CORPS OF ENGINEERS, U. S. ARMY

POTAMOLOGY INVESTIGATIONS

REPORT NO. 9-1

BANK CAVING INVESTIGATIONS
KEMPE BEND REVETMENT, MISSISSIPPI RIVER

SOILS INVESTIGATION

PREPARED FOR

THE PRESIDENT, MISSISSIPPI RIVER COMMISSION

CORPS OF ENGINEERS, U. S. ARMY

VICKSBURG, MISSISSIPPI

BY

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

ARMY-MRC VICKSBURG, MISS.

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Preface

The District Engineer, Vicksburg District, CE, in a letter dated 31 July 1950, subject "Kempe Bend Soils Explorations," requested the Waterways Experiment Station to investigate and analyze soil conditions existing at the site of the Kempe Bend revetment extension. The Waterways Experiment Station outlined the proposed investigational program in a letter to the Vicksburg District dated 22 August 1950, subject "Investigation of Kempe Bend Revetment Extension." This program was later modified to some extent in that the exploration phase was reduced and the analytical phase expanded.

Messrs. W. J. Turnbull, S. J. Johnson, W. G. Shockley, P. K. Garber, and R. F. Reuss of the Soils Division, Waterways Experiment Station, were actively engaged in the investigation. Mr. Garber prepared this report.

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BANK CAVING INVESTIGATIONS

KEMPE BEND REVETMENT, MISSISSIPPI RIVER

Purpose and Scope of Investigation

1. The investigation to determine the possibility of flow slides at Kempe Bend revetment extension, located on the west bank of the Mississippi River near Waterproof, Louisiana, was begun in August 1950 while bank grading and revetting operations (by the Vicksburg District) were in progress. Several bank failures occurring during the month of September 1950, as discussed later, afforded an opportunity to correlate bank conditions with stability. The investigation included undisturbed sand borings and cone penetrometer tests, and laboratory density tests.

General Soil and Geologic Conditions

2. The soils composing the bank of the Kempe Bend revetment site are point-bar deposits, bounded at the upstream end of the revetment extension and at the downstream end of the old revetment by shallow channel fillings. The locations of the channel fillings are shown on plate 1. The general soil conditions are similar to those observed and studied at other sites along the Lower Mississippi River. The soils may be subdivided into three major units or groups on the basis of certain characteristics. These groups are discussed below.

3. The entire area is covered by natural levee and point-bar overburden soils. These soils are very similar and have been grouped as one unit, point-bar overburden, on the soil profiles (plates 2, 3, and 4).

This unit is thin (10 to 30 ft in thickness) and is composed predominantly of silty soils and some lean clays. The primary basis of identification of these materials is grain size and penetration resistance.

4. The overburden soils are underlain by 70 to 90 ft of clean fine sands (hereinafter referred to as the "upper sand series"). In general, these sands are finest at the top of the unit and become coarser with depth. The increase in grain size with depth is somewhat erratic and adjacent strata may differ considerably in this respect. Identification of these soils is based on grain size, natural density, and penetration resistance. The upper sand series at this site is susceptible of subdivision into two distinct zones, as discussed later.

5. The upper sand series is underlain, in turn, by the "lower sand series," composed primarily of coarse sand and gravel. The thickness of this unit was not determined at Kempe Bend.

6. The channel filling soils located between ranges 18U and 32U (plate 3) are thick (approximately 80 ft) but are exceptionally sandy. These materials are similar to the point-bar overburden soils.

Hydrographic Surveys

Upstream of range 0

7. No detailed hydrographic surveys covering a period of years are available for the portion of the revetment extension upstream of range 0. However, certain clues as to the types of failures which have occurred in the past and may be anticipated in the future can be obtained from survey data available for the area downstream from range 0 and from bank failures occurring during grading operations upstream from range 0.

Generally speaking, the failures have been very shallow and have not gone below an elevation of +20 ft msl. In spite of this, the failures did extend 25 to 30 ft down into the fine sands, they occurred on very flat slopes, and the shapes were typical of the large flow failures studied at other sites. The large scallop between ranges 14U and 19U is typical in this respect. This scallop, shown in plan on plate 5 and in profile on plate 6, did not occur as one large failure. Successive bank line surveys (see plates 5 and 6) indicate that it has been progressive. The most recent recession (between the August 1946 and August 1950 surveys) involved that portion of the bank between stations -100 ft and +250 ft on range 16U (plate 6). The survey of August 1950 indicates that the last recession, or failure, did not extend below an elevation of +10 ft msl. The entire recession of the bank probably took place in the following manner: a series of small, shallow flow failures occurred to an approximate elevation of +10 to +20 ft msl followed by river attack and scouring of the bank below that elevation.

Downstream of range 0

8. A limited number of surveys were made in the downstream portion of the site between ranges 0 and 16D which had been previously revetted. These surveys were made on the following dates:

December 1945 and January 1946

August 1946 (not continuous)

January 1947

July 1947

August 1950.

A study of the surveys reveals certain general conditions:

a. Bank recession has been general and continuous.

b. In profile, the amount of recession has been variable; frequent small recessions have occurred between the top of bank and an elevation of 0 to +20 ft msl; a few larger recessions have occurred which appear to extend from the thalweg to the top of bank.

c. In plan, the bank recession (with one exception) does not form the pattern of cut and fill typical of large flow failures extending to the thalweg of the river -- the larger recessions shown in profile do not extend to other ranges upstream or downstream.

9. Conditions a and b listed above are illustrated by bank profiles at ranges 4D and 12D, plates 6 and 7. The recession at range 4D between January 1946 and January 1947 extended from the thalweg to the top of bank. Recession occurred between the top of bank and elevation +20 ft msl between January 1947 and August 1950 with some deepening at the thalweg. The recession at range 12D has occurred only between the top of the bank and elevation 0 to +20 ft msl and at the thalweg, with the bank from elevation 0 to -20 ft msl remaining fairly stable. The recessions at these ranges cannot be connected in plan (as stated in c above) to form a pattern indicative of large flow failures. The most logical explanation of the bank recession is that numerous shallow flow failures have occurred down to elevations of approximately +20 msl, accompanied by scour at the thalweg.

10. A possible exception to the general rule of shallow flow failures occurred between ranges 13D and 17D sometime during the period of August 1946 to January 1947. A profile along range 15D is shown on plate 7. The amount of recession is shown on plate 8 in contours of cut (measured in feet), the maximum amount being 40 ft on range 15D. No

fill was found, but it probably was removed during the time between surveys. The pattern of cut shown on plate 8 is typical of scallops observed at other sites which are thought to have been flow failures. The scallop at this site is the largest observed between any two surveys, and the period between surveys was shorter (6 months compared to 1 year at most other ranges). It seems probable that this scallop actually represents a large deep failure, although the recession may have occurred as a series of small shallow failures followed by scour.

Failures in 1950

11. On 10, 15 and 19 September 1950 a series of small failures occurred between ranges 4U and 10U during bank-grading operations. These failures were observed by personnel of the Vicksburg District and the Waterways Experiment Station. A limited amount of survey data was obtained during grading operations which indicated the following characteristics:

- a. The failures did not generally extend back beyond the top of the graded bank.
- b. The failures did not go below an elevation of +20 to +30 ft msl.
- c. The after-failure slope was nearly vertical from the top bank down to elevation 30 ft msl. The remainder of the slope was very flat.
- d. The failures were practically continuous over a distance of 900 ft (measured parallel to the river).
- e. The visible portion of the failures occurred in a matter of minutes.

It is also important to note that these failures did not occur after a major drop in river surface elevation (see plate 9). The maximum fall of the river prior to the last failures was in the order of 2 ft and the river had actually risen approximately 10 ft prior to the first failure. On the other hand, the failures did occur during bank-grading operations when a large amount of heavy equipment was being moved over the top bank area. It was observed that the upper bank became soft and spongy during these operations and excess water was visible on the surface. Based on the observed characteristics of the failures and the river and bank conditions, it seems reasonable to assume that these failures are typical of those previously discussed; i.e., they are relatively shallow flow failures.

12. This conclusion was discussed with representatives of the Vicksburg District. It was stated that the portion of bank above +20 ft msl appeared to be unstable and that this conclusion was substantiated both by performance and by the limited amount of soils data then available (as described later in this report). Recommendation was made that the portions of the bank which had remained stable during grading (referred to as "hard points" in the discussion with Vicksburg District personnel) be used to advantage in that they be graded the minimum amount necessary to obtain a relatively smooth bank, at the same time permitting them to project into the river as natural groins. It is understood that this was done and that a double layer of revetment was used in the areas where the failures occurred.

Exploration Program

13. The locations of all soil borings are shown on plate 1. They include general sample borings made by the Vicksburg District, and

undisturbed sample borings and cone penetrometer soundings made by the Waterways Experiment Station. The borings made by the Vicksburg District are shown on plate 1 with a symbol having the prefix "K." The symbol for the borings made by the Waterways Experiment Station has a prefix which corresponds to the range number. It was originally proposed that the Waterways Experiment Station make 6 undisturbed borings and 13 cone soundings. However, numerous available boring results (plates 2 and 3) indicated uniform soil conditions over the entire reach of the revetment extension; consequently, the number of undisturbed borings and cone soundings were reduced to 5 and 10, respectively.

Laboratory Testing

14. Laboratory testing included the following:

- a. Natural density (γd): Undisturbed 3-in.-diameter Shelby tube samples were cut in 3-in. increments and the natural density of each increment was measured.
- b. Grain-size determination: Mechanical analyses were performed on the soils in each Shelby tube and at the strata changes.
- c. Maximum and minimum density (γd max and γd min) and relative density (R D %): Maximum and minimum density tests were performed on representative samples selected on the basis of grain-size distribution. Relative density was then computed as

$$R\,D\,\% = \frac{\gamma d - \gamma d \text{ min}}{\gamma d \text{ max} - \gamma d \text{ min}} \cdot \frac{\gamma d \text{ max}}{\gamma d} \cdot 100 .$$

Discussion of Bank Conditions

15. The detailed results of all borings and cone penetration tests are shown on plates 10 through 20. It would appear from these results

that the soil conditions are generally the same over the entire reach of the revetment extension and, in the vicinity of range 16U, from the top of bank to the toe of the levee. The major exception is the channel filling at the upstream end of the revetment extension. In view of the similarity between borings, a detailed discussion of each will not be presented in this report. The general soils conditions are best illustrated by the soil profile section c-c, plate 4, as previously discussed in paragraphs 2-6. The correlation of bank stability with soil type is discussed in the following paragraphs.

16. Point-bar overburden soils are not considered susceptible to the liquefaction type of failure, since they exhibit a certain amount of cohesion. All soils having more than 10 per cent (by weight) finer than 0.074 mm (No. 200 U. S. Standard sieve) are included in this unit. Cone penetration resistance is normally less than 1000 lb. In some instances, such as at Free Nigger Point and Morville, Louisiana, these soils have had a restrictive effect upon the shape of the failures where liquefaction occurred. This effect has been more pronounced where the thickness of the overburden varied considerably because of the presence of swale fillings. The thickness of the overburden at Kempe Bend is not sufficient to have any appreciable effect on the size or shape of liquefaction failures.

17. The lower sand series has never been involved in any flow failures studied to date. These soils have more than 50 per cent (by weight) coarser than 0.42 mm, natural densities normally in excess of 105 lb per cu ft, and cone penetration resistances greater than 8000 lb. The shallow failures which have occurred at this site and the depth to the lower sand series make it extremely doubtful that this series

contributes to either the stability or instability of the bank.

18. The susceptibility of a given slope to liquefaction apparently is entirely dependent upon the dimensions of and the conditions existing within the upper sand series. The soils in this series have less than 10 per cent finer than 0.074 mm and more than 50 per cent finer than 0.42 mm (U. S. Standard sieve No. 40). Natural densities are normally less than 105 lb per cu ft and cone penetration resistance less than 8000 lb. A rather distinct change in cone thrust, natural density, and grain size of the sands was observed at this site in the upper sand series at approximately elev +20 ft msl. A careful study was then made of all soils data to determine the significance of this change since it occurred at an elevation corresponding to the depth of the failures. It was possible to subdivide the upper sand series into two zones as discussed in the following paragraphs. In this discussion the values given for each subdivision of the upper sand series are based on statistical averages, and occasional exceptions occur which probably represent the cumulative effect of small errors and variations in the techniques used to determine the values. These exceptions are probably insignificant and, if they represent cumulative errors, cannot be avoided when large numbers of tests are performed. They are mentioned here to preclude concern wherever they may be observed, particularly in future investigations.

19. The top 20 to 25 ft of the upper sand series, hereinafter referred to as Zone A, has properties which significantly differ from the remainder of the series. This zone is represented by the soils above an elevation of +20 to +30 ft msl (see plate 4). The cone penetration resistance was continuously less than 4000 lb within this zone. Any given

sample of sand had at least 90 per cent (by weight) of the individual grain diameters greater than 0.074 mm (No. 200 U. S. Standard sieve) and 50 per cent smaller than 0.250 mm (No. 60 U. S. Standard sieve). The densities of these sands varied from 94 to 102 lb per cu ft; these values corresponded to a range of relative densities from 50 to 80 per cent.

20. The lower portion of the upper sand series, Zone B (see plate 4), had numerous strata of sand similar to those described above, but also contained strata of coarser sand, 50 per cent greater than 0.250 mm, at densities greater than 102 lb per cu ft which had penetration resistances in excess of 4000 lb. The higher densities of these strata result in a higher average relative density for Zone B than for Zone A. The over-all average relative density of Zone A is in the order of 50 to 65 per cent whereas the average for Zone B is from 70 to 90 per cent.

Bank Stability

21. The foregoing analyses of bank recession and soil conditions at the site of the revetment extension result in two related conclusions; first, the portion of the bank above an elevation of approximately +20 ft msl is more susceptible to flow failures than the remainder of the bank; and secondly, a distinct change in soil conditions occurs at this same general elevation. The upper portion of the upper sand series, Zone A, is apparently unstable. The stability of this zone is dependent upon that of the fine sands in which the major portion of the failures occurred. Compared with the other sands, the sands in Zone A are distinguished by low penetration resistances ($<$ 4000 lb) and low relative and natural densities ($<$ 80% and $<$102 lb per cu ft, respectively).

22. The stability of the lower portion of the upper sand series, Zone B, is debatable. At least one large failure, previously discussed, may have extended into Zone B. If this is the case, Zone B is susceptible to liquefaction provided the conditions causing failure are severe enough. On the other hand, the large failure may have occurred at a location where Zone A extends down to the top of the lower sand series as it does at range 5D. If this latter condition were proved to be the case, it would be possible to say that Zone B is not susceptible to liquefaction. Any statement concerning the stability of Zone B must, for the present, remain in the realm of conjecture. It would seem most likely, however, that its stability is dependent upon the thickness and spacing of the coarser, more dense strata contained in Zone B. If these strata are rare or very thin, Zone B would probably be susceptible to flow failures under conditions only slightly more severe than those required to cause failure in Zone A. If the strata are relatively numerous, Zone B is probably stable.

23. It is unlikely that the conditions observed at Kempe Bend are unique. If the results of future investigations at other locations indicate that a similar relationship exists between stability and soil properties, it may be possible to distinguish rather closely between stable and unstable slopes composed of cohesionless soils.

24. Shallow failures will probably occur at the site of the revetment extension, since Zone A is apparently continuous over the entire reach. The continuity of these failures may be somewhat altered or possibly prevented by the remedial measures taken at the sites of the 1950 bank failures. A deep failure may occur at range 5D since Zone A

is very deep at this location, however, bank surveys show no past indications of large failures. The thickness of Zone A may not be as great at the face of the riverbank slope on range 5D as it is at the location of the boring. Soil conditions at other unexplored locations may be similar to those at range 5D and thus permit large failures to occur. It seems reasonable to suspect that this may be true at range 15D.

Conclusions

25. The following conclusions are believed justified:

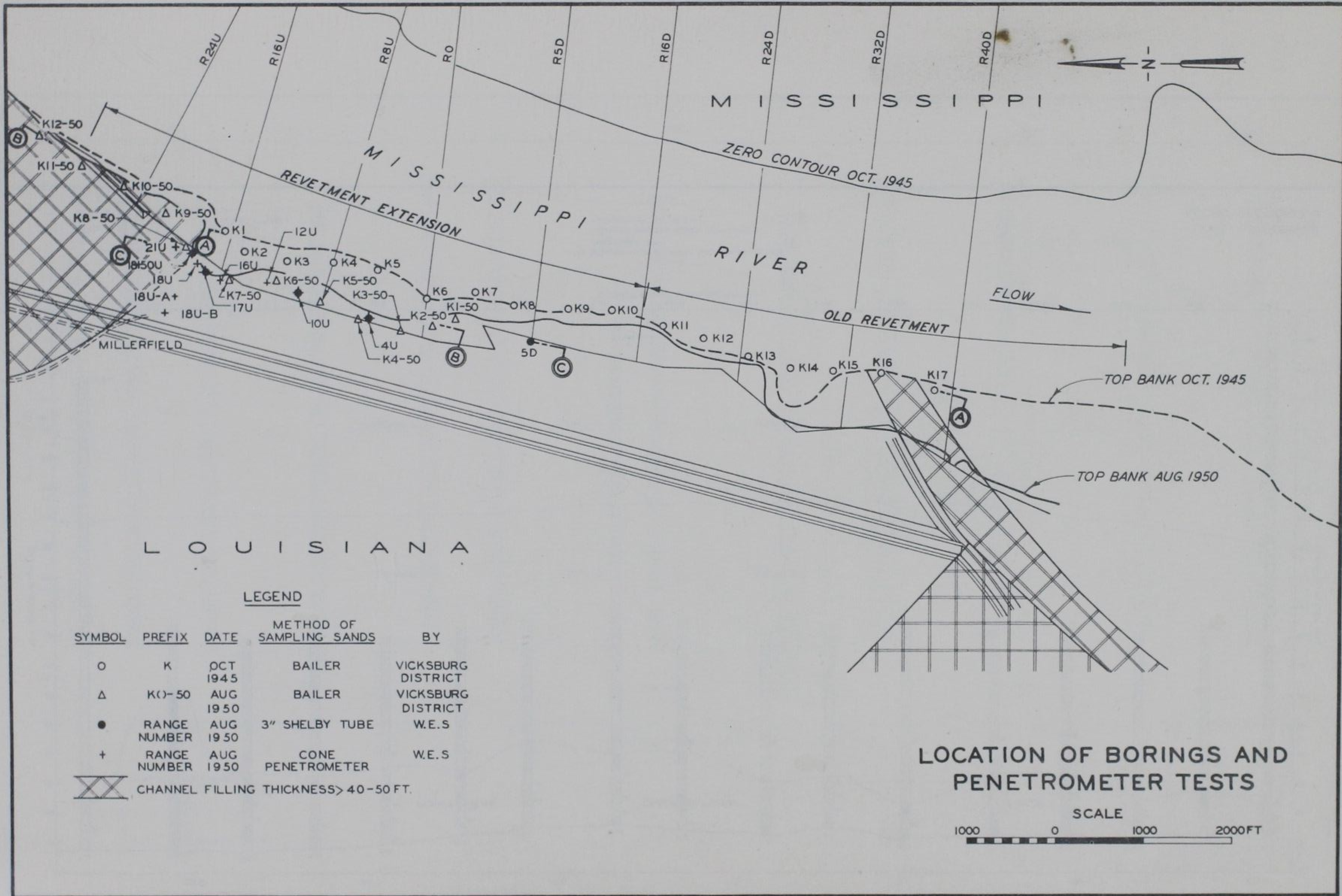
a. The portion of the revetment extension upstream of range 19U is composed of slightly cohesive channel filling soils and, therefore, is probably not susceptible to flow failures.

b. The portion of the revetment extension downstream of range 19U is probably susceptible, in varying degrees, to flow failures in the sands occurring beneath the overburden.

c. The upper portion of these sands (Zone A) is more susceptible to liquefaction than the remainder of the sands. Zone A exists under the entire reach downstream of range 19U to a depth sufficient to permit shallow flow failures. Shallow failures probably will occur in the future and should be anticipated. Zone A has sufficient depth at range 5D, and possibly at other unexplored locations, to permit deep flow failures.

d. Zone B is believed to be less susceptible to liquefaction than Zone A because numerous strata of coarser, more dense sands are found in Zone B.

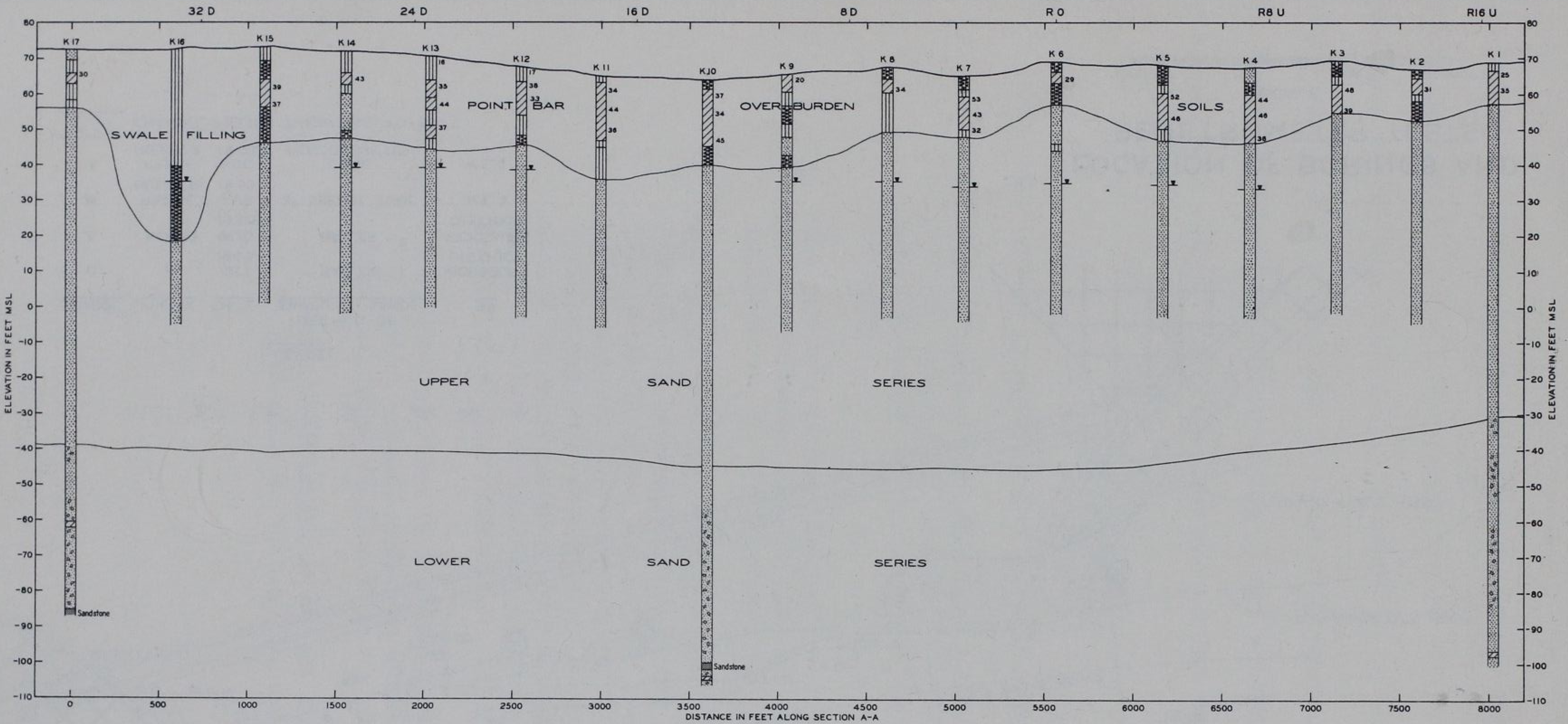
e. Soil conditions probably do not improve between the present top of bank and the toe of the existing levee.



LOCATION OF BORINGS AND PENETROMETER TESTS

PLATE 1

PLATE 2



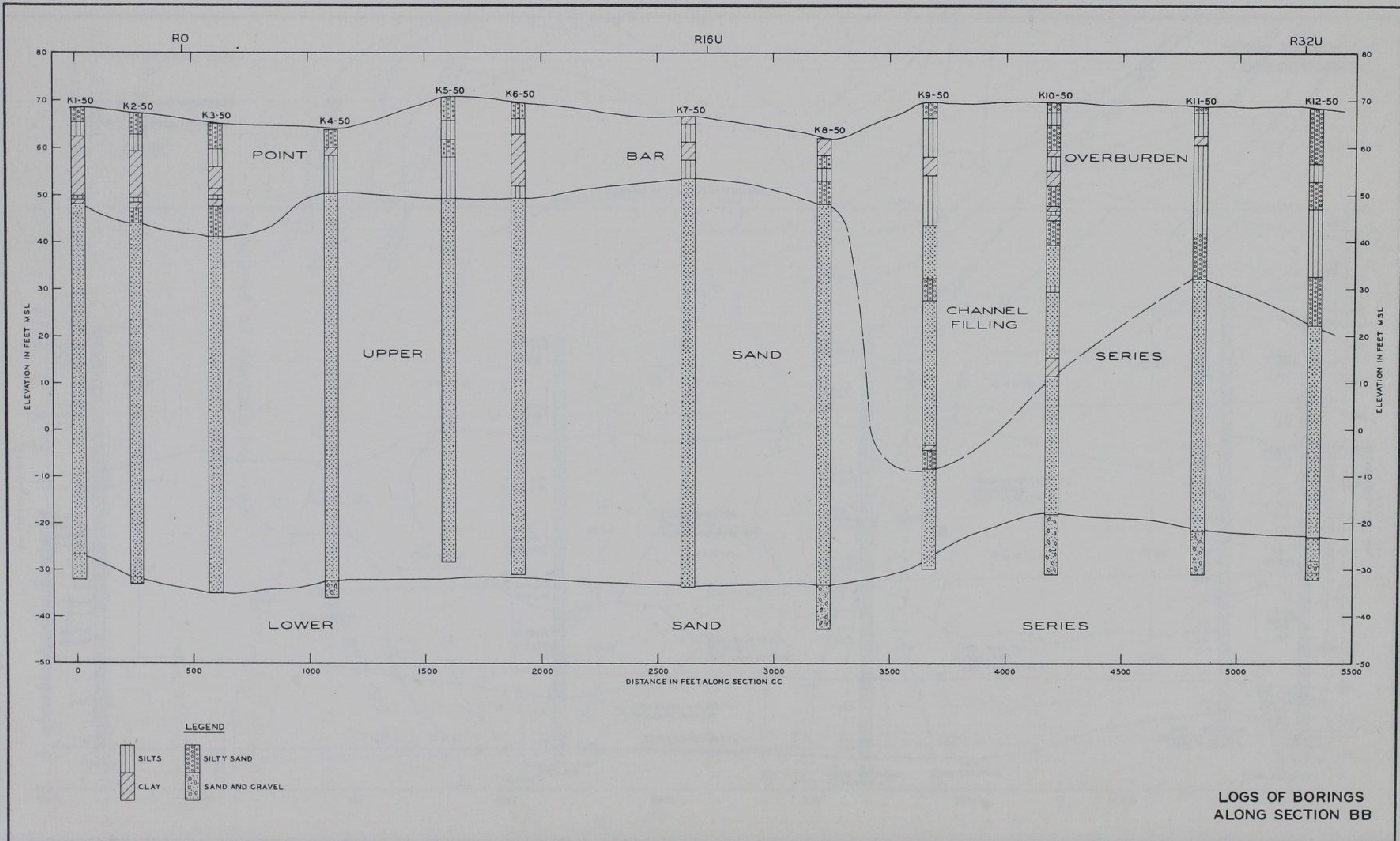
LEGEND

SILT
CLAY
SILTY SAND
SAND AND GRAVEL
WATER TABLE

NOTE: BORINGS MADE BY AUGER AND BAILER METHOD DURING OCT 1945.
NUMBERS INDICATE WATER CONTENTS IN PER CENT OF DRY WEIGHT.

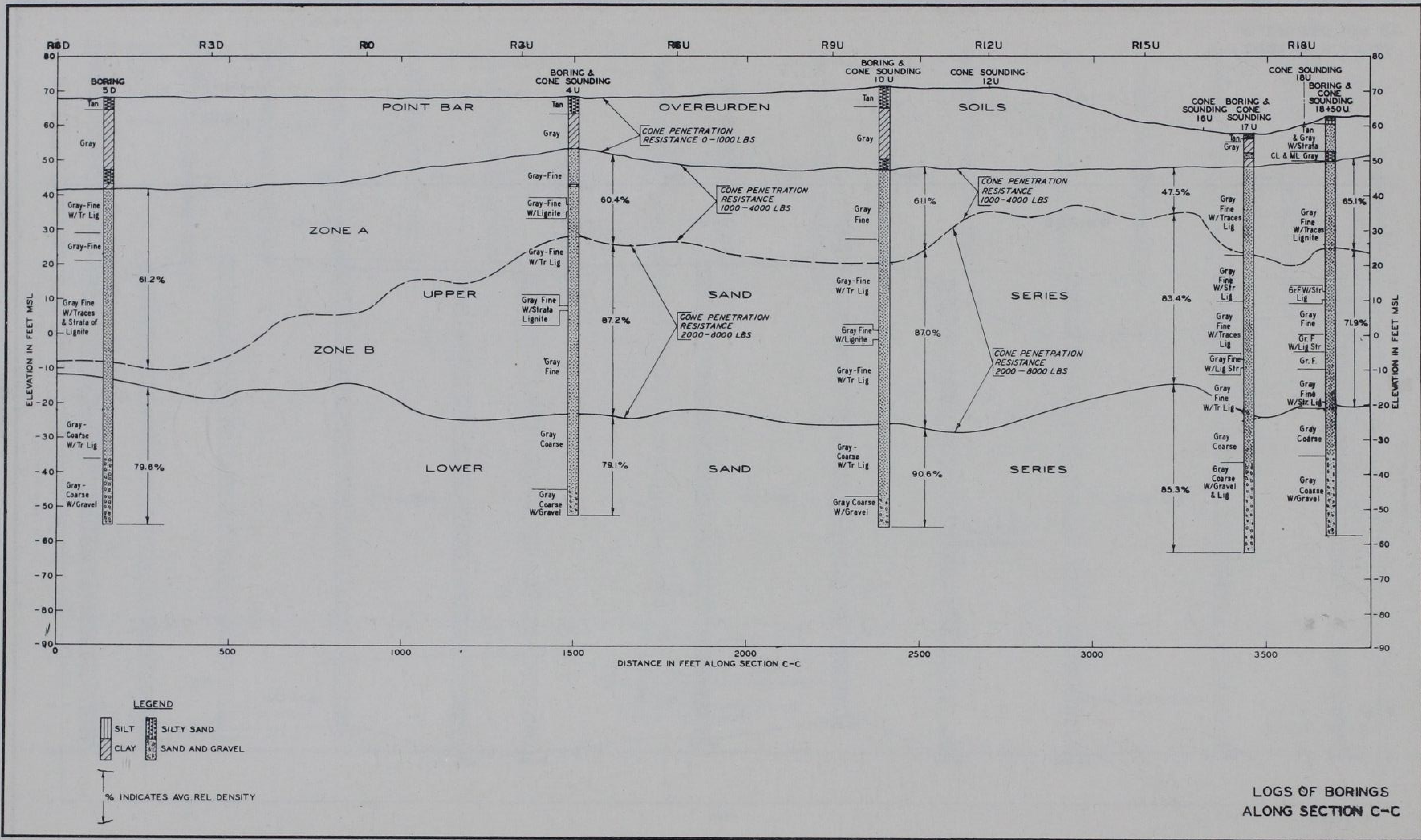
LOGS OF BORINGS ALONG SECTION A-A

PLATE 3



LOGS OF BORINGS
ALONG SECTION BB

PLATE 4



LOGS OF BORINGS
ALONG SECTION C-C

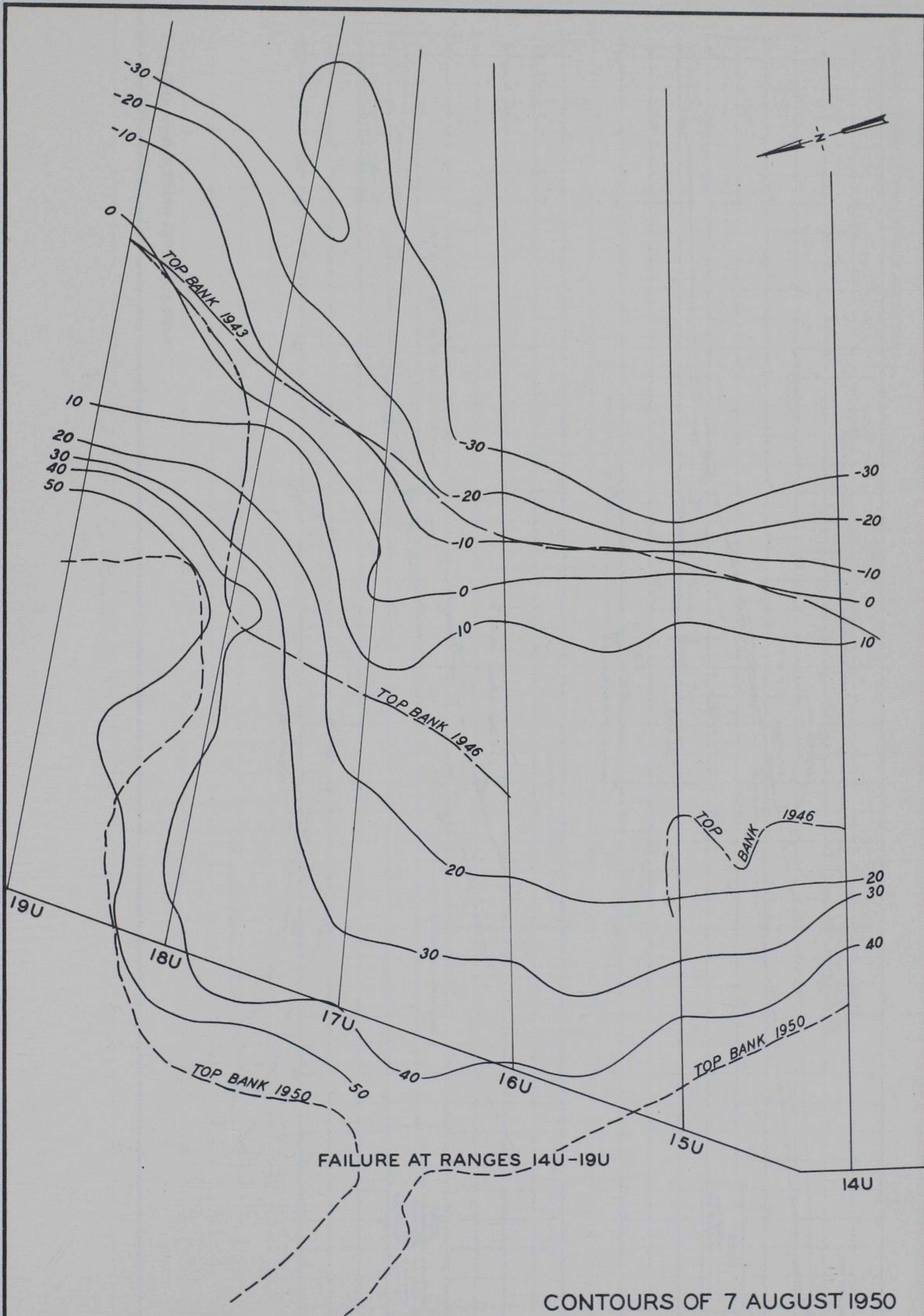
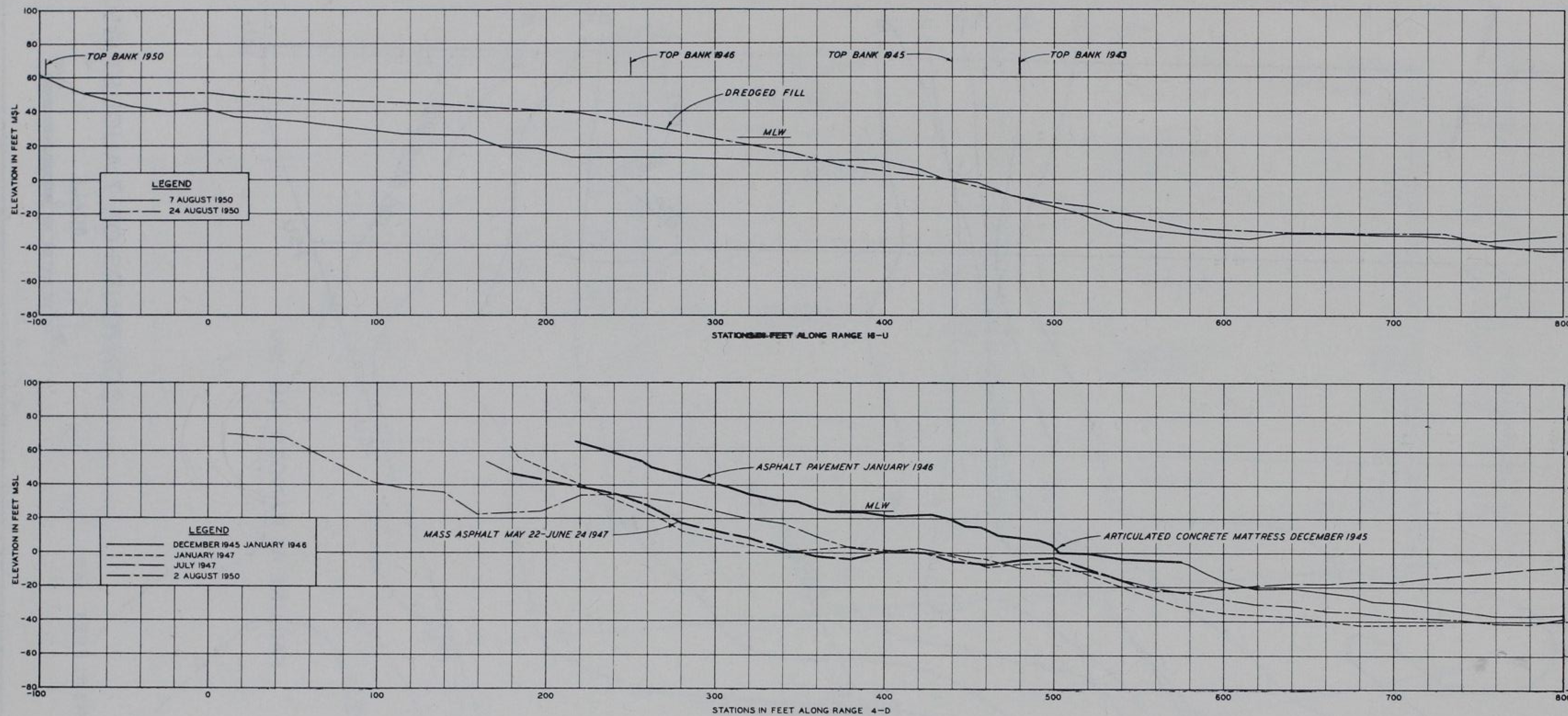
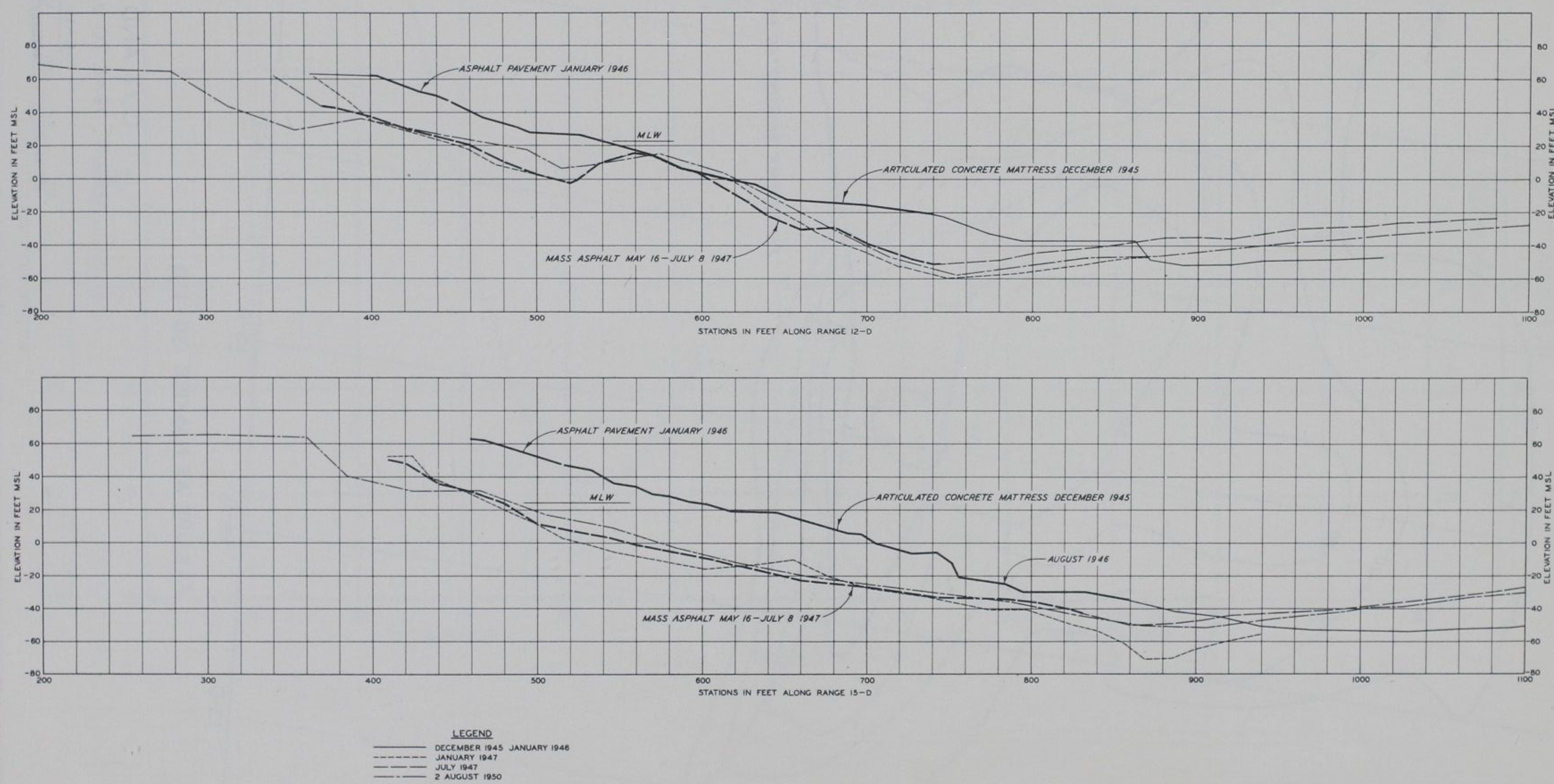

-30
-20
-10
0
TOP BANK 1943
10
20
30
40
50
-30
-20
-10
0
10
TOP BANK 1946
TOP BANK 1946
20
30
40
50
19U
18U
17U
16U
15U
14U
TOP BANK 1950
TOP BANK 1950
N
FAILURE AT RANGES 14U-19U
NOTE: CONTOURS IN FEET MSL
CONTOURS OF 7 AUGUST 1950
SCALE
1000
0
1000

PLATE 6

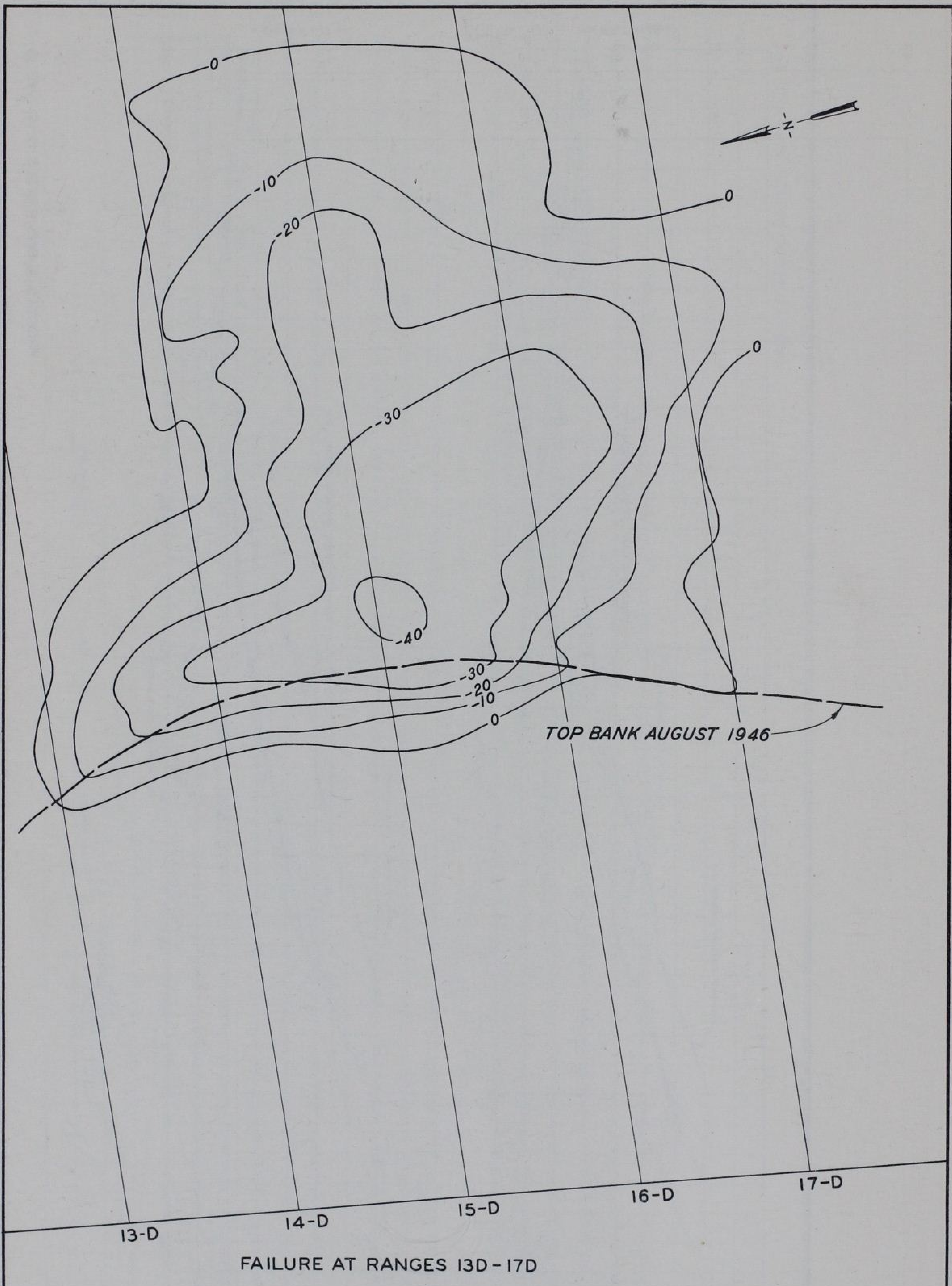


PROFILES ALONG RANGES 16-U AND 4-D



PROFILES ALONG RANGES 12—D AND 15—D

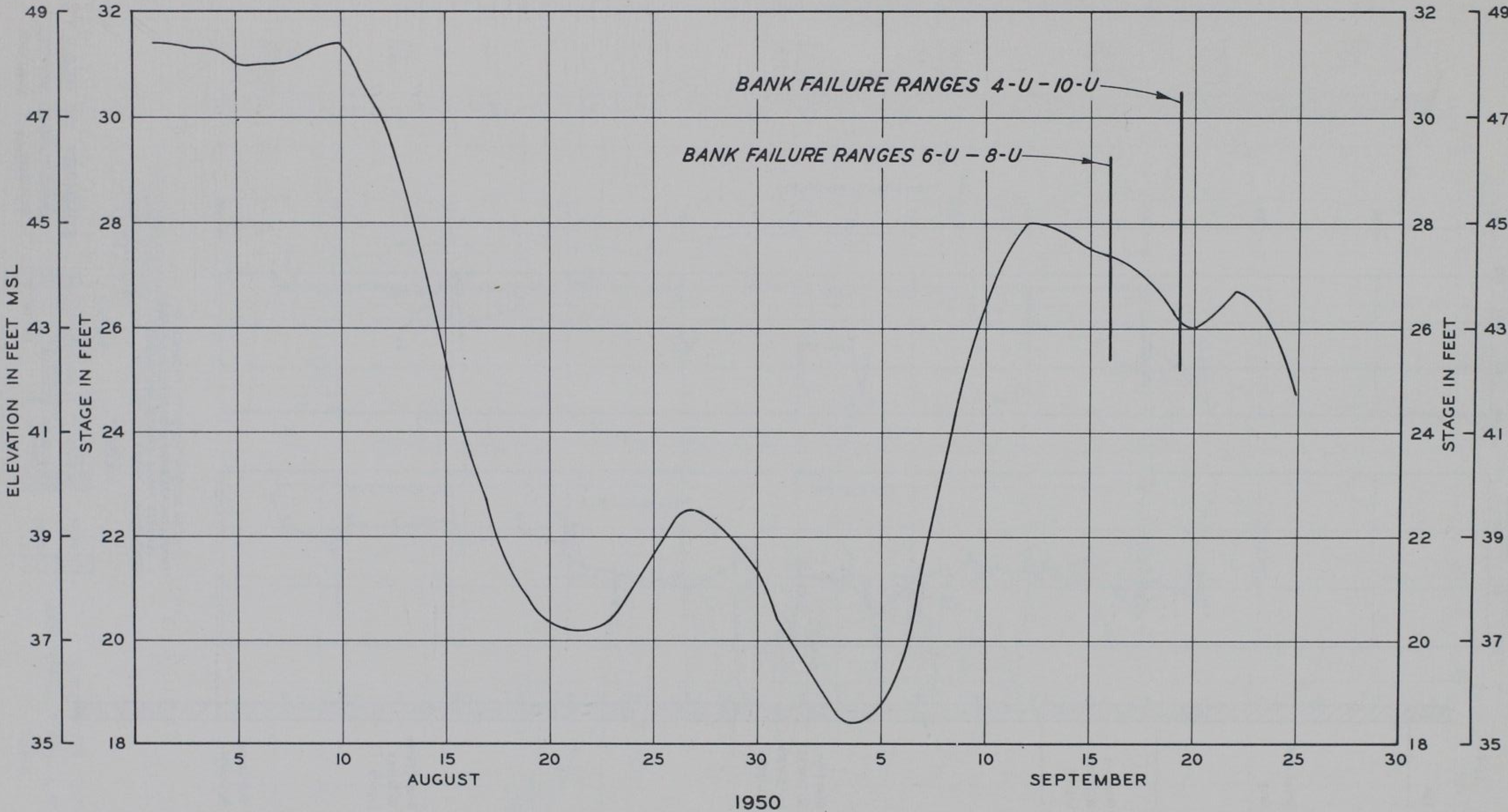
PLATE 7



FAILURE AT RANGES 13D - 17D

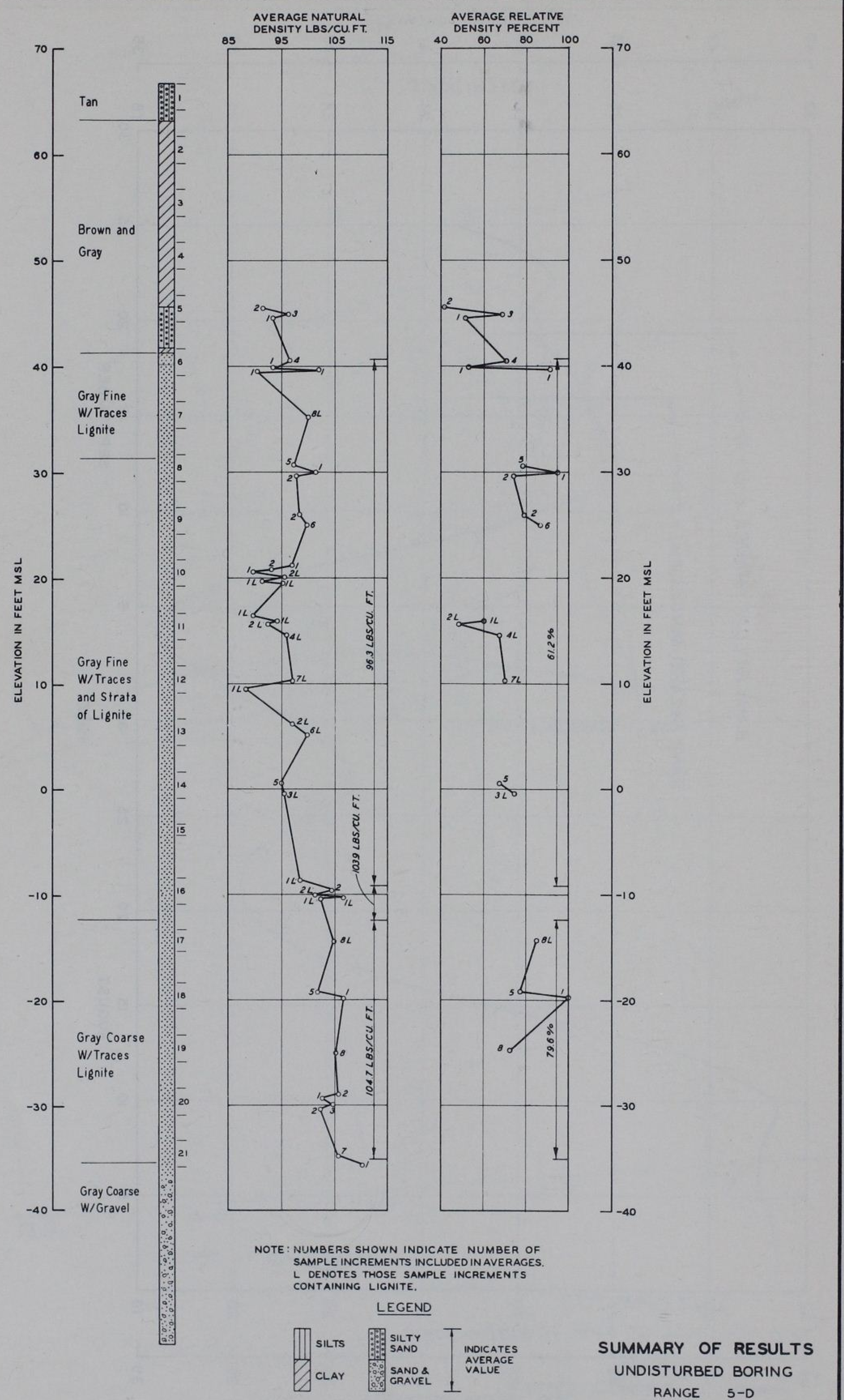
CUT AND FILL
AUGUST 1946 TO JANUARY 1947

PLATE 8



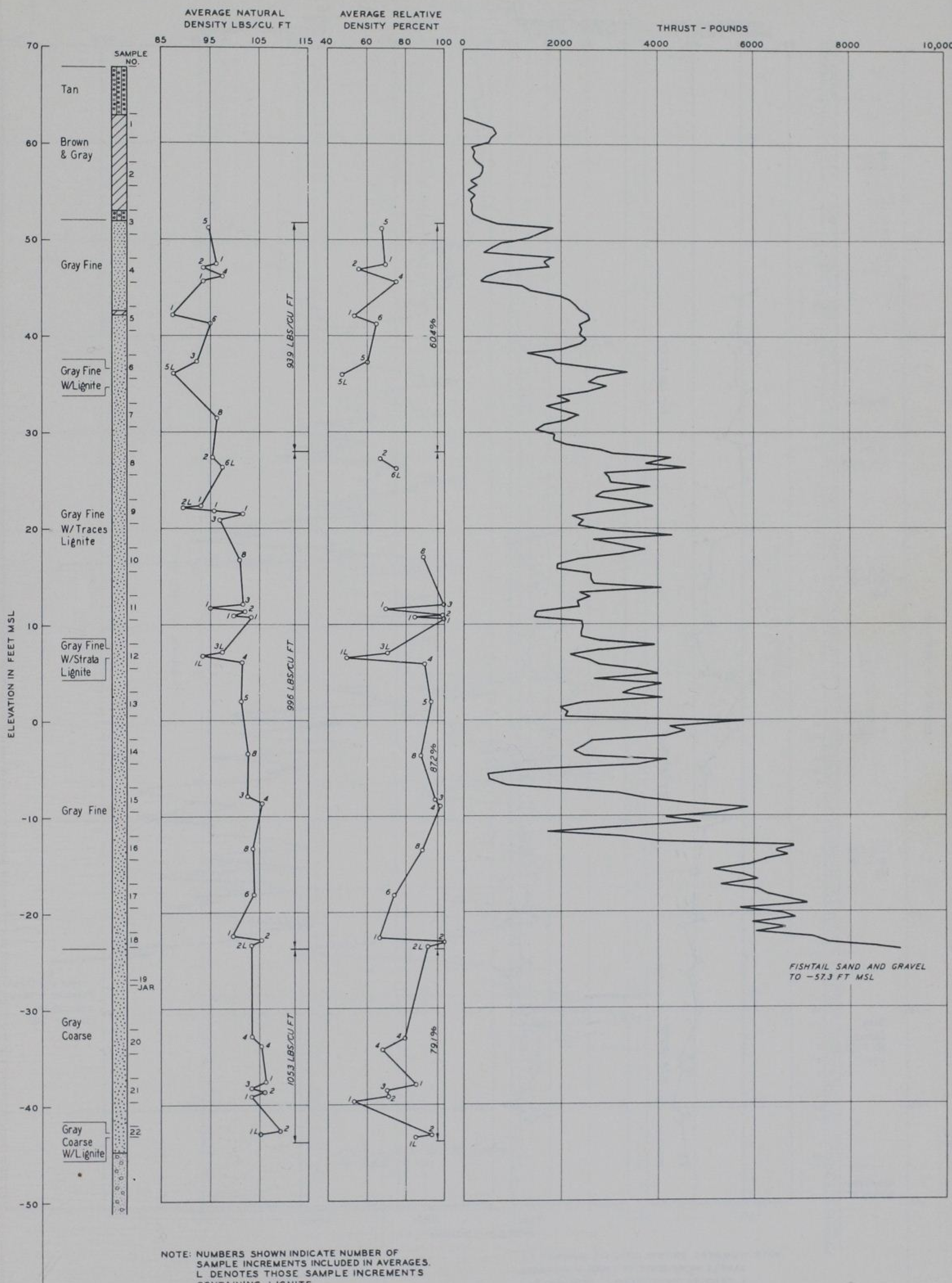
STAGE HYDROGRAPH
NATCHEZ BRIDGE GAGE

PLATE 9



SUMMARY OF RESULTS
UNDISTURBED BORING
RANGE 5-D

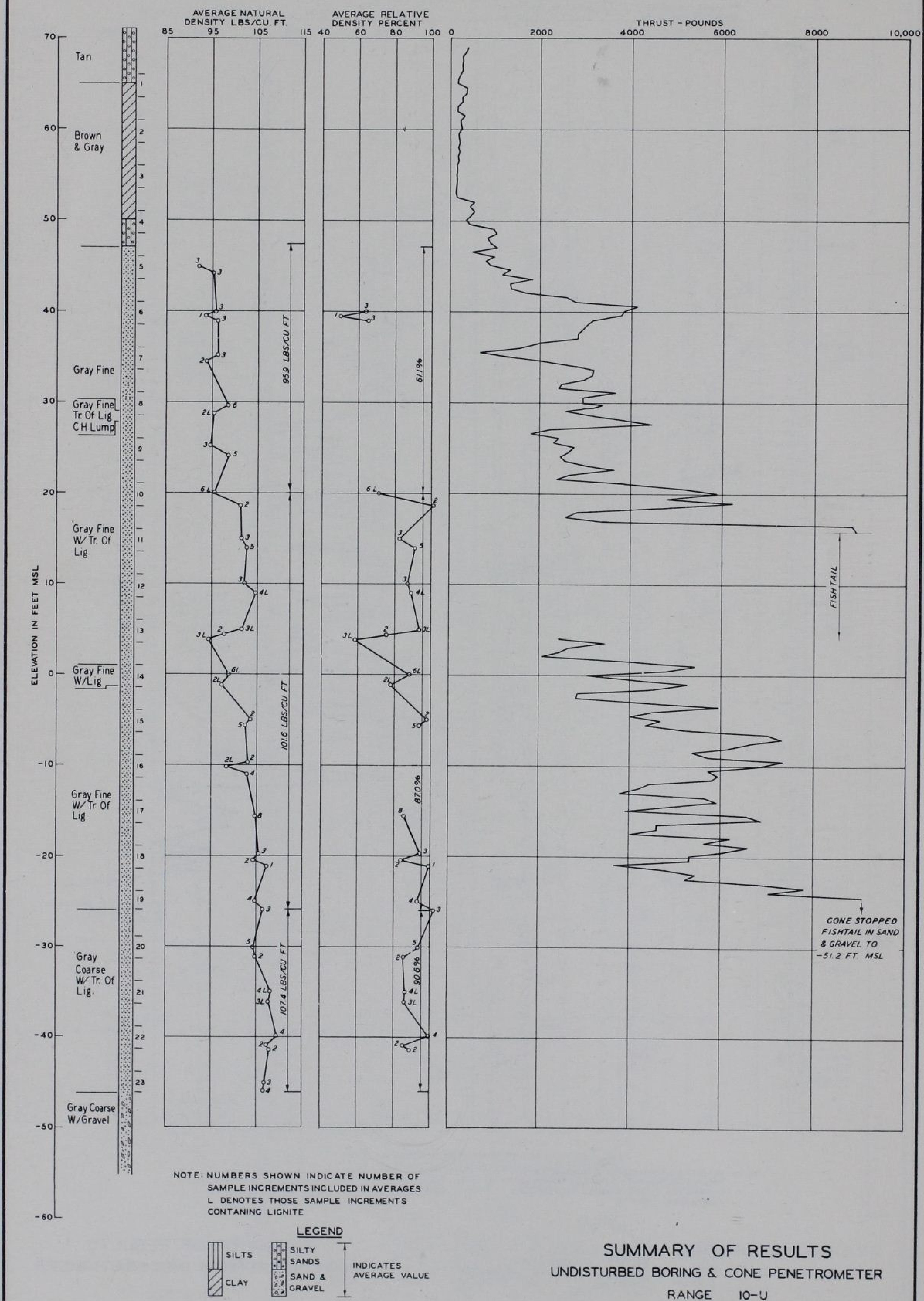
PLATE 10



SUMMARY OF RESULTS

UNDISTURBED BORING & CONE PENETROMETER

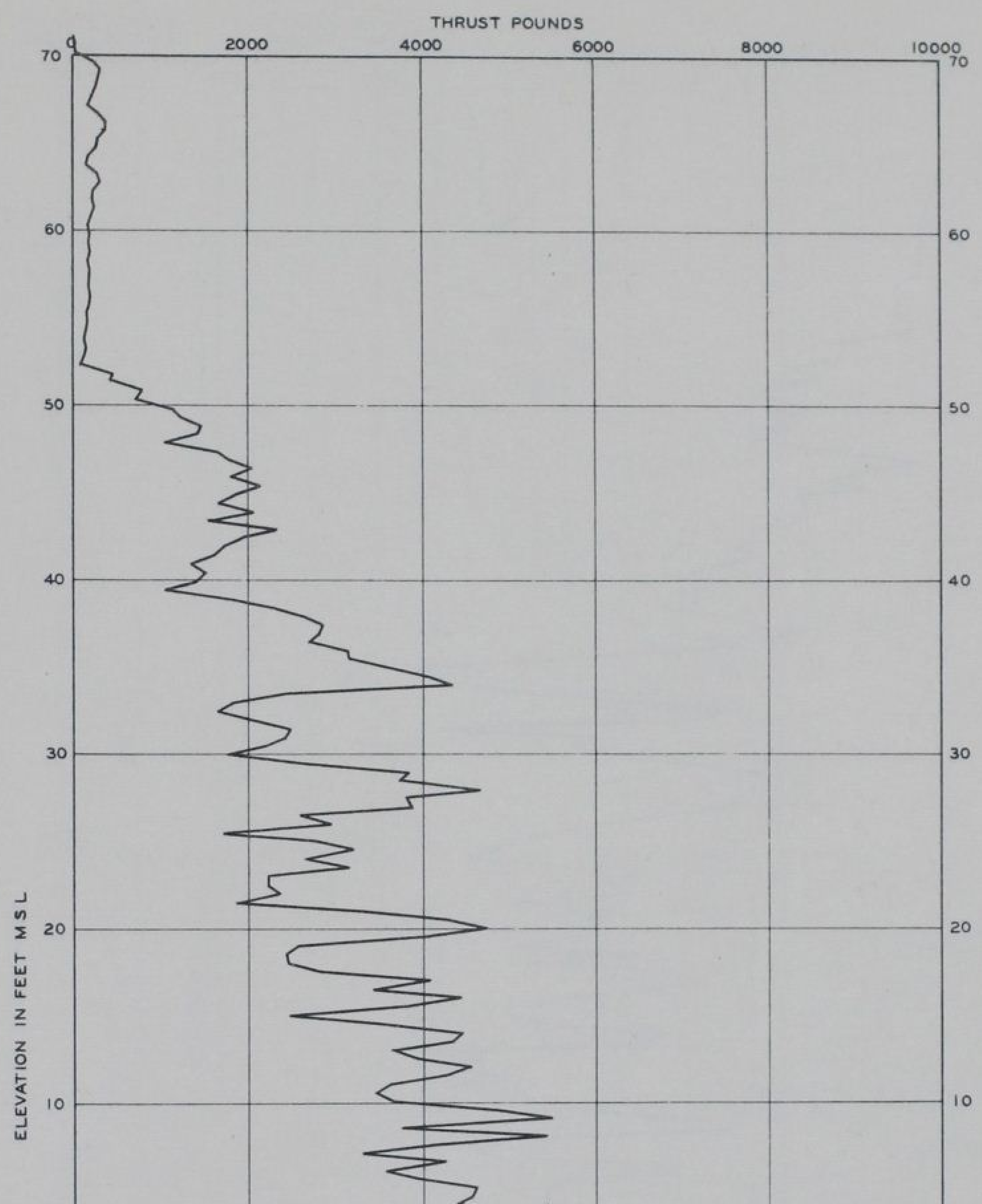
RANGE 4-U



SUMMARY OF RESULTS

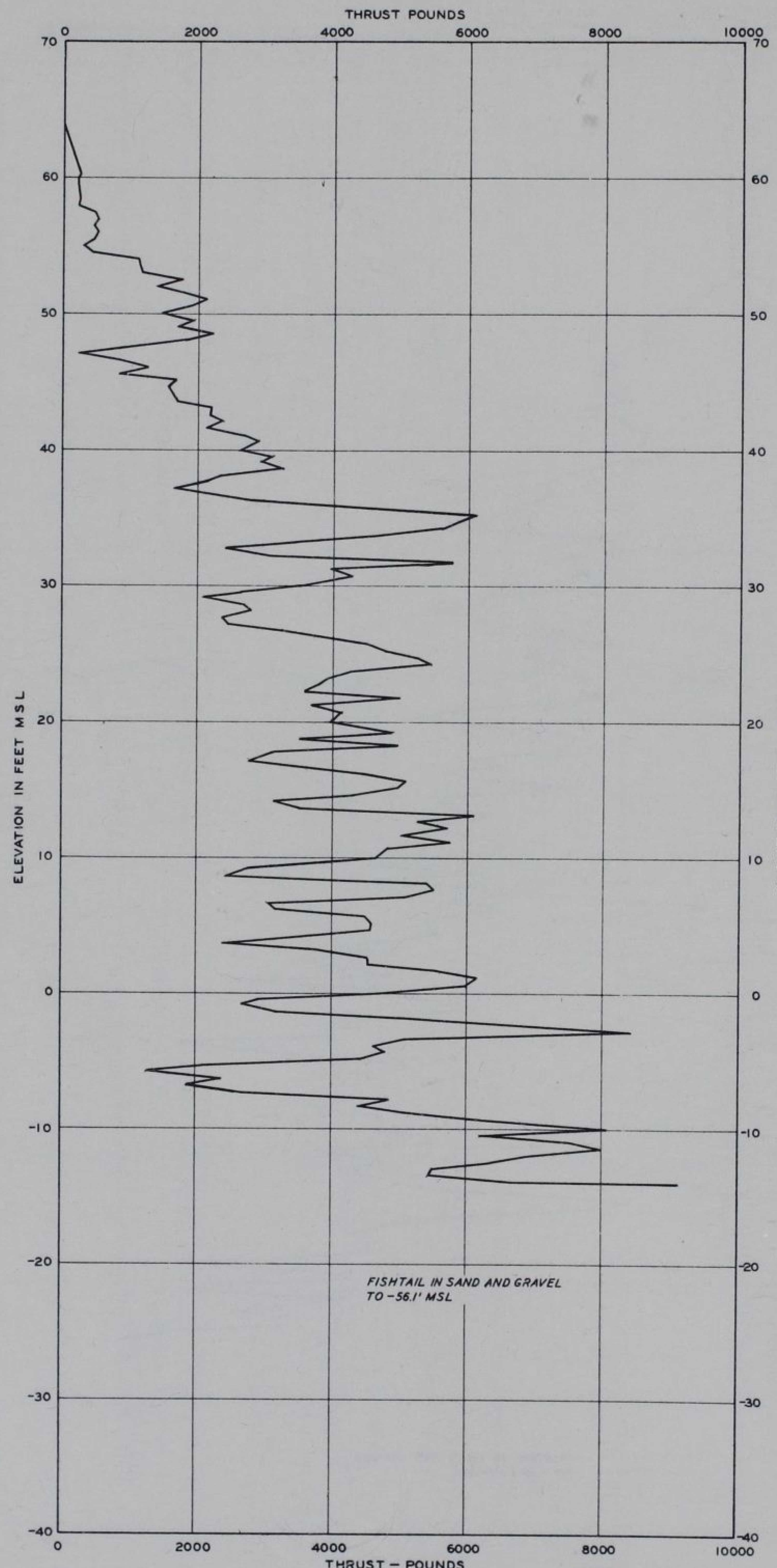
UNDISTURBED BORING & CONE PENETROMETER

RANGE 10-U



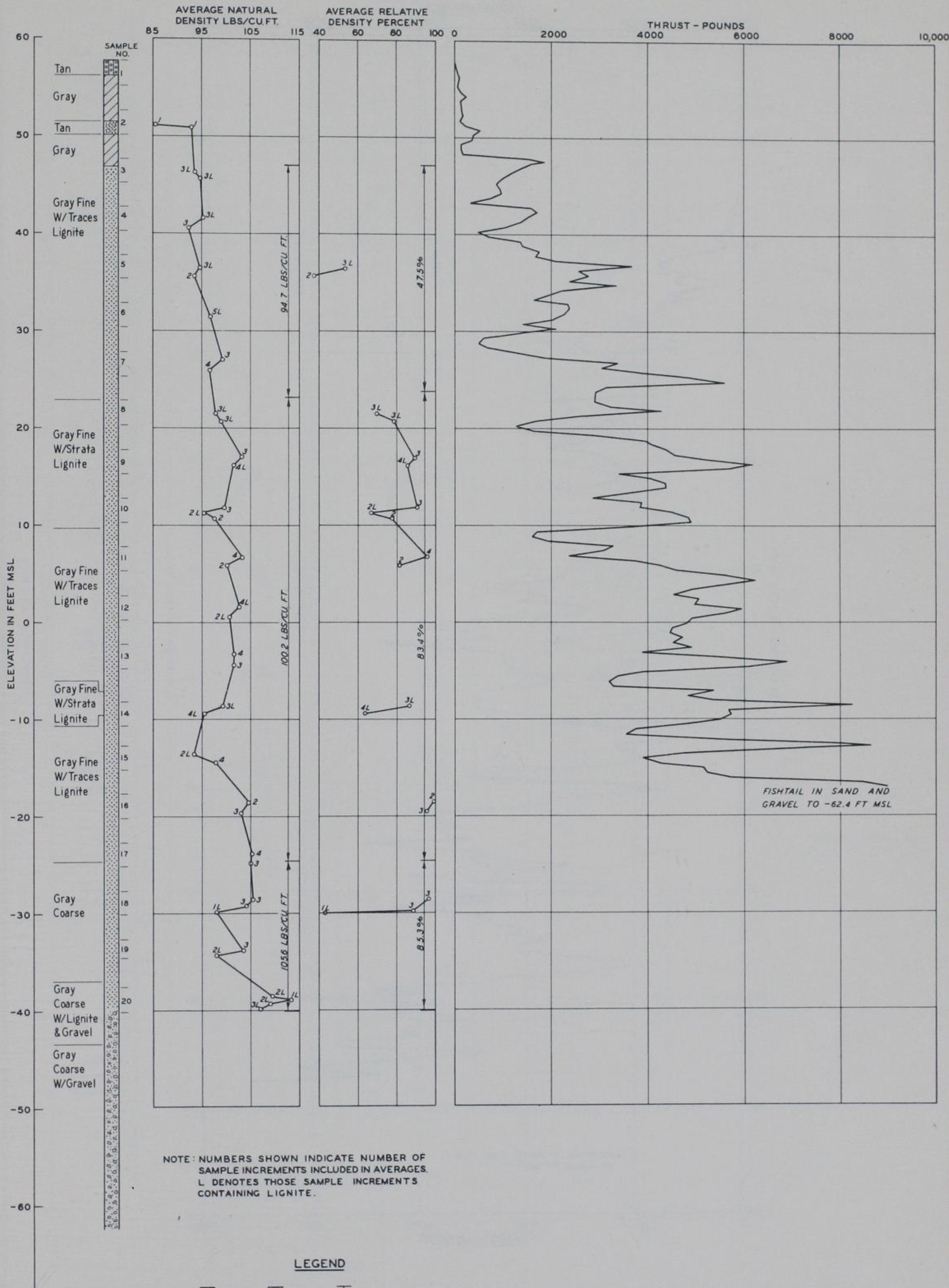
CONE PENETROMETER THRUST

RANGE 12U



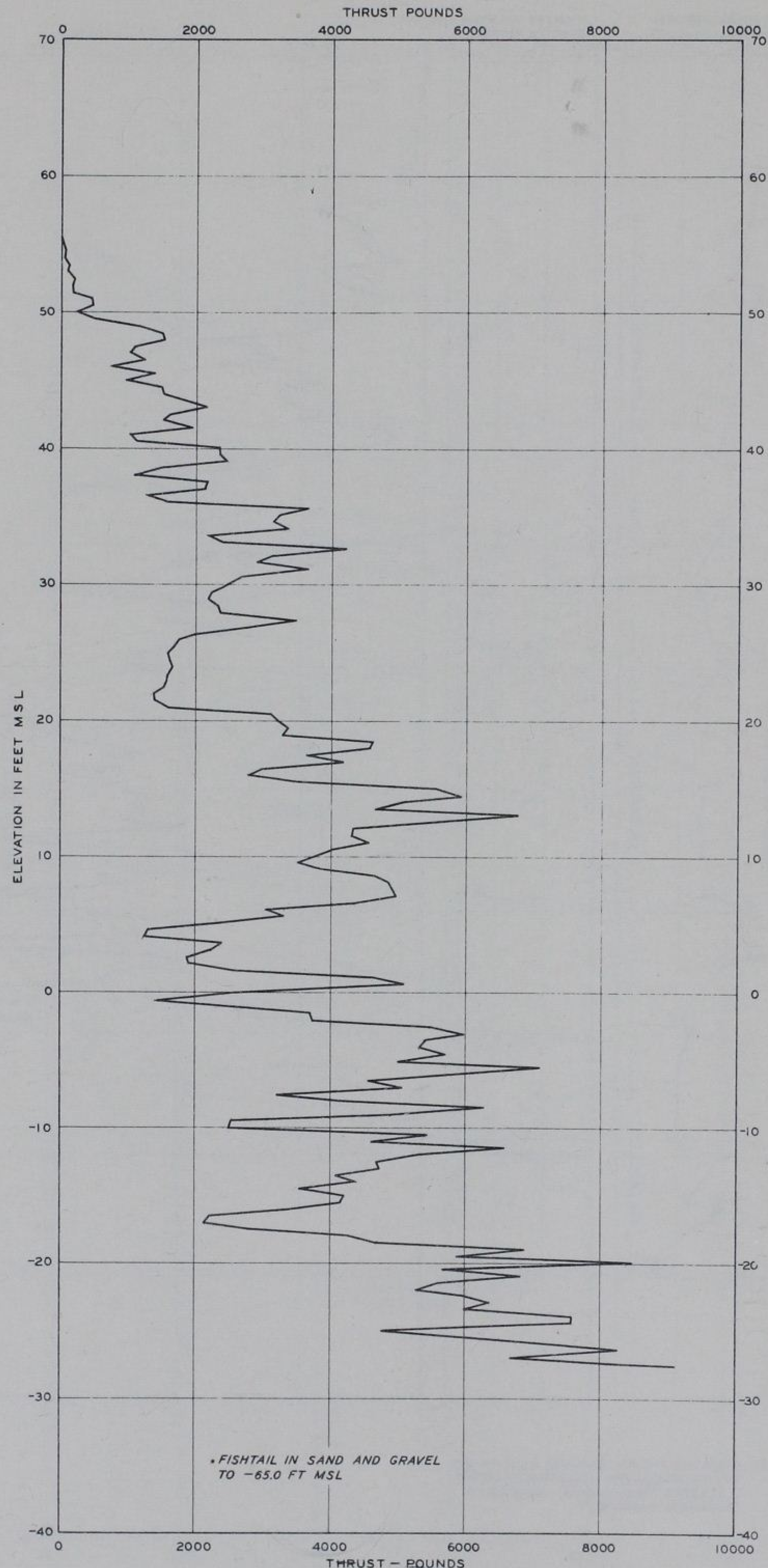
CONE PENETROMETER THRUST

RANGE 16U



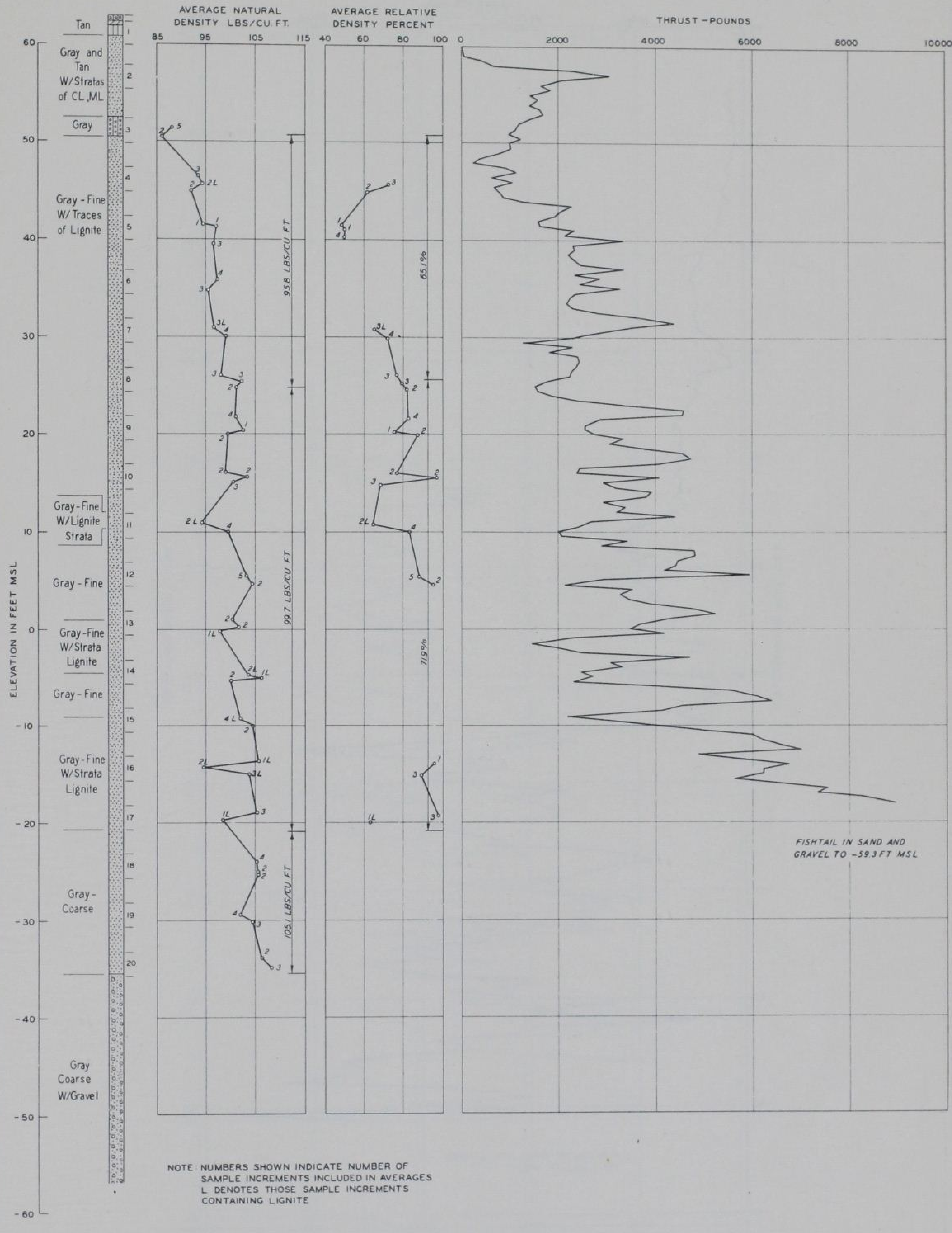
SUMMARY OF RESULTS
UNDISTURBED BORING & CONE PENETROMETER

RANGE 17-U



CONE PENETROMETER THRUST

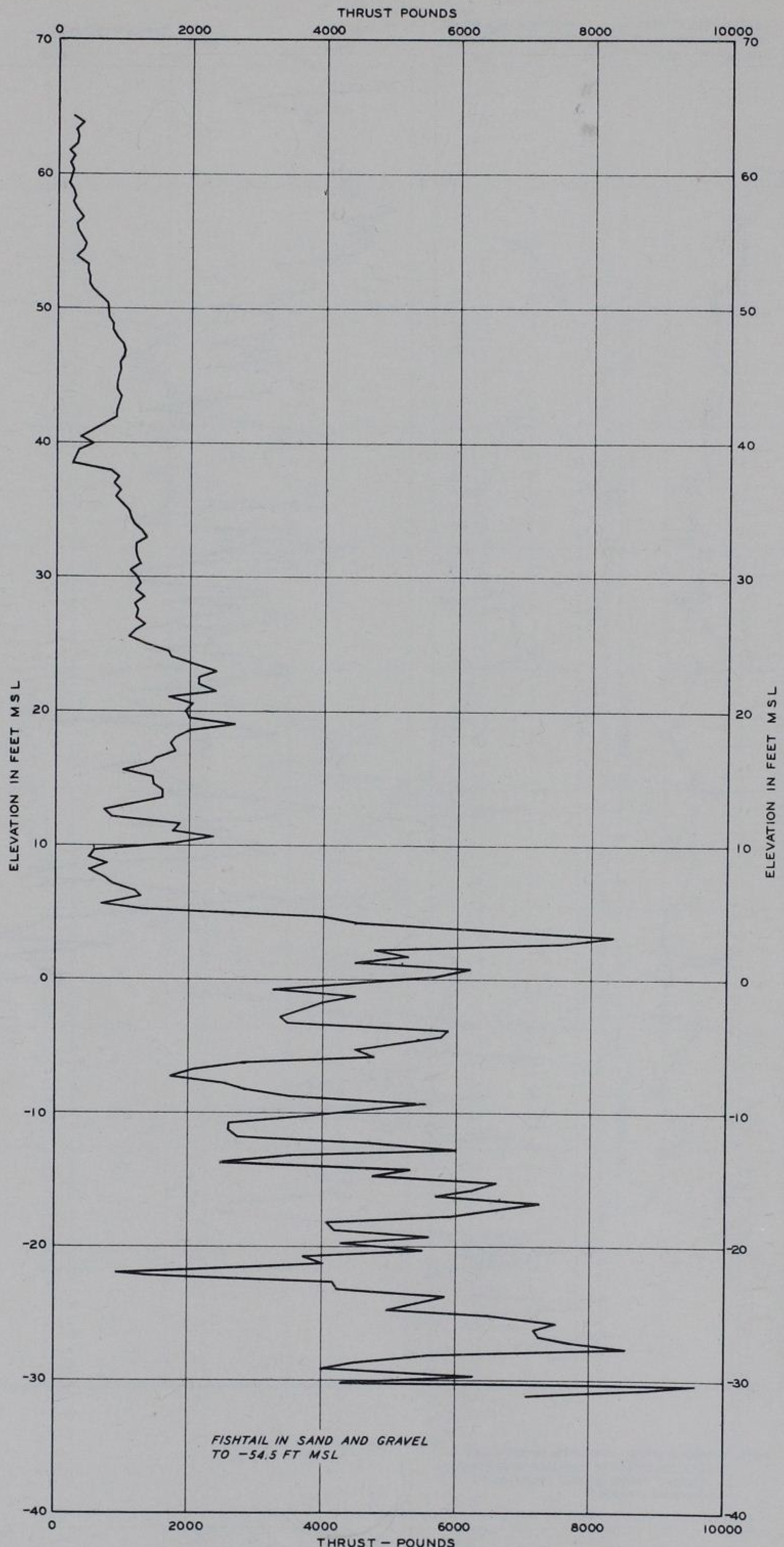
RANGE 18U



SUMMARY OF RESULTS

UNDISTURBED BORING & CONE PENETROMETER

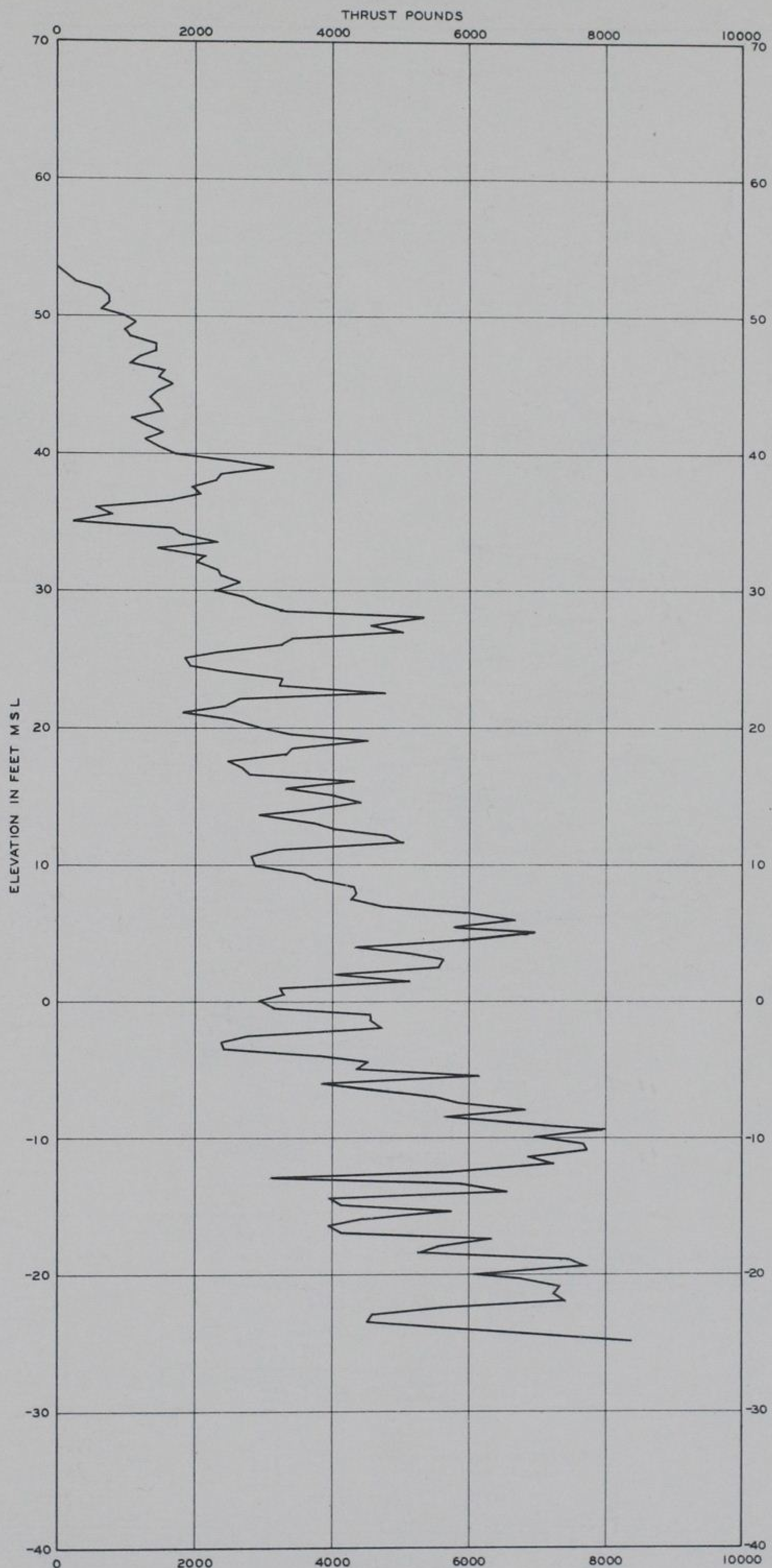
RANGE 18+50-U



CONE PENETROMETER THRUST

RANGE 21U

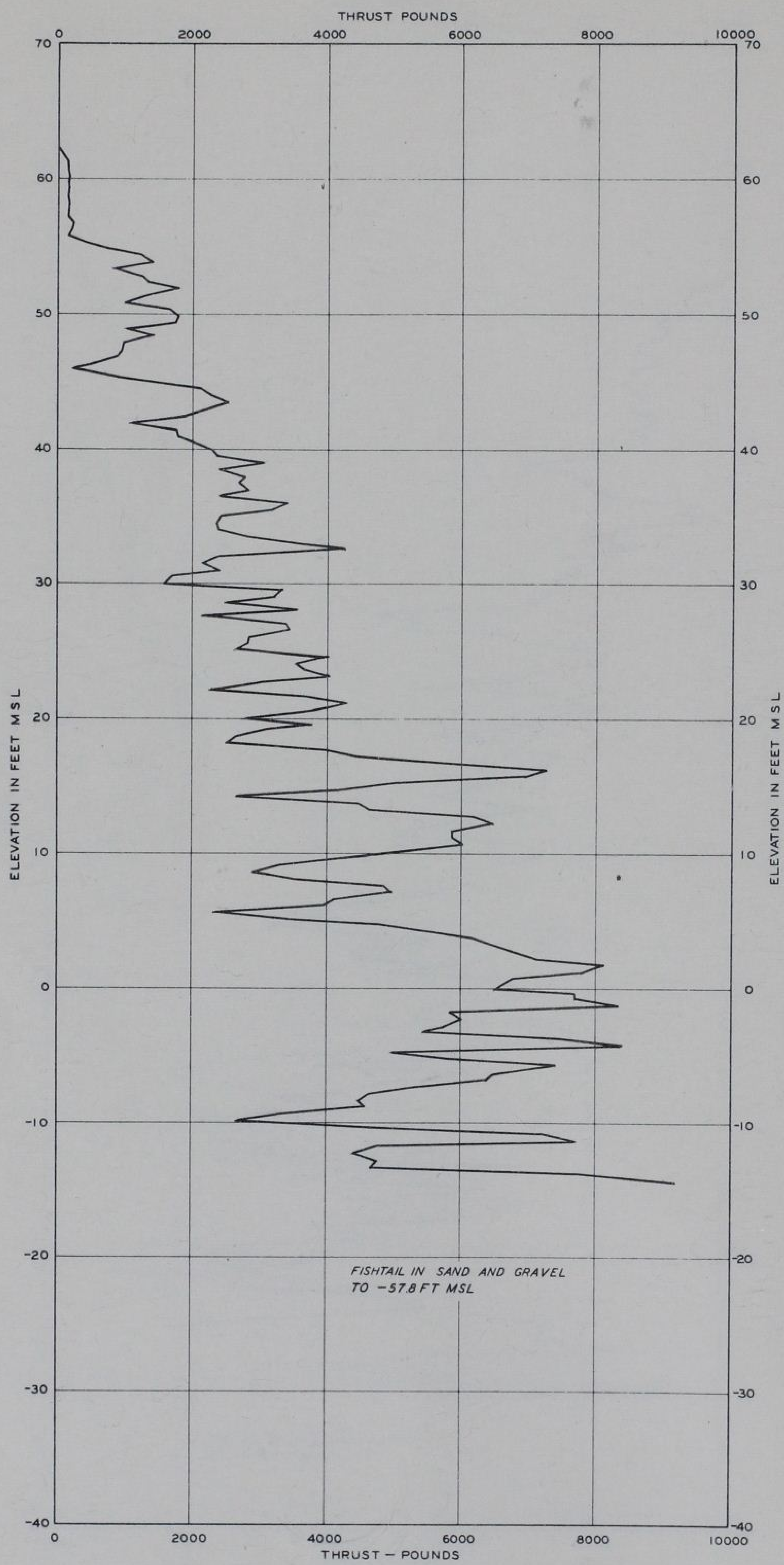
PLATE 18



CONE PENETROMETER THRUST

SOUNDING 18U-A

RANGE 18U



CONE PENETROMETER THRUST

SOUNDING 18U-B

RANGE 18U

ASSOCIATED REPORTS

Study of Materials in Suspension, Mississippi River	Feb 1939
Study of Materials in Transport, Passes of the Mississippi River	Sept 1939
Geological Investigation of the Alluvial Valley of the Lower Mississippi River	Dec 1944
A Laboratory Study of the Meandering of Alluvial Rivers	May 1945
Fine-Grained Alluvial Deposits and Their Effects on Mississippi River Activity	July 1947
Report of Conference on Sand-asphalt Revetment, 12 August 1948	Aug 1948
Geological Investigation of Mississippi River Activity, Memphis, Tenn., to Mouth of Arkansas River	June 1949
Bank Caving Investigations, Morville Revetment, Mississippi River	Sept 1950
Investigation of Free Nigger Point Crevasse, Mississippi River	Dec 1950
Investigation of Mass Placement of Sand Asphalt for Underwater Protection of River Banks	Aug 1951