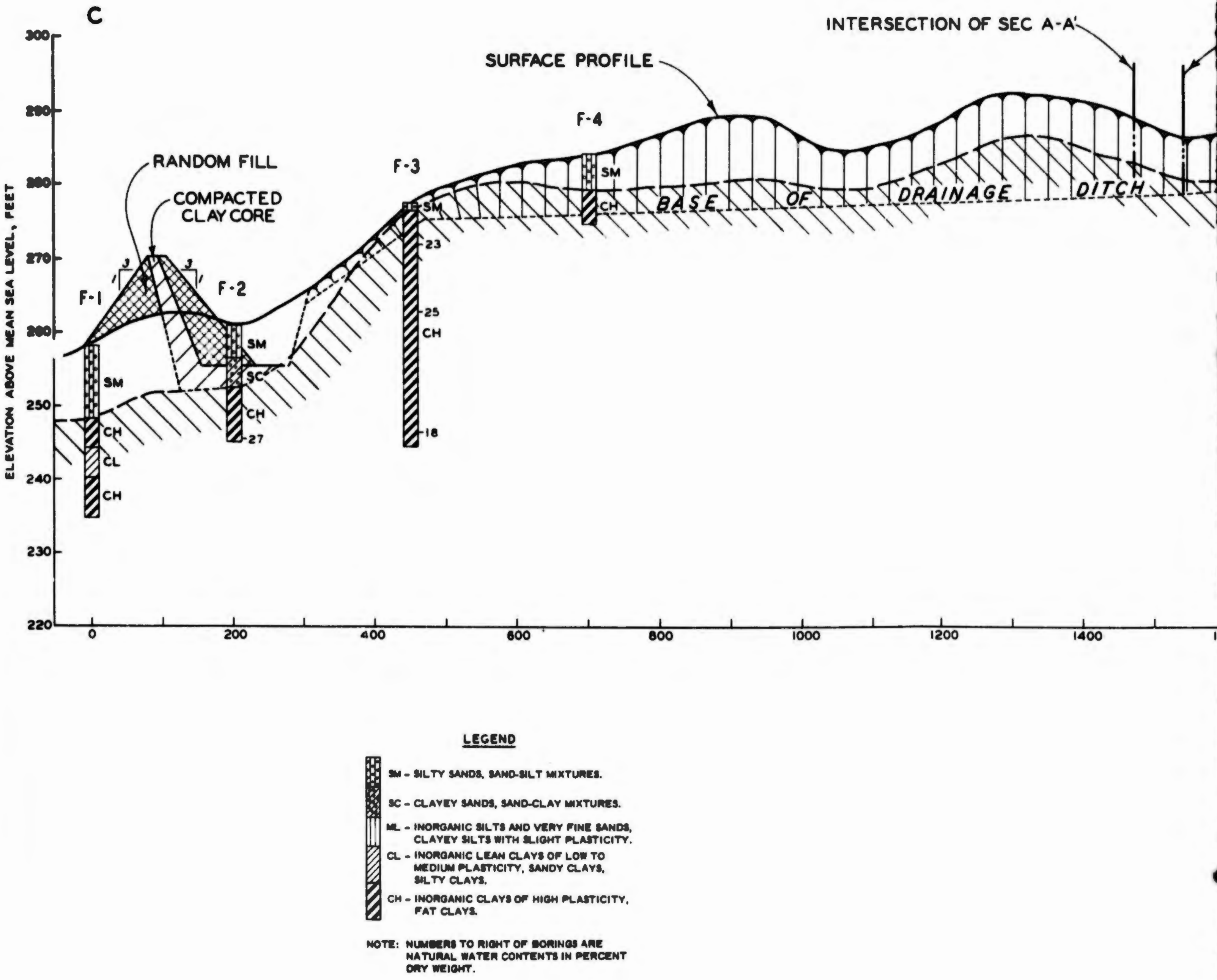

SURFACE PROFILE
A-9
REA
A-7
A-6
DEFLECTION DIKE
DRAINAGE DITCH
SM
NATURAL CLAY
A-5
CH
SM
CH
SC
ML
CH
18
28
LEGEND
SM - SILTY SANDS, SAND-SILT MIXTURES.
SC - CLAYEY SANDS, SAND-CLAY MIXTURES.
ML - INORGANIC SILTS AND VERY FINE SANDS, CLAYEY SILTS WITH SLIGHT PLASTICITY.
CL - INORGANIC LEAN CLAYS OF LOW TO MEDIUM PLASTICITY, SANDY CLAYS, SILTY CLAYS.
CH - INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
NOTE: NUMBERS TO RIGHT OF BORINGS ARE NATURAL WATER CONTENTS IN PERCENT DRY WEIGHT.
1000
1200
1400
1600
1800
2000
2200
2400
2600
DISTANCE IN FEET
DIKE ELEV 270.0'

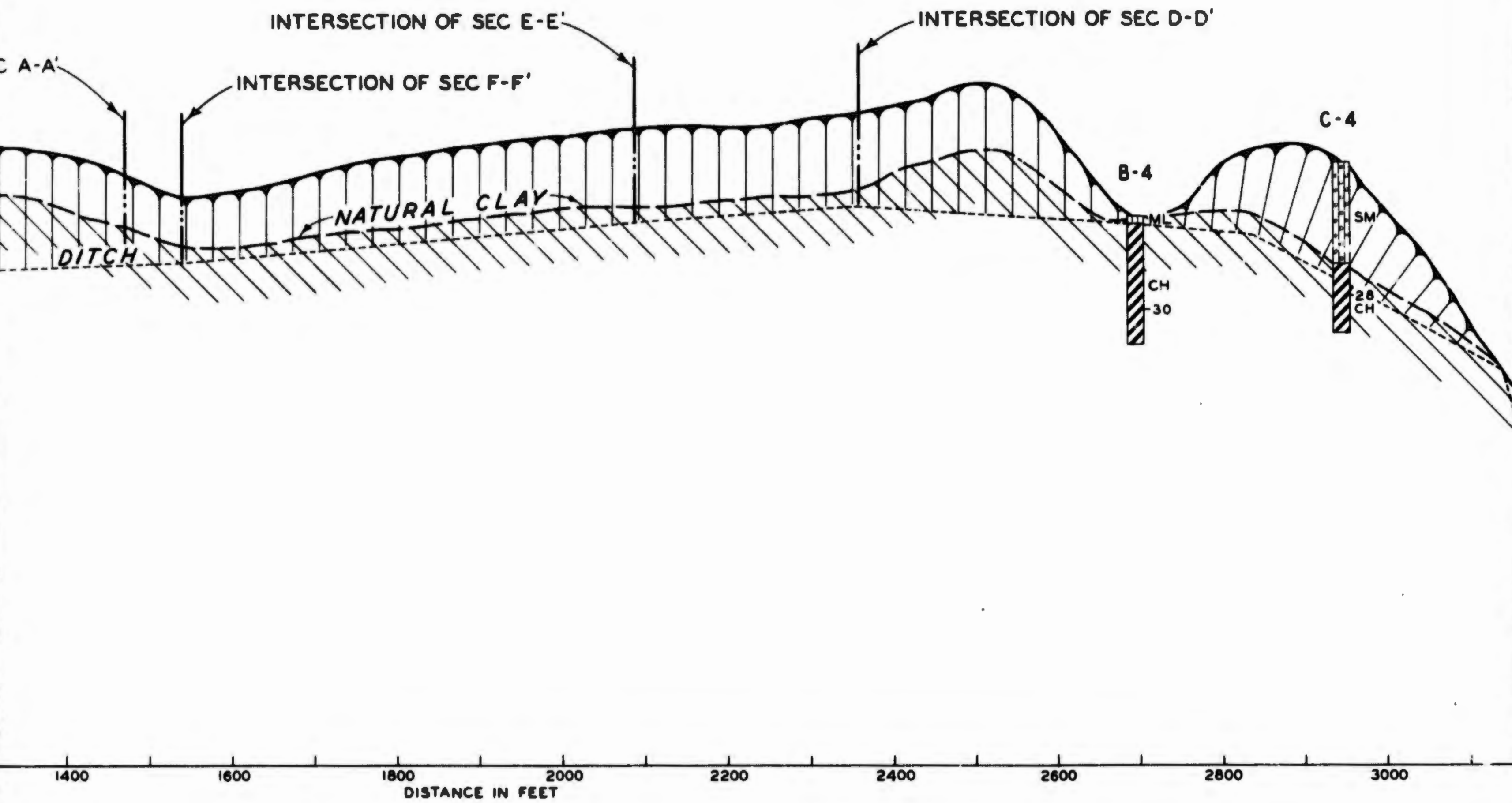

A-1
SURFACE PROFILE
COMPACTED CLAY PAD
AF-1
AE-1
E-1
DE-1
D-2
SM
18
CH
SC
SM
RANDOM FILL
CL
31
27
21
29
28
2800
220
1200
1400
1600
1800
2000
2200
2400
2600
DISTANCE IN FEET



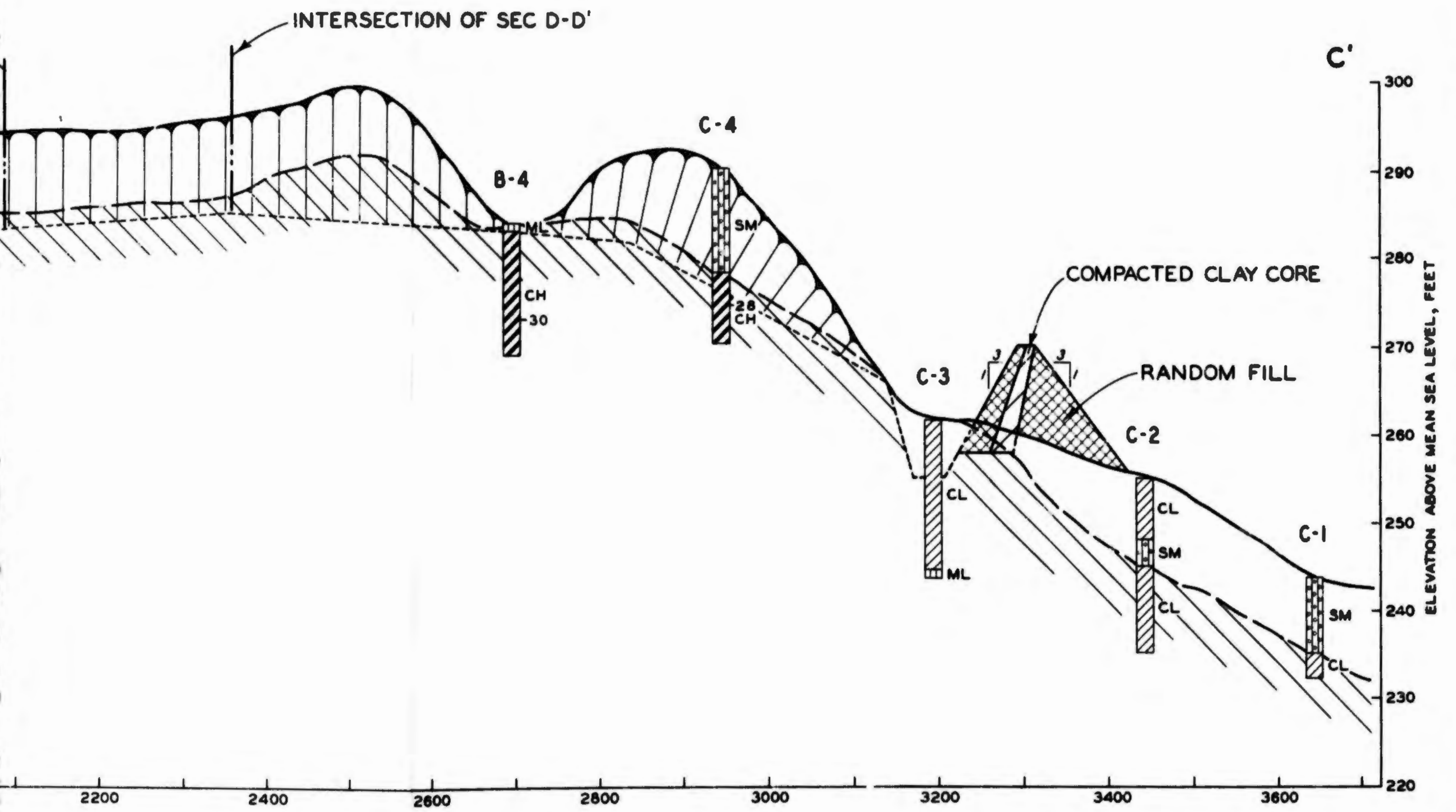
SECTIONS A-A' & B-B'(DIKE SECTION)

PLATE 2


C
INTERSECTION OF SEC A-A'
SURFACE PROFILE
F-4
RANDOM FILL
COMPACTED CLAY CORE
F-3
F-1
F-2
SM
CH
SC
CL
23
25
27
18
BASE OF DRAINAGE DITCH
ELEVATION ABOVE MEAN SEA LEVEL, FEET
300
290
280
270
260
250
240
230
220
0
200
400
600
800
1000
1200
1400
LEGEND
SM - SILTY SANDS, SAND-SILT MIXTURES.
SC - CLAYEY SANDS, SAND-CLAY MIXTURES.
ML - INORGANIC SILTS AND VERY FINE SANDS, CLAYEY SILTS WITH SLIGHT PLASTICITY.
CL - INORGANIC LEAN CLAYS OF LOW TO MEDIUM PLASTICITY, SANDY CLAYS, SILTY CLAYS.
CH - INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.
NOTE: NUMBERS TO RIGHT OF BORINGS ARE NATURAL WATER CONTENTS IN PERCENT DRY WEIGHT.

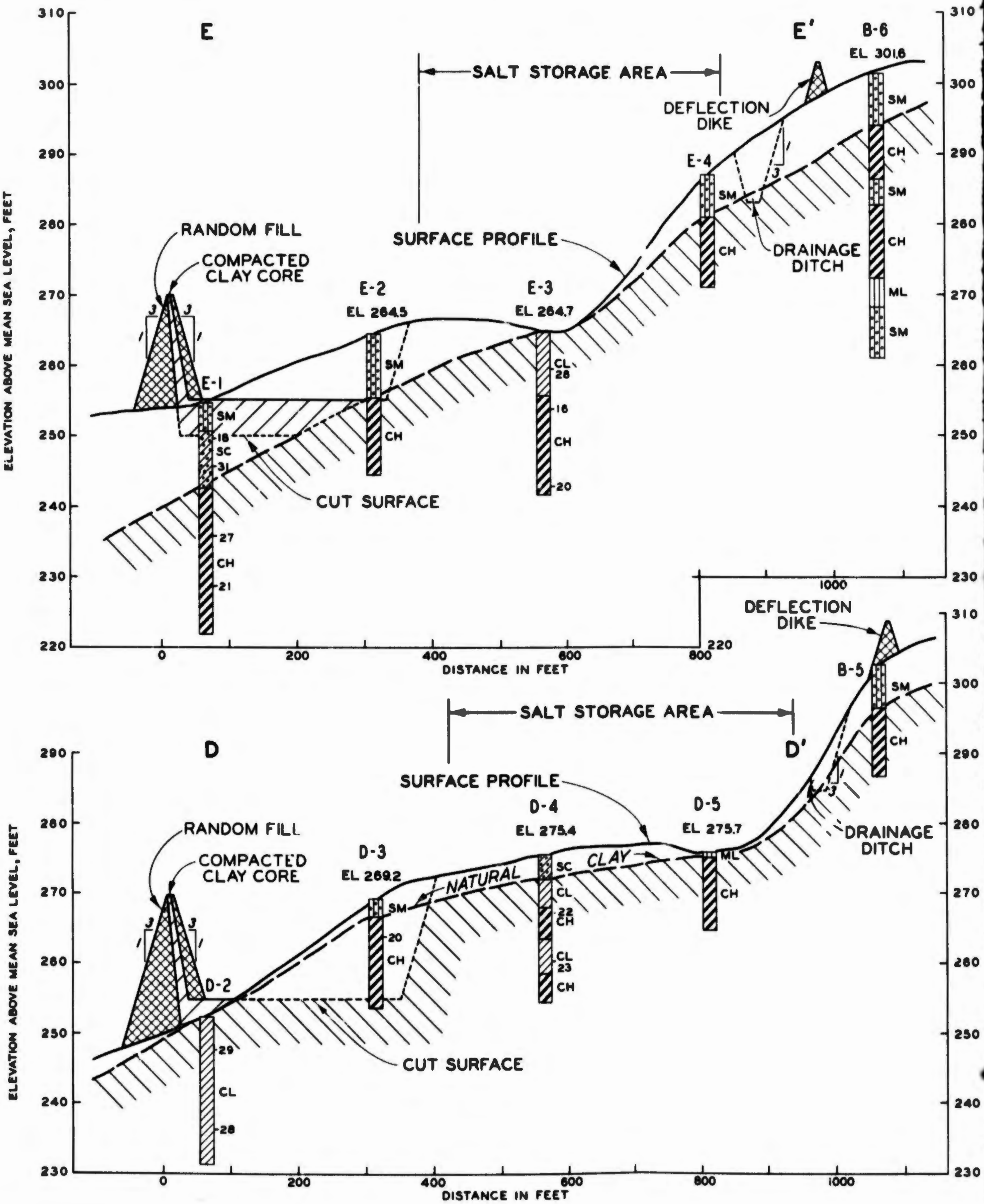


C A-A'
INTERSECTION OF SEC F-F'
INTERSECTION OF SEC E-E'
INTERSECTION OF SEC D-D'
NATURAL CLAY
DITCH
B-4
ML
CH
30
C-4
SM
28
CH
1400
1600
1800
2000
2200
2400
2600
2800
3000
DISTANCE IN FEET

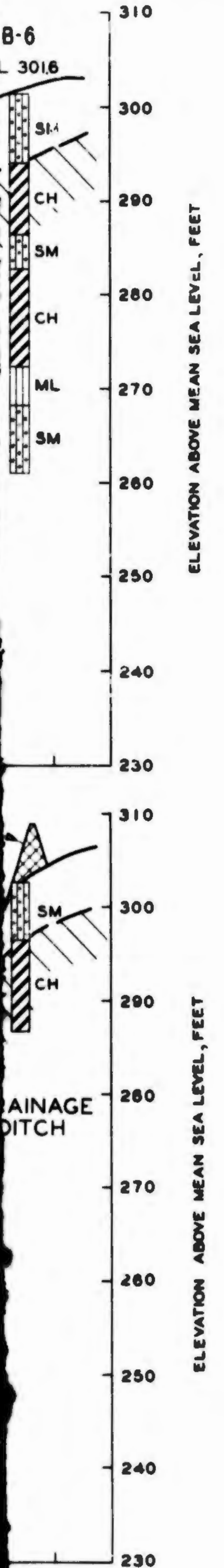


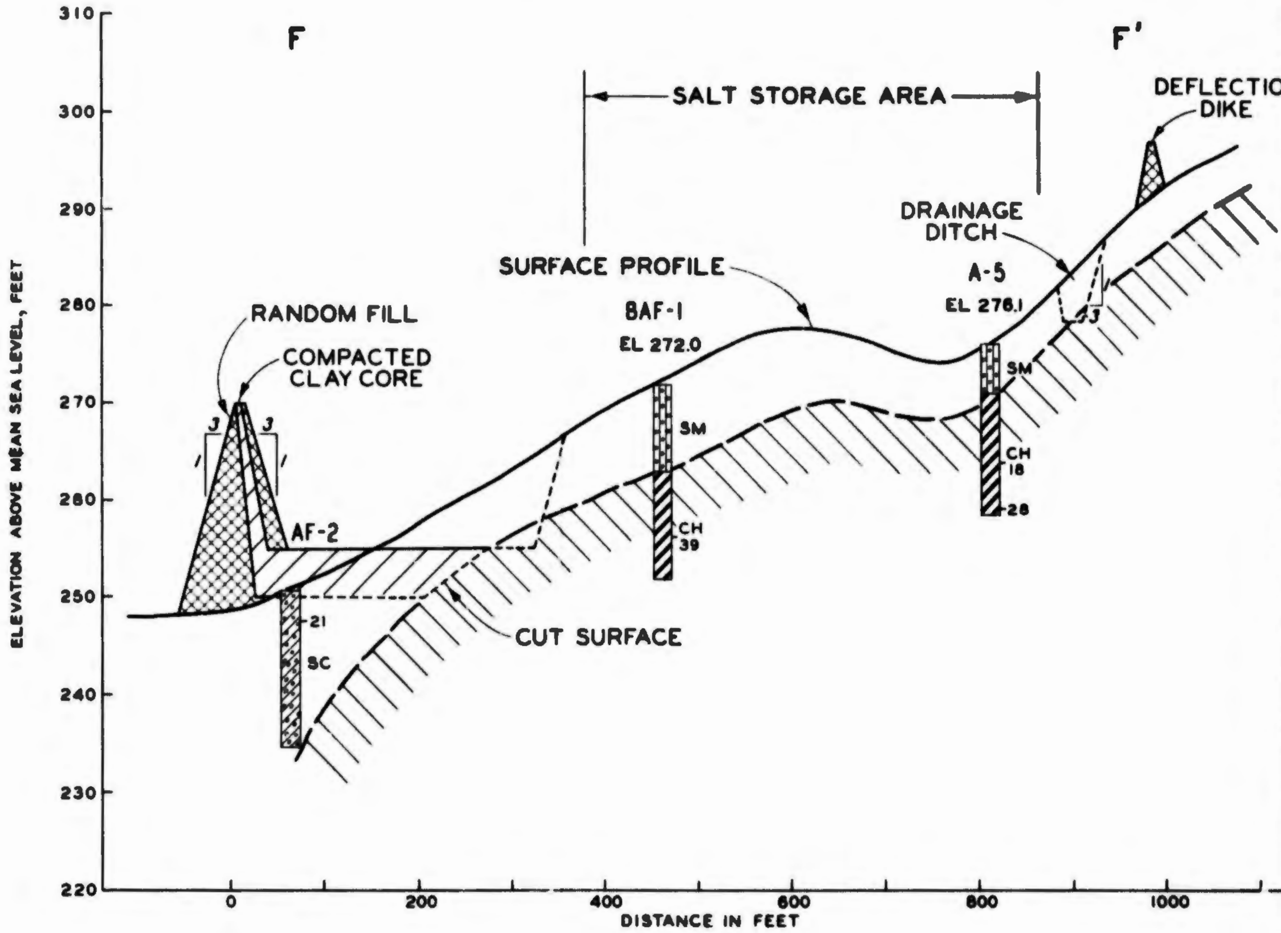
SECTION C-C'

PLATE 3



E
E'
SALT STORAGE AREA
B-6
EL 301.6
DEFLECTION DIKE
E-4
SM
CH
DRAINAGE DITCH
ML
RANDOM FILL
COMPACTED CLAY CORE
SURFACE PROFILE
E-2
EL 264.5
E-3
EL 264.7
E-1
CL
28
16
18
SC
31
27
21
20
CUT SURFACE
ELEVATION ABOVE MEAN SEA LEVEL, FEET
DISTANCE IN FEET
D
D'
SALT STORAGE AREA
B-5
D-3
EL 269.2
D-4
EL 275.4
D-5
EL 275.7
NATURAL
CLAY
D-2
29
CL
28
22
23
CUT SURFACE
DRAINAGE DITCH
DEFLECTION DIKE



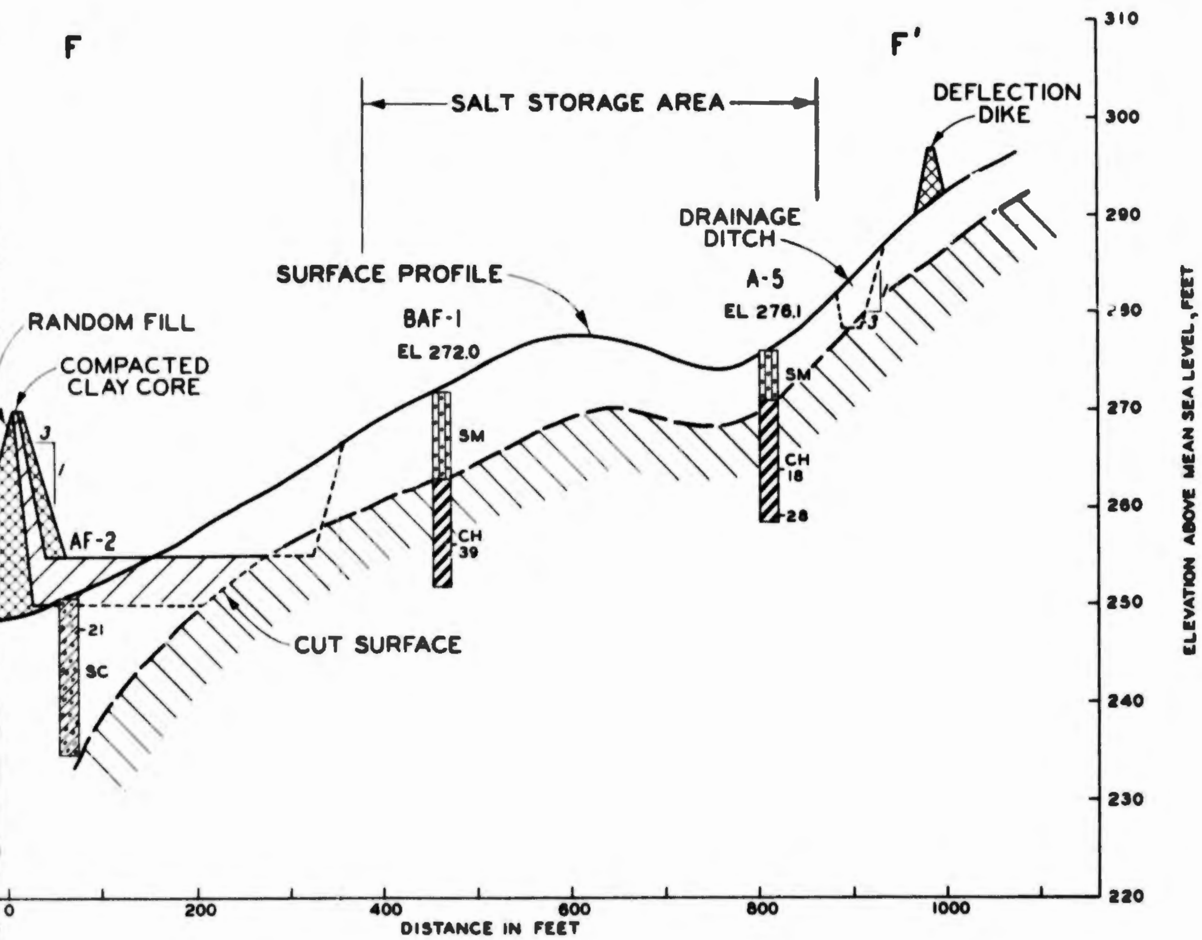


LEGEND

- SM - SILTY SANDS, SAND-SILT MIXTURES.
- SC - CLAYEY SANDS, SAND-CLAY MIXTURES.
- ML - INORGANIC SILTS AND VERY FINE SANDS, CLAYEY SILTS WITH SLIGHT PLASTICITY.
- CL - INORGANIC LEAN CLAYS OF LOW TO MEDIUM PLASTICITY, SANDY CLAYS, SILTY CLAYS
- CH - INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.

NOTE: NUMBERS TO RIGHT OF BORINGS ARE NATURAL WATER CONTENTS IN PERCENT DRY WEIGHT.

SECTION



LEGEND

SM - SILTY SANDS, SAND-SILT MIXTURES.

SC - CLAYEY SANDS, SAND-CLAY MIXTURES.

ML - INORGANIC SILTS AND VERY FINE SANDS, CLAYEY SILTS WITH SLIGHT PLASTICITY.

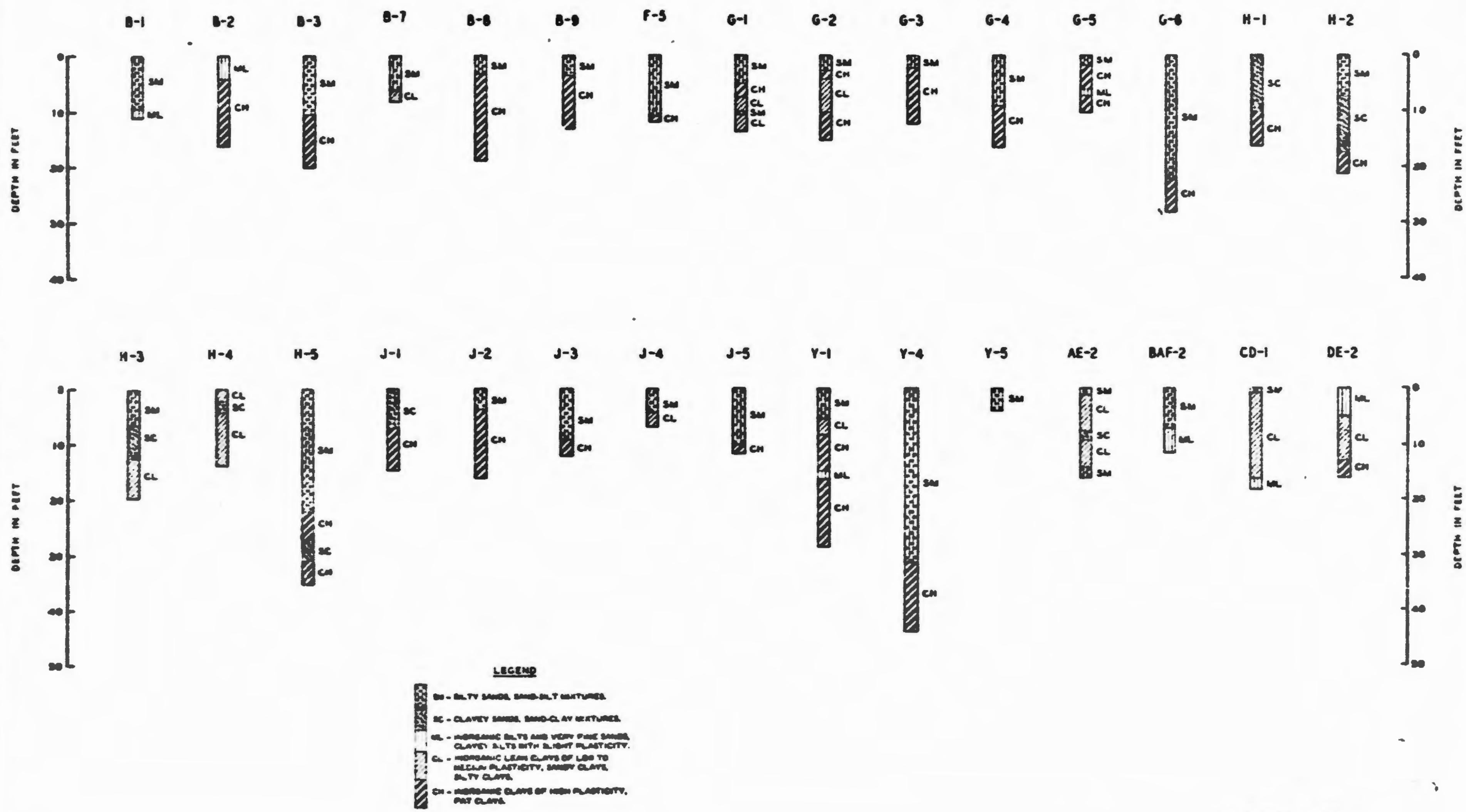
CL - INORGANIC LEAN CLAYS OF LOW TO MEDIUM PLASTICITY, SANDY CLAYS, SILTY CLAYS.

CH - INORGANIC CLAYS OF HIGH PLASTICITY, AT CLAYS.

NOTE: NUMBERS TO RIGHT OF BORINGS ARE NATURAL WATER CON[illegible]TS IN PERCENT DRY WEIGHT.

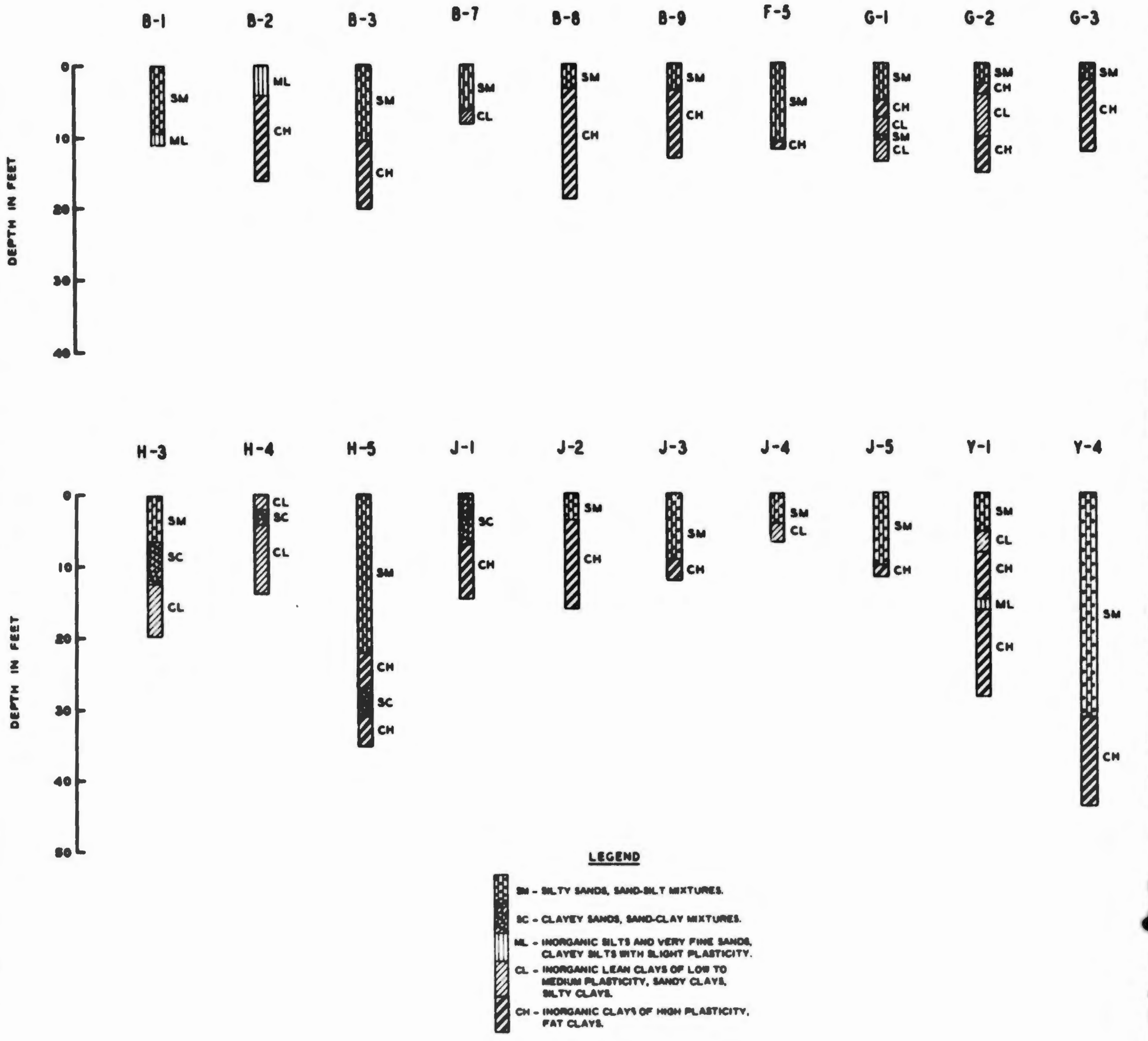
SECTIONS D-D', E-E' & F-F'

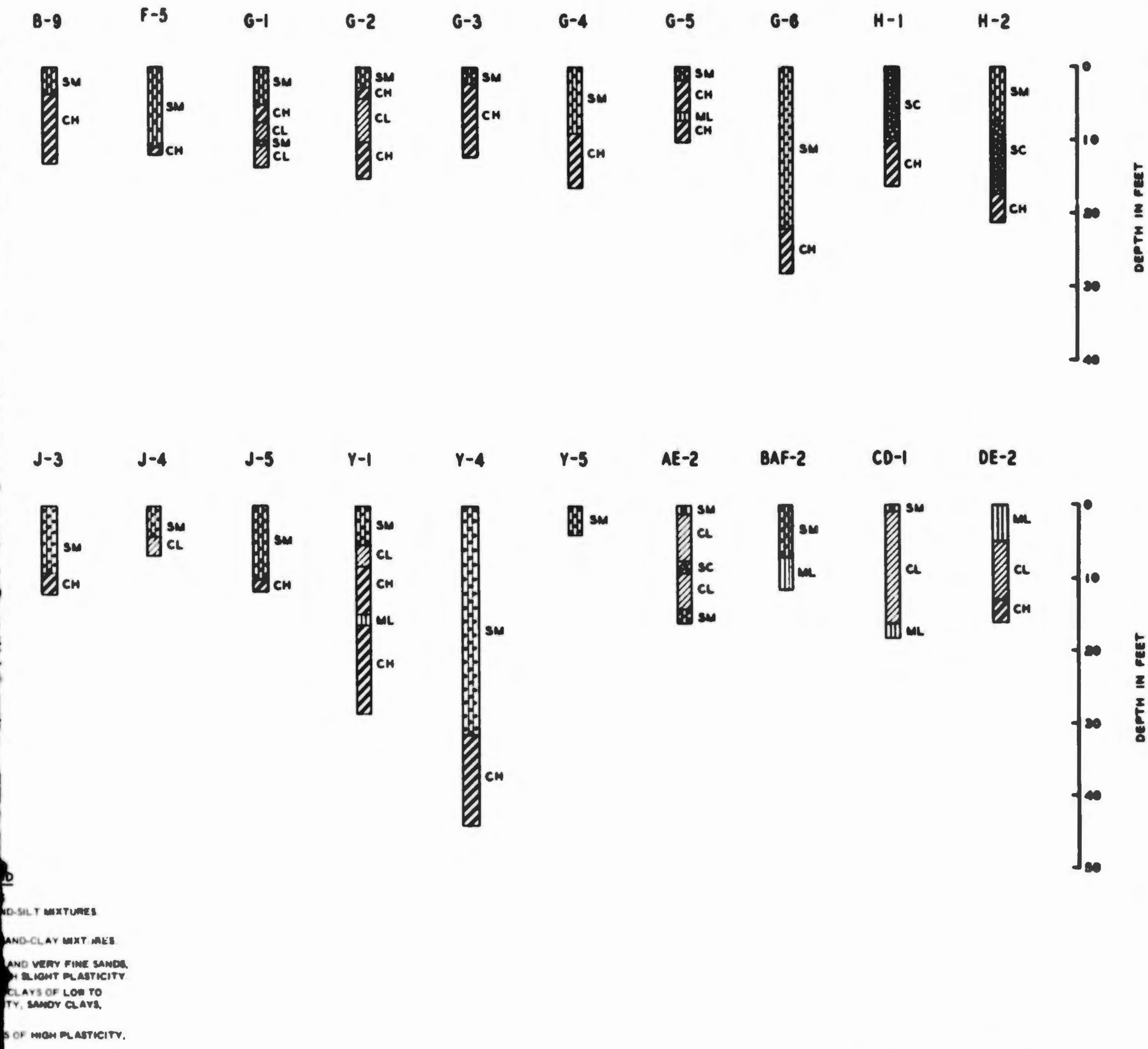
PLATE 4



LOGS OF
MISCELLANEOUS BORINGS

PLATE 5


DEPTH IN FEET
0
10
20
30
40
B-1
SM
ML
B-2
ML
CH
B-3
SM
CH
B-7
SM
CL
B-8
SM
CH
B-9
SM
CH
F-5
SM
CH
G-1
SM
CH
CL
SM
CL
G-2
SM
CH
CL
CH
G-3
SM
CH
DEPTH IN FEET
0
10
20
30
40
50
H-3
SM
SC
CL
H-4
CL
SC
CL
H-5
SM
CH
SC
CH
J-1
SC
CH
J-2
SM
CH
J-3
SM
CH
J-4
SM
CL
J-5
SM
CH
Y-1
SM
CL
CH
ML
CH
Y-4
SM
CH
LEGEND
SM - SILTY SANDS, SAND-SILT MIXTURES.
SC - CLAYEY SANDS, SAND-CLAY MIXTURES.
ML - INORGANIC SILTS AND VERY FINE SANDS, CLAYEY SILTS WITH SLIGHT PLASTICITY.
CL - INORGANIC LEAN CLAYS OF LOW TO MEDIUM PLASTICITY, SANDY CLAYS, SILTY CLAYS.
CH - INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.



LOGS OF
MISCELLANEOUS BORINGS

PLATE 5