CORRELATION OF GEOPHYSICAL AND GEOTECHNICAL SITE INVESTIGATION METHODS

MORRIS, D.V., Department of Civil Engineering, Texas A&M University, College Station, Texas 77843.
CALDWELL, J.A., Jacobs Engineers, 1700-5381 Central Ave. N.E., Albuquerque, New Mexico 87108.
SCHWARZ, S.D., GeoRecon, Inc., P. O. Box 55189, Seattle, WA 98155.

SYNOPSIS

The paper compares the predictions of a geophysical survey carried out specifically for geotechnical purposes, with the actual results of a later conventional geotechnical site investigation. The geology at the location consisted of deep soft soil deposits overlying hard schistose rock, and would normally be considered as ideal for this type of work, and yet substantial discrepancies were still noted.

The two geophysical methods used (which largely complement each other) were seismic refraction and electrical resistivity, both of which also had the traditional advantages of cheapness and rapidity. Seismic refraction lines were used primarily to obtain soil depths to bedrock, together with an estimation of the competence of the rock. This was followed by an electrical resistivity survey of the electrical properties of the soil with depth, thus enabling the nature of the soil stratigraphy to be estimated.

The subsequent geotechnical site investigation program (which it was, of course, possible to optimize to a large degree on the basis of the prior geophysical information) utilized traditional drilling and sampling. The experience showed that seismic refraction enabled rock depths to be fairly accurately estimated (within 10%) so long as the rock slope was not too steep, but that only an approximate indication of the rock quality could be obtained. Very broad variations in the soil sequence could be detected by resistance methods, but detailed resolution of the soil type was not possible (such as interbedded glaciofluvial gravels and silts which were subsequently discovered to be present).

Introduction

In order to characterize the soil and rock conditions at the proposed location of a high rolled earth embankment, an extensive site investigation program was carried out. Its primary purpose was to enable the foundation of the embankment to be safely designed to withstand the substantial applied stresses. In addition the information was to be sufficient to allow the general geology to be approximately defined, so that an optimum layout could be identified, and suitable construction materials located.

Geology

The bedrock geology in the region is relalatively complex and a map of the regional geology is shown on Figure 1. The site is located on Admiralty Island, off the coast of Southeast Alaska. Basement rocks in the area are of Devonian and Permian age and consist of greywacke, argillite, phyllite, mafic tuff and schist that have been deformed into a NW/SE trending anticlinorium. These rocks have in turn been faulted by a series of NW/SE trending high angle faults.

Tectonic activity, together with glacial and emergent shoreline processes have dominated the geomorphic development of the area. Isostatic rebound associated with the retreat of the ice sheets has produced an emergent landscape marked by raised beaches and rejuvenated rivers. The topography of the site is shown in Figure 2. together with the proposed embankment location.

The soil geology is similarly primarily glacial in origin, with tills and moraines. Glacio-fluvial action has produced occasional eskers and outwash gravels, and deposition in glacial lakes or marine fiords has given rise to extensive deposits of soft layered silts and clays, often including cobbles introduced by ice rafting.

Initial Geotechnical Work

Initial exploration at the site involved test pits and a limited number of boreholes advanced with a portable drilling rig, that enabled wash samples and SPT blow counts to be obtained. Soft surface deposits of muskeg were also probed with rods. The result of this initial work showed that bedrock at the proposed site of the embankment was up to 30 m (100 ft) deep, and that the general soil profile overlying bedrock consisted of about 3 m (10 ft) of muskeg, 3 m (10 ft) of firm silty clay with cobbles, 20 m (65 ft) of very soft silts and clay, and 4 m (15 ft) of clayey gravels.

It was clear at a fairly early stage in the investigation, that the soil conditions would not be particularly favorable for the foundation of a large embankment. The project would be feasible but costly, and significant additional effort in site investigation would be necessary. Access for drilling equipment was very difficult and very expensive, because equipment had to be broken down into helicopter transportable sections. As a result, a major program of geophysical investigation was undertaken in advance of any further geotechnical boreholes.

Geophysical Investigation

Both seismic refraction lines and electrical resistivity soundings were specified, as it was believed that these two techniques largely complement each other. Seismic lines are efficient in detecting sharp changes in compressive wave velocity, and it was hoped that they would be particularly effective in measuring the position of bedrock across the site. Resistivity measurements are sensitive to changes in water content and pore fluid chemistry, so that it was hoped that these would be efficient in the delineation of the soil stratigraphy above bedrock.

Figure 3 shows the layout of the seismic lines and electrical soundings, together with the positions of the boreholes (most of which were carried out later, so that their position could be optimized on the basis of the much cheaper geophysical results). A total of 23 seismic refraction traverses were carried out, with a combined length of 5,000 m (16,400 ft); together with electrical resistivity measurements at 7 locations.

The equipment employed for the seismic survey was a Geometrics Model ES 1200, 12-channel signal enhancement seismograph with associated cables and geophones. Mark Products L-15 geophones were used with marsh cases, and these were pushed through surface muskeg with a planter pole wherever possible. Geophone spacings were mostly at 10 m (30 ft), except occasionally when bedrock was deep it was necessary to increase this to 20 m (60 ft). Small explosive changes with electrical detonators were used as a source of seismic energy.

The electrical resistivity survey was completed with an ABEM SAS 300 Terrameter signal enhancement system using the Wenner electrode configuration.

The initial purpose of these surveys was to attempt to identify a more favorable site for the proposed embankment, particularly if it were possible to move it slightly to a location with much shallower depths of soft soil. In fact little improvement was found, regarding a different site for the embankment, but preliminary knowledge of site conditions was greatly improved. The extensive information concerning the soil depth to bedrock, that it was possible to obtain relatively cheaply in this way, allowed the subsequent conventional geotechnical drilling to be optimized to a very high degree. Boreholes could be drilled (and sample taken) on the site of the deep soil deposits, where the stability of an embankment was likely to be most critical, without unnecessary expenditure on holes in regions of shallow soil where stability was less likely to be a problem.

Results of Seismic Surveys

The layout of the seismic lines is shown in Figure 3, and the data was reduced to form the map of bedrock contours (above mean sea level) shown in Figure 4. As can be seen, it was possible to build up a relatively comprehensive distribution of depth to bedrock information, in a fraction of the time (and expense) that would have been required by conventional drilling and sampling. The map shows that the site is a complex series of NW/SE trending valleys, channels, depression, saddles and ridges. The general trend of the bedrock topography appears to coincide with the strike of the regional geologic structure and to be controlled by the differential erodability of the steeply dipping beds. Major bedrock features are a northwest depression, eastern valley, western valley, and a southern valley.

In conjunction with surface geologic mapping, it was possible to say that the overburden along the flanks of the valley at the tailings impoundment site was predominantly talus and slope wash possibly overlying minor deposits of glacial till and outwash, while the deeper sections of the valley contained mostly glacially derived soft clays and silts.

Of particular significance in this context, was the fact that the bedrock surface formed a high point in the middle of the proposed site. This is very clear in the accompanying cross sections A, B and C, shown in Figure 5, derived from the map of bedrock contours. Any potential stability problems would be minimized if it were possible to locate the embankment foundation as far as possible on bedrock. On the basis of this information, the proposed embankment could be sited almost immediately on an optimum location represented by the proposed center line shown in Figure 4.

It was also possible to correlate absolute values of seismic compressive wave velocity with material type. Velocities in surface organic material and muskeg were very slow, about 500 m/s, and significantly less than the speed of sound in water (1400 m/s) - presumably because this material was not fully saturated. Glacial soils appeared to have compressive wave velocities of between 1500 and 2000 m/s, and wave speeds in intact rock were mostly between 4000 and 5000 m/s. However zones of what were presumably weaker rock were encountered, in which wave speeds of 3000 m/s or less were measured. These zones generally coincided with channels or depressions in the bedrock topography, and were presumably associated therefore with the greater erodability of the rock in these regions.

Results of Resistivity Surveys

The resistivity measurements were fewer in number, but gave data concerning soil resistivities with depth. It was hoped that this could be correlated with soil types, to allow the overburden stratigraphy to be determined. Figure 6 shows a sample result for a section along seismic line 10, along which three electrical resistivity soundings were conducted (sites R-2, R-3 and R-4).

High material resistivity values of 100 to 1000 ohm. m were associated with the surface covering of muskeg and organic soils (possibly surprising, in view of the very high water content of this material). The main deposits of glacial soil appeared to be associated with intermediate resistivity values of around 100 ohm. m, and the bedrock resistivity was low, with values of 50 ohm. m or less, decreasing with depth. The explanation for this decrease with depth in rock was not immediately obvious, as the closing up of fractures and consequent reduction in porosity (and pore fluid quantities) with depth would normally be expected to result in increasing resistivity. However this appeared to be a well documented result on this site, that could not be explained by changes in rock type, as the rock geology appeared to be relativly uniform.

Geotechnical Investigation

After completion of the geophysical work, a substantial program of geotechnical investigation was undertaken, carefully planned as a result of the previous work, and it was possible to compare the two. A total of 15 further test borings were completed, as shown in Figure 3.

Some of these were with a conventional rotary CME 45 soil and rock drill, which allowed thin tube soil samples to be taken either by driving or with a Pitcher sample. These samples were of sufficiently high quality to enable intact specimens to be prepared for laboratory strength tests. However in cohesionless soil which could not be retained in a smoth walled tube, Standard Penetration Tests were performed and (where possible) split spoon samples recovered. Rotary drilling could also be continued into bedrock, usually for a minimum of 10 ft, and rock core recovered in a twin tube sampler.

In addition, for speed, some of the holes were conducted with a proprietary vibratory overburden sampling system ("Wink Vibracore") which allowed rapid sampling of overburden soils in 10 ft runs. The soil was retained in long transparent plastic tubes, but it was not possible to penetrate into rock, or even into dense gravel if encountered at some depth. Although the material was mechanically disturbed (rendering strength measurements relatively useless) the geologic stratigraphy was relatively undisturbed, allowing the soil to be logged and classified in the normal way. Conventional index tests could also be performed.

Two other specialist geotechnical in-situ tests were utilized as part of the site investigation program. The first was a selfboring pressuremeter, which could be introduced into the soil with a minimum of disturbance, and then subsequently inflated to determine the soil strength. A cone penetration test was also carried out on a single occasion.

Correlation of Geophysical and Geotechnical Data

The agreement between depth to bedrock as determined from seismic refraction lines and as determined from drill hole data, were generally good, and within about 10% or better. As an example Figure 7 shows a seismic velocity profile on which a test boring has been made. The test boring is in fact displaced from the seismic line by about 50 ft, and the agreement in terms of depth to rock, is nevertheless quite reasonable. Unfortunately relatively little information is provided on the soil classifications within the region otherwise simply described as overburden, and this can in reality be of significant importance in geotechnical design. It was hoped that further definition of this region would be provided by the electrical resistivity measurements, as the two methods would appear largely to complement each other in this respect.

The correlation between resistivity values and soil types was found to be poor, however. Figure 8 shows a detailed comparison of the results of an electrical sounding and a borehole stratigraphic log. It is possible to make general correlations between soil types - sands and gravels being of high resistivity (greater than 100 ohm. m), while fine-grained soils are of lower resistivity (less than 100 ohm. m). Rock was of low resistivity (50 ohm. m or less) inexplicably decreasing with depth. However the correspondence can not be said to be particularly conclusive in delineating strata within the overburden column.

It would appear that the seismic refraction method is generally better for determining the depth (and to some extent also the quality) of bedrock than the electrical resistivity method is for determining details of soil deposits. However the two methods do address differing needs, and it is usually not much more expensive to take some electrical measurements at the same time as a seismic survey is carried out.

Conclusions

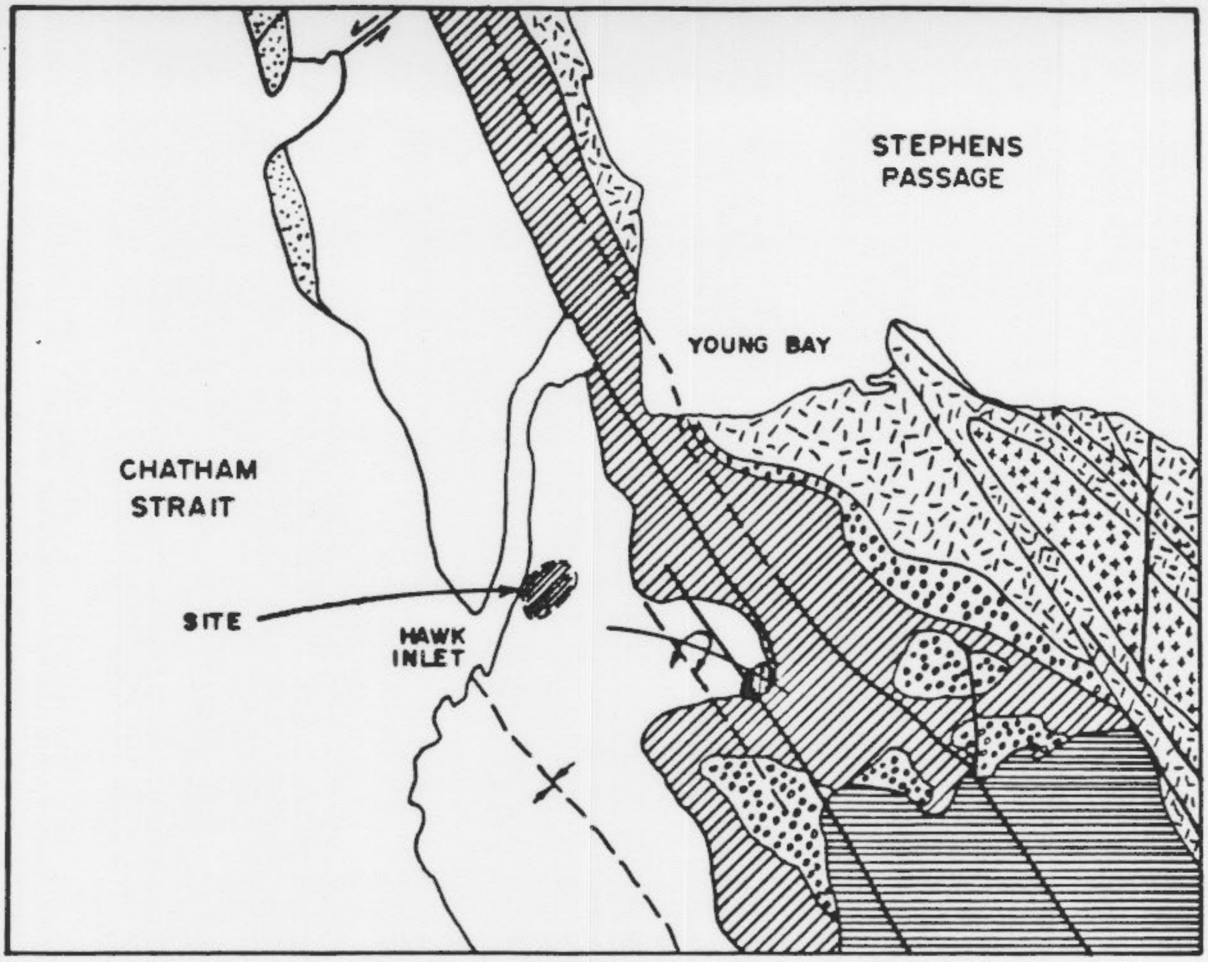
Although not normally a component of geotechnical site investigations the geophysical methods of seismic refraction and electrical resistivity proved to be very useful in this instance as an addition to the conventional engineering program of rotary drilling and sampling.

Seismic refraction proved to be an accurate way of determining depth to bedrock very cost effectively (though not soil types) particularly on a site where access was difficult. Definition of the shape of the bedrock surface (necessary for optimizing the project location) would have been very difficult by boreholes alone, as the topography was complex. Some indication of the rock quality was also given by seismic velocities, and when considered with the bedrock topography and a knowledge of the local geology, bedding planes and fault system, this also helped to explain the topography. Generally, depressions in the bedrock profile coincided with zones of low velocity (and weaker) bedrock and ridges with zones of high velocity (and stronger) bedrock.

Electrical resistivity methods can also be used to augment borehole data to indicate soil profiles at places where no borehole information is available, but on the basis of this evidence cannot be considered to be particularly reliable unless the results are carefully correlated for the site in question.

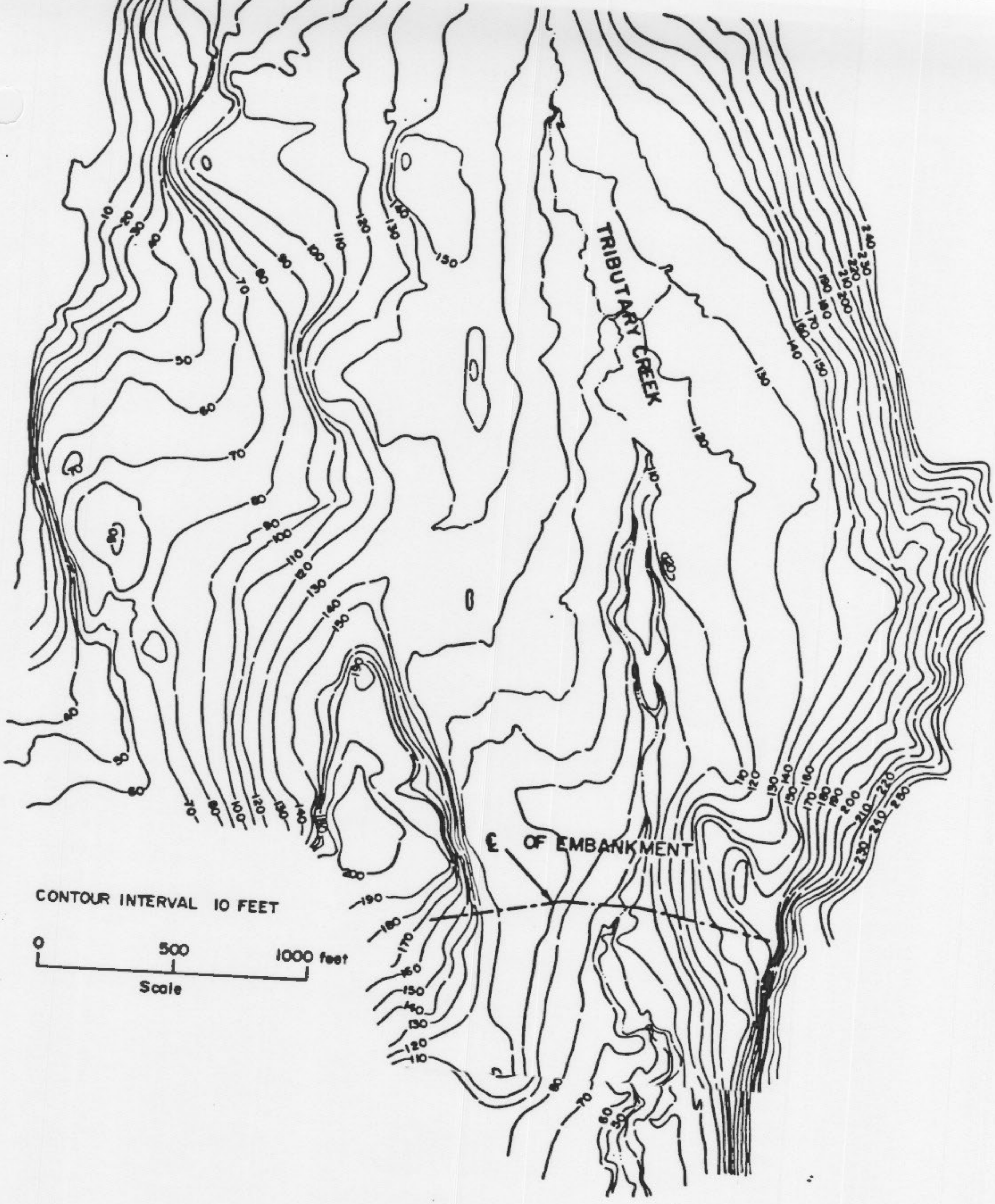
References

Griffiths, D.H. and King, R.F., "Applied Geophysics for Engineers and Geologists," Pergamon Press, 1965.



- RETREAT GROUP-DEVONIAN? - SILURIAN? - mafic tuffs, flows & sediments
- PLUTONIC ROCKS - CRETACEOUS
- MIGMATITE, GNEISS, FELDSPAR SCHIST — Mz, Pz?
- CANNERY FORMATION - PERMIAN? - carbonaceous argillite & phyllite
- HYD FORMATION - TRIASSIC — mafic volcanics
- SEYMOUR CANAL FORMATION — sediments
- JURASSIC & CRETACEOUS - sediments
- MAJOR FAULTS
- SYNFORM - Indicates general downward convergence of beds, foliation, or compositional banding in structurally complex rocks.
- OVERTURNED ANTICLINE

FIG. 1 REGIONAL GEOLOGY


TRIBUTARY CREEK
℄ OF EMBANKMENT
CONTOUR INTERVAL 10 FEET
0
500
1000 feet
Scale

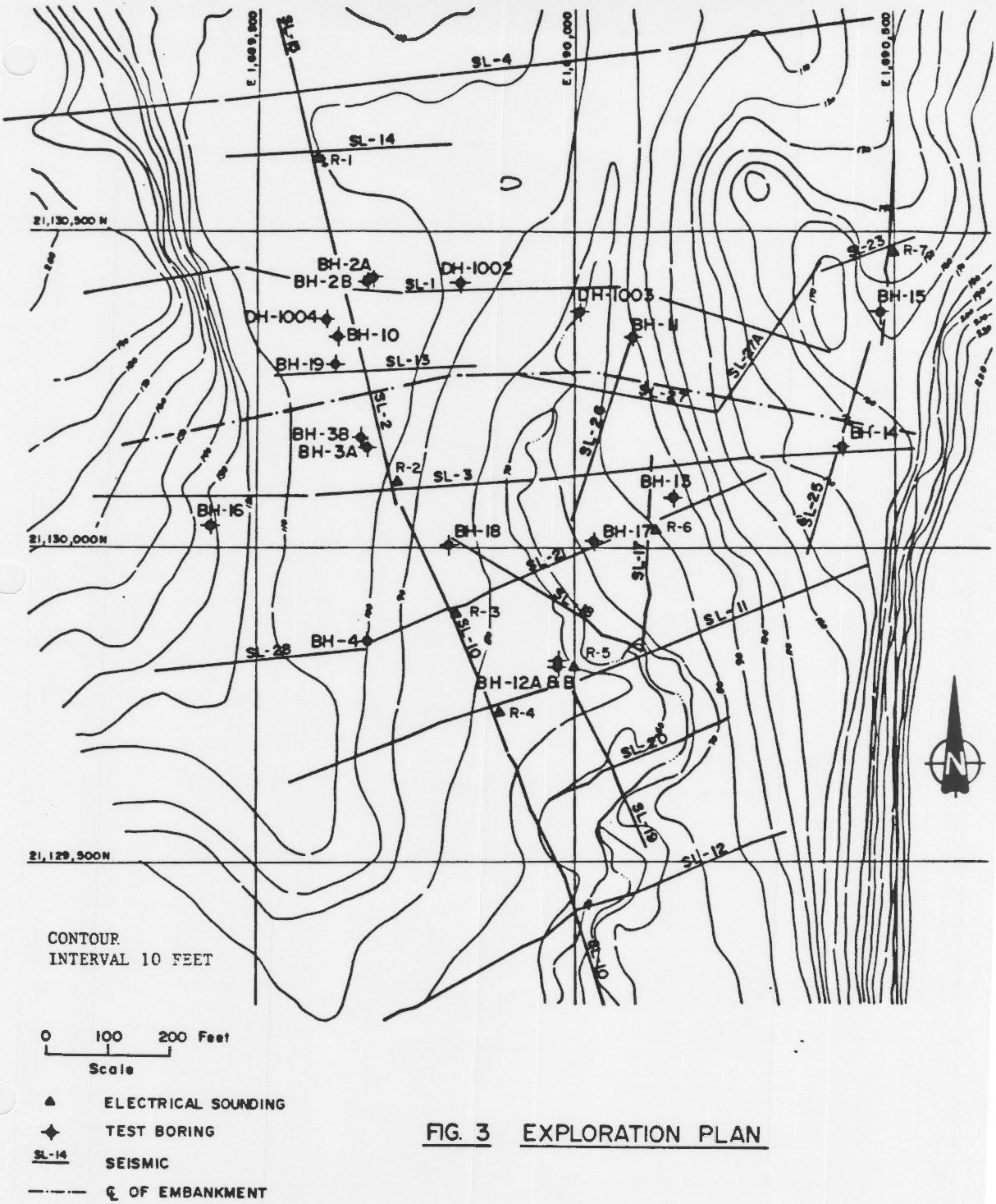
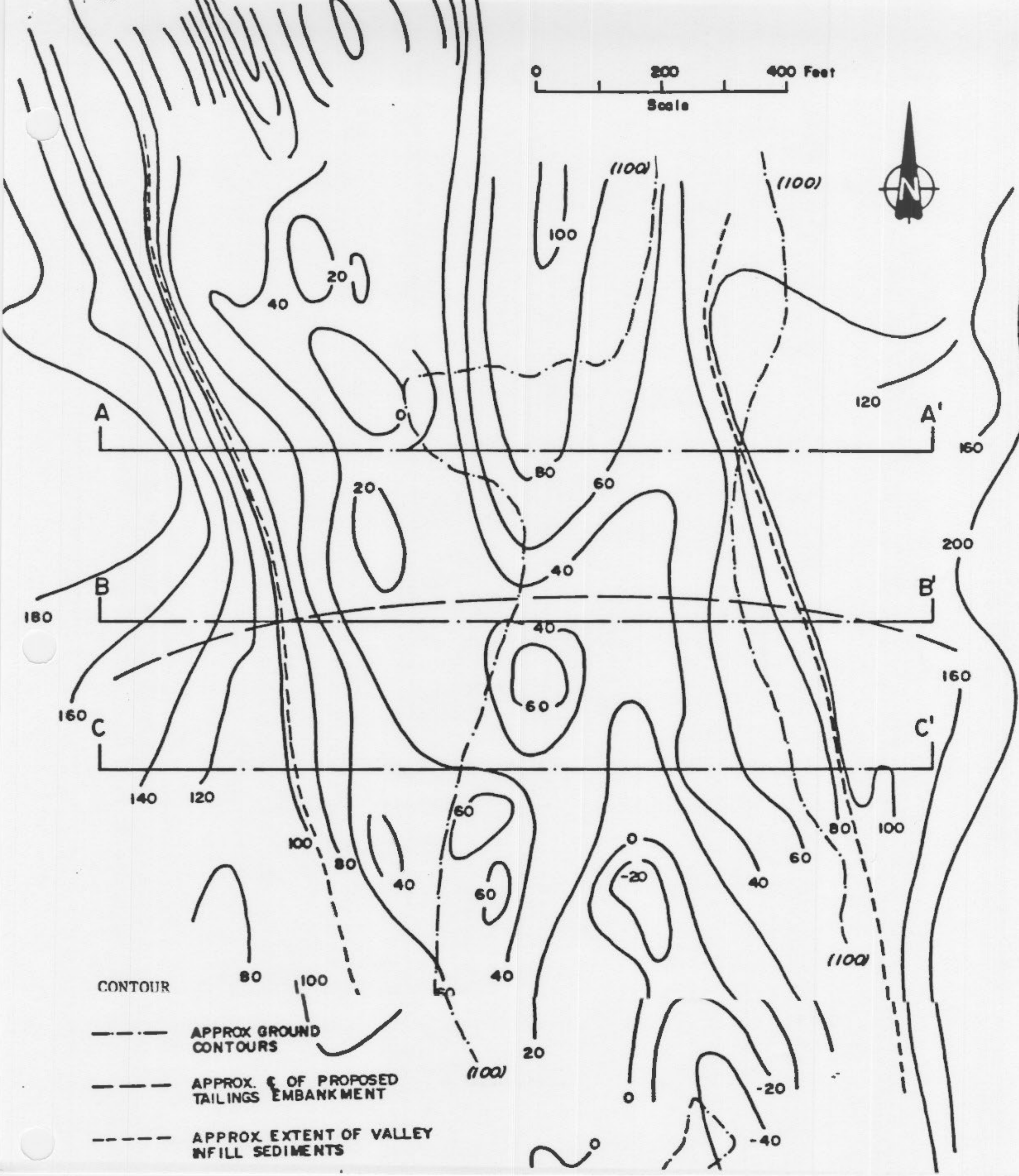


FIG. 3 EXPLORATION PLAN


0
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200
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CONTOUR
APPROX GROUND CONTOURS
APPROX. ℄ OF PROPOSED TAILINGS EMBANKMENT
APPROX EXTENT OF VALLEY INFILL SEDIMENTS

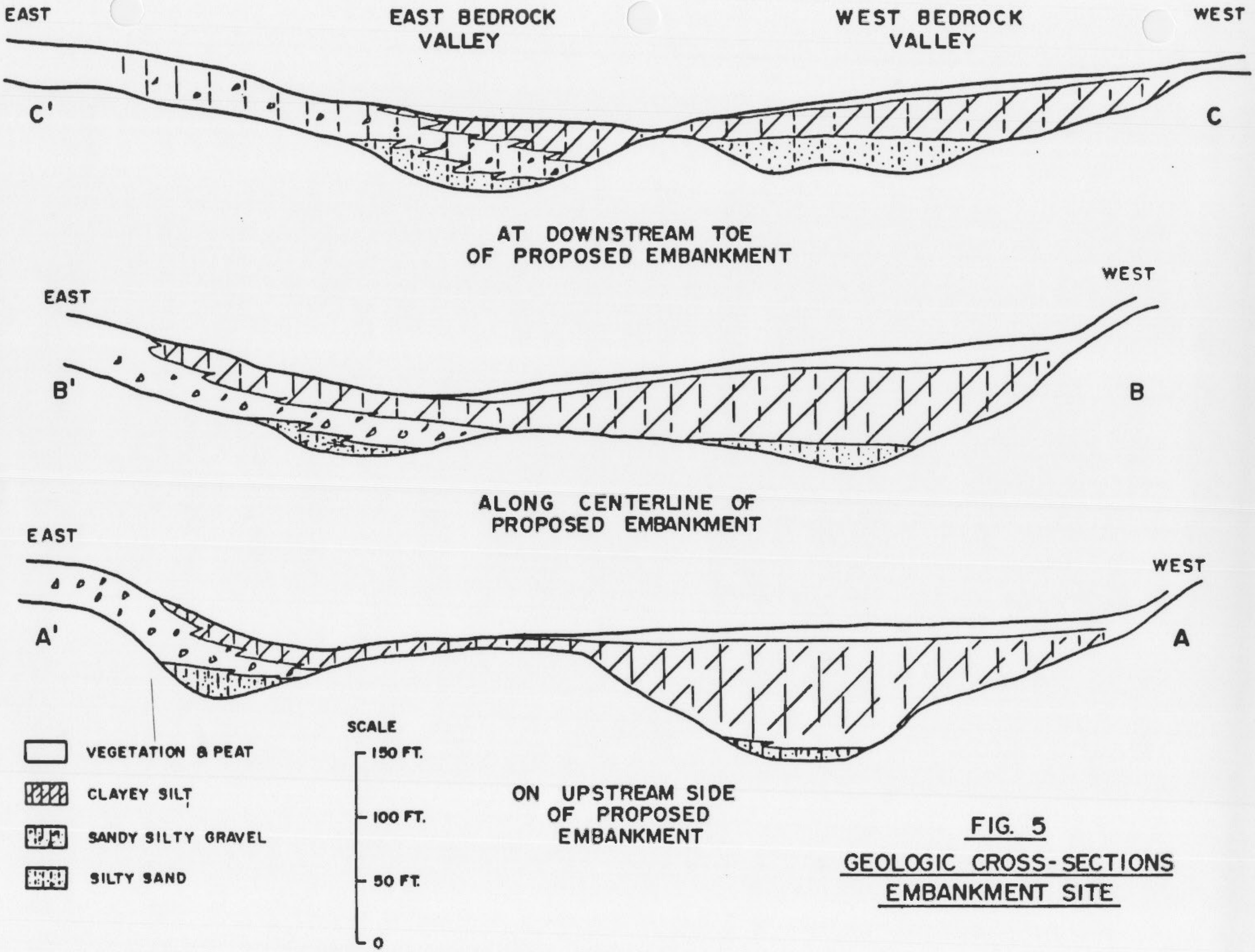

FIG. 5

GEOLOGIC CROSS-SECTIONS EMBANKMENT SITE

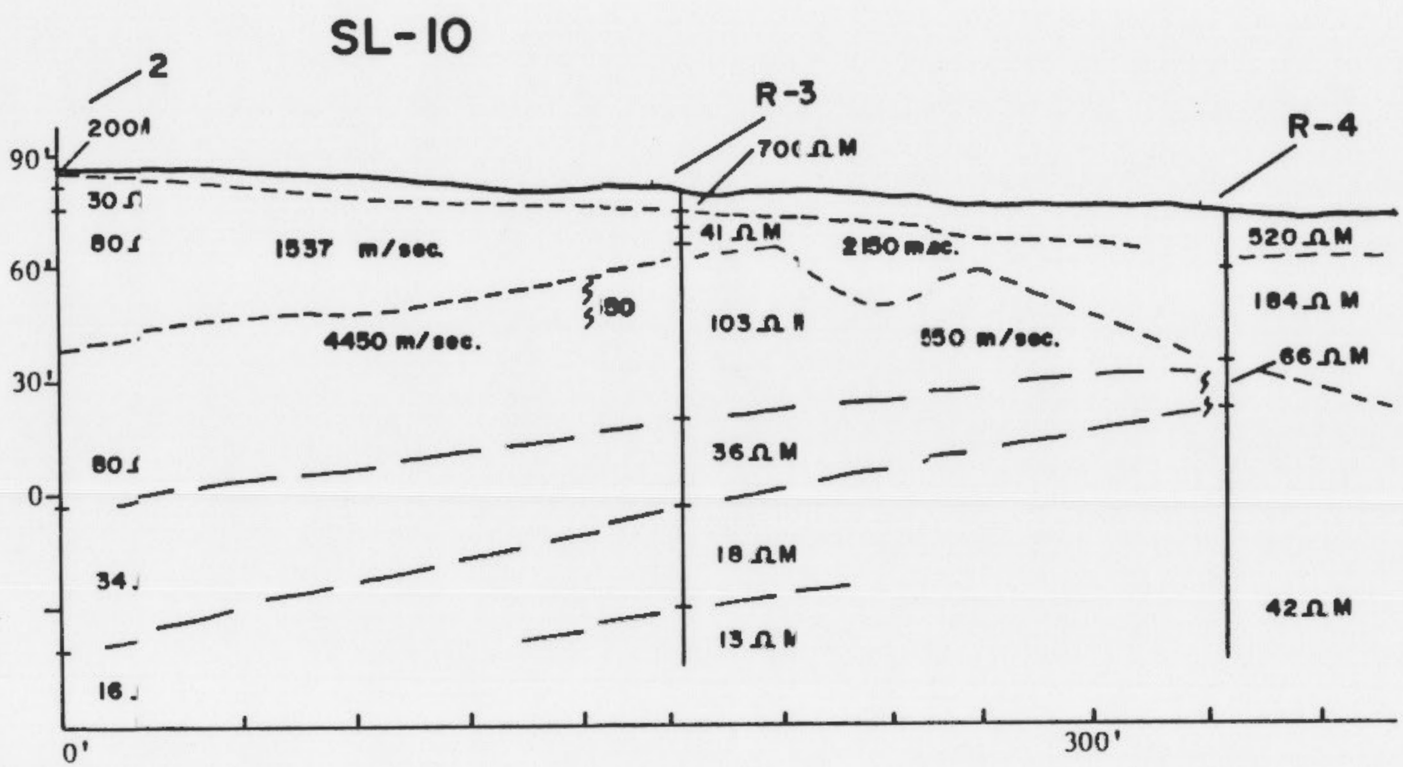

FIG 6 SEISMIC ND ELECTRICAL PROFILE

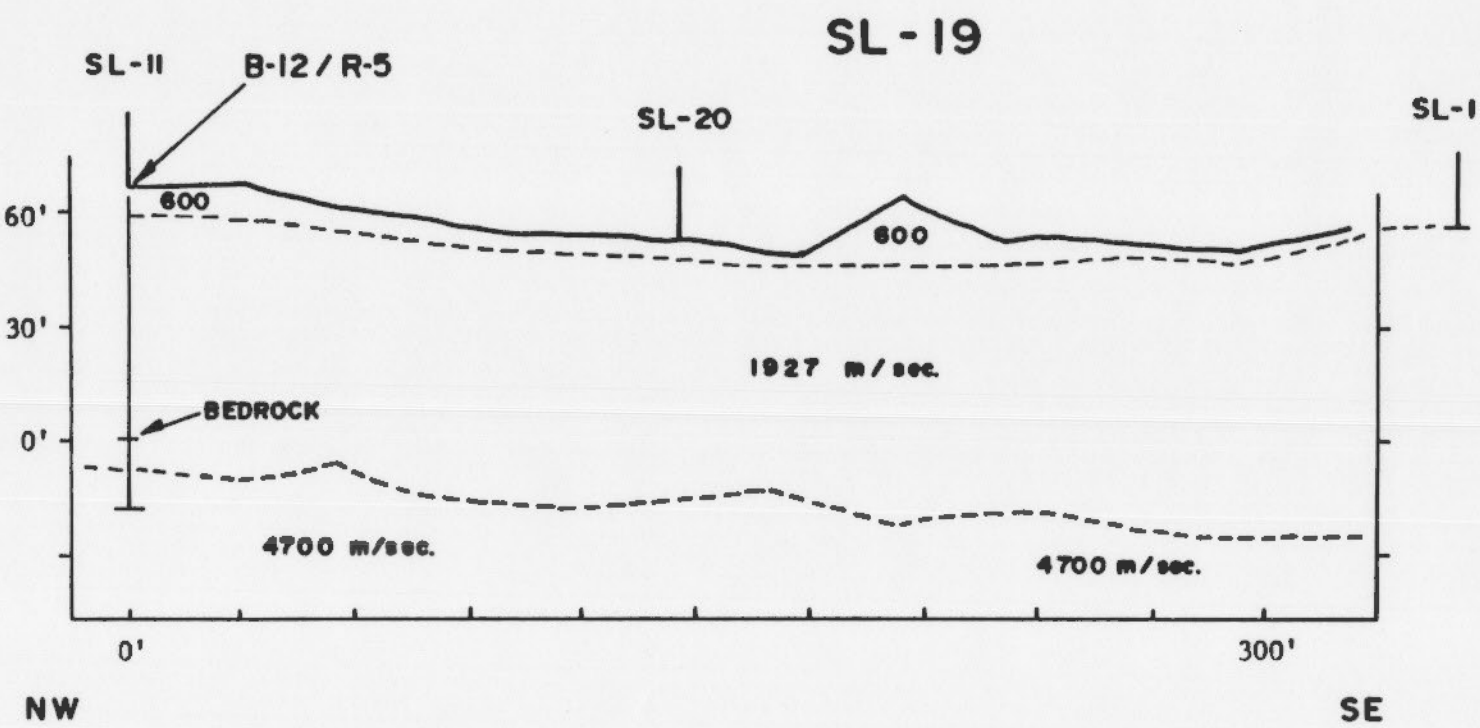

FIG. 7 SEISMIC AND BOREHOLE CORRELATION

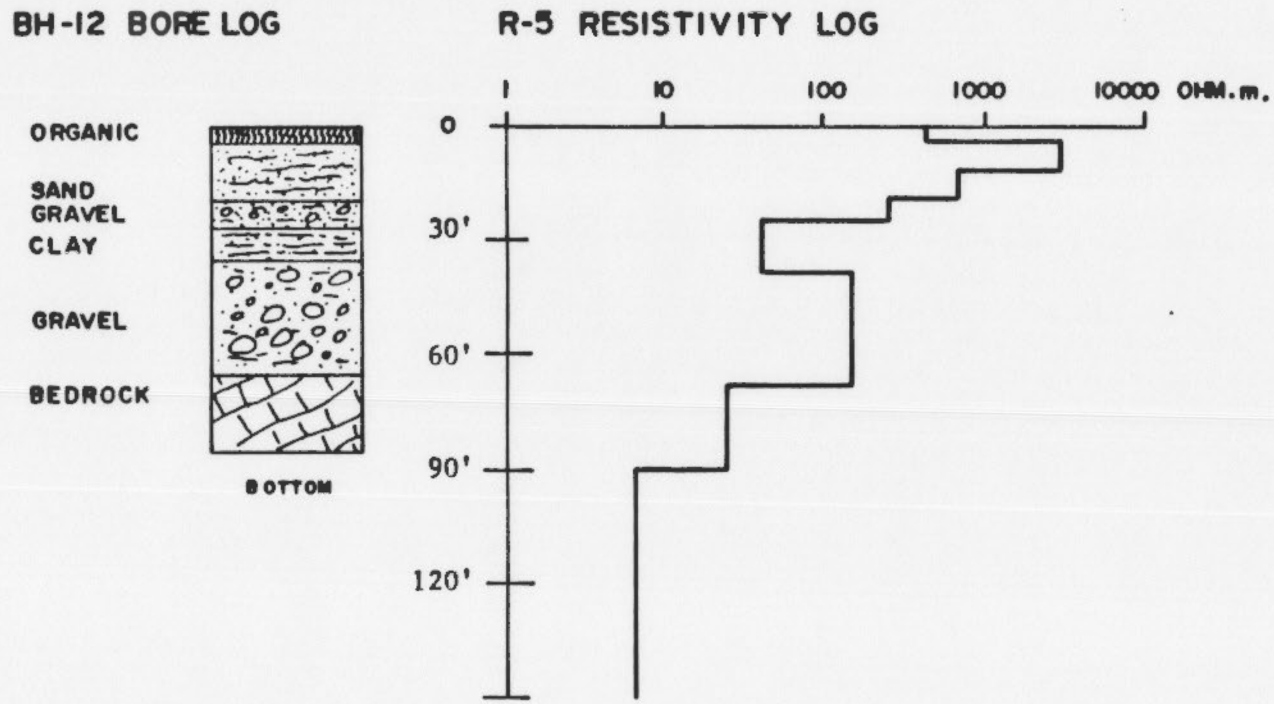

FIG. 8 RESISTIVITY AND BOREHOLE CORRELATION