GEOTECHNICAL MAPPING FOR STRUCTURAL BUILDING PURPOSES WITH AN EXAMPLE FROM THE CITY OF COLOMBO

by

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Abstract

A large number of site investigations for building purposes has been undertaken in the City of Colombo over the past 10 years, and this paper is an outline of a method which can be used to present the data from these investigations in a manner which would be of much use to Civil Engineers in the future.

It is shown that Geotechnical Maps can be prepared for varying engineering purposes. The map for Structural Building purposes aims to provide information that will assist the engineer (i) to plan future site investigation works, and (ii) to make preliminary evaluations of possible foundation types for buildings. The estimation of the allowable bearing capacity at different elevations is an important consideration for the latter. Thus, it is proposed that the Geotechnical Map be prepared on the basis of soil genesis with the boundaries between the different soil types being used as the boundaries of the map. Four main soil types consisting of (i) sand, (ii) alluvium, (iii) peat, and (iv) residual, have been identified for the preparation of this map. The position of the ground water table, the depth to rock, and the soil parameters necessary to compute the allowable bearing capacity have been identified as the other important data to be entered in the map.

The results from 62 sites have been studied. It is observed that most of the soil data available is in the form of the SPT value N. Although, this is sufficiently reliable for the sandy soils, it is not so for the other soil types. Therefore, the map requires improvement by the determination of the relevant soil parameters for the other soil types.

In this paper, the cross sections of the maps have been prepared to a horizontal scale of 1:18,466 and a vertical scale of 1:222. It is shown that with the availability of more data, not only can the maps be constantly updated, but

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also a larger horizontal scale can be used to provide more reliable preliminary information for future building works.

01. Introduction

A map consists of the representation of the spatial distribution of some physical features of the earth to a suitable scale. It shows boundaries differentiating the physical features being shown. For example, the topographic maps show the different elevations of the ground surface by means of contours which represent lines of equal height. Similarly, a geological map would show the boundaries between the different rock types as observed on the surface of the rock. A 'Geotechnical Map' (sometimes called an 'Engineering Geology Map') is one where the map is prepared so that its boundaries are defined by the changes in some engineering property. Fookes (1969) has stated that Geotechnical Maps can be prepared based on one (or sets) of the following properties:

a) By mapping soil or rock in descriptive (general) geology terms with weight being given to information of engineering interest.
b) By mapping in terms of index properties alone, such as the Unified Soil Classification System.
c) By mapping in terms of a design parameter such as the permeability or strength.

A detailed study of the preparation of Geotechnical Maps has been made by UNESCO - Ref. Anon (1969). This study shows that many types of Geotechnical Maps can be prepared and therefore needs classification. One such method is the classification according to the purpose of the map. Special Purpose Maps can be prepared to cover one specific engineering aspect; e.g. evaluation of landslide prone areas; and Multi-Purpose Maps can be prepared to provide information conveying many aspects of engineering geology. In the latter case, the danger exists that the inclusion of too many engineering parameters on a single map could cause much confusion to the user.

This paper deals with the development of a Special Purpose Geotechnical Map for structural building purposes. When designing and constructing structures for buildings, it is necessary to know some of the physical properties of the overburden soil, the depths and thicknesses of the various soil strata, the position of the groundwater table, the depth to rock, etc. Therefore, this Special Purpose Geotechnical Map should show as much as possible of this information. Since the variations of the properties (or the engineering boundaries) occur in three dimensions, a Geotechnical Map should in addition to the normal plan of the area, also provide vertical cross-sections giving the necessary information.

The preparation of such a Geotechnical Map is of great value to civil engineers as it will help both in the rational design of a site investigation, and a preliminary evaluation of the possible foundation types and the possible construction problems for a structure. However, it must be emphasised, that such a map cannot replace the detailed site investigation necessary for any building.

02. The Collection of Relevant Engineering Information

Cooray (1967) has reproduced a sketch map of the Colombo area as prepared by D.N. Wadia, and this is shown in Fig. 1. This map which has been drawn to a scale of 1 mile to 1 inch (i.e. a scale of 1:63,000) demarcates the soil and rock outcrops as seen on the surface, as well as the waterways consisting of rivers, canals and lakes. The soil and rock outcrops as seen on the surface have been further sub-divided into

i) alluvium,
ii) sand and semi-compact sandstone,
iii) littoral shelly sandstone,
iv) crystalline rock outcrop, and
v) laterite.

As mentioned previously, a Geotechnical Map should be much more detailed. It should be constructed to a much larger scale, and it should also contain vertical cross-sections giving the relevant engineering parameters.

The collection of this relevant engineering information for building purposes would be an extremely expensive and time consuming process as many augerholes and boreholes would have to be advanced. Senanayake (1986) has reported an investigation being carried out for the Geotechnical Mapping of Low-Lying Areas in and around Colombo where a total of 40 augerholes and 188 boreholes had to be advanced.

A considerable amount of building activity has taken place in Colombo during the past 10 years, and there are several organisations having records of site investigations done in Colombo. Many of these organisations volunteered to give this information for this study, and they are acknowledged later in the paper. The information from a total of 62 sites, numbered 1 to 62 in Fig. 2, was made available.

In almost all these site investigations, the boreholes were advanced by shell and auger boring, and standard penetration tests were carried out approximately every 1.52m (5 ft.). In a few of the investigations, undisturbed samples had been taken from the cohesive soils using thin walled samplers, and these samples were later tested in the laboratory. The groundwater level at the time of the investigation has also been recorded.

The depth to which the borehole was advanced has been variable. Whilst in the large building projects the drilling has continued upto rock, at many of the other sites the drilling has been terminated at a depth of around 7.6 m (25 ft.) in the overburden.

03. The Presentation of the Engineering Information

3.1 The Selection of the Scale of the Geotechnical Map

Whereas Geological Maps are prepared on a fairly small scale (e.g. 1:500,000 to 1:25,000), the Geotechnical Maps are usually prepared to a much larger scale (e.g. 1:12,000) to 1:100). The Surveyor General's Department has a Topography Map of the City of Colombo showing the Municipal Wards to a scale of 16 chains to 1 inch (1:12,672), and also a 2-foot Contour Map drawn to a scale of 4 chains to 1 inch (1:3168). The locations of the 62 sites were first marked in the Topography Map, and these were shown in Fig. 2. From the locations of these sites, four cross-sections were selected for study, and are

i) Fig.3a : 21-61-59-20-8-9-51;
ii) Fig.3b : 54-52-6-35;
iii) Fig.3c : 61-56-1-58-32; and
iv) Fig.3d : 8-62-6-57

(Similarly, other cross-sections can be constructed when more borehole information becomes available).

The horizontal and vertical scales for the cross-section were selected so as to enable all four cross-sections to be each represented on an A-4 sized paper. This gave a horizontal scale of 1:18,466 and a vertical scale of 1:222. (As the actual magnitudes of these scales would change depending on the printing, the scales used are shown marked in each of the fitures). It is observed that in this mapping procedure, the vertical scale has been magnified by over 80 times the horizontal scale. A much larger horizontal scale can be used to provide more accurately the spatial variations in the engineering properties; but with the limited amount of information available at present, this does not seem justitied.

In many of the site investigation reports it was found that the ground level at the borehole was not recorded. Therefore, as a first approximation, the level of the site was taken as that given in the 2-foot Contour Map.

3.2 The Soil Classification System Used

The geotechnical mapping of soils in terms of a classification system such as the Unified Soil Classification System is not very useful because it has been shown that this classification which has been developed for the transported soils in the West is not applicable for many of the residual soils in the arid zones.

In the City of Colombo, the soils have been formed and placed in their locations by many different geological processes, and the engineering properties of each of these soils are quite variable from one soil to another. It is, therefore, proposed that the boundaries of the Geotechnical Maps be prepared using a classification system based on soil genesis.

According to the Geological Survey Department - Ref. Anon (1981) - soils in the City of Colombo can be categorised into

i) Regosols of recent beach and sand dunes;
ii) Bog and half bog soils;
iii) Alluvium soils of variable texture and drainage;
iv) Latesol and Regosol of old sand; and
v) Lateritic Soils.

3.2.1 Regosols of recent beach

These are the soils found extensively on the unconsolidated sands along the coast e.g. Location 61 in Fig.3a. These are marine deposits which are loose and porous.

3.2.2 Bog soils

Bogs are regions of water logged soils where oxygen is scarce. In such conditions, the anaerobic micro-organisms decompose organic matter and large quantities of humus gets collected. The geologists refer to any soil which has more than one foot thickness of humus as a peat.

It has been reported by Ray et al. (1986) that "there are in Colombo small, irregular bodies of water which are usually drowned valleys formed due to minor oscillations of sea level in geologically recent times. Haphazard urban growth has gradually sealed off the outlets resulting in the formation of swamps and lakes. The native vegetation that covers these water bodies give rise to, on decomposition and accumulation over a period of years, organic soils in which the solid constituents consist predominantly of vegetable matter in varying stages of decomposition or preservation." Ray et al. refer to these soils as the peats.

3.2.3 Alluvium soils

The alluvium soils are a variety of soils found in the river valleys and flood plains deposited during the flooding season. They are generally soft silty sands in which the incorporated humus (the decomposed matter from organic litter) gives them a characteristic brown colour. This often leads to the incorrect classification of the soil as a peat. (The determination of the natural water content of the soil could be a quick and easy test to differentiate between a peat and an alluvium. Peat has a great capacity for taking up and holding water. Ray et al. (1986) show that the peats in Colombo have moisture contents lying between 100% and 500%).

3.2.4 Regosol of old sand

These refer to the consolidated, deep layers of sand found in certain areas along the coastline; e.g. Locations 59 and 20 of Fig.3b at depths greater than about 20 ft. This same figure shows that this dense consolidated layer of sand is virtually absent a short distance away at Location 8. Therefore, in the preparation of the Geotechnical Map, no attempt has been made to differentiate between the 'new' and 'old' sands as there is at present insufficient information to do so.

3.2.5 Lateritic soils

The laterites belong to the class of soils termed the residual soils which lie above the parent rock as a product of the in-situ weathering of the rock. The process of laterization where water percolating downwards during rainy weather removes soluble salts leaving behind residual iron and aluminium oxides commonly occurs in the hot-wet climates of Sri Lanka, with Colombo being one of them. The regions where the lateritic soils appear at the ground surface can be seen in Fig. 1, whilst Fig. 3a, 3b, 3c and 3d show the residual soils which lie immediately above the parent rock.

3.2.6 Soil types used for Geotechnical Mapping in this paper

It is proposed that a Geotechnical Map for Colombo be produced on the basis of soil genesis, with the main soils at this stage being identified as

i) sand (both the 'new' and 'old' sands included)
ii) alluvium
iii) peat
iv) residual (The term residual soil is being preferred to laterite as it is a more general term which encompasses all the weathered soils lying above the parent rock).

i.e. the boundaries of the map be prepared so as to represent the boundaries between the above types of soils.

3.3 <u>The information to be presented in the Geotechnical Map</u>

A Special Purpose Geotechnical Map is prepared for a specific engineering purpose, and in this case it is a map for structural building purposes. This requires the following information to be presented in the map.

3.3.1 Depth of Groundwater Level

The groundwater level usually fluctuates between the rainy season and the dry season. The water levels recorded in the boreholes are those observed at the time of drilling as a measured depth below ground surface. However, it is sufficiently accurate for a preliminary evaluation of the type of foundation that would be economical for a structure. In Figs. 3a, 3b, 3c and 3d the groundwater line has been drawn making use of the observed depth of the groundwater at a borehole, and the level of the top of the borehole as obtained from the 2-foot contour map. Whilst the groundwater line seems to fit reasonably well with the levels of water in the Beira and the MSL, a matter of interest for the Geologists would be the perched water-table between Locations 21 and 61 in Fig. 3a.

3.3.2 Depth to Bedrock, and the Depths and Thicknesses of the Different Soil Layers

Although, in general, many boreholes are advanced at any one location for a building site, it is not possible to represent the information from each of these boreholes in the Geotechnical Map where the cross-sections have been prepared to a horizontal scale of 1:18,466 (approximately 1539 ft. to 1 inch). However, when more information is available, a larger horizontal scale could be used so as to show the variations which occur over shorter distances.

A major disadvantage in the use of the horizontal scale used in Figs. 3a, 3b, 3c and 3d is that there are many locations at which the local variations in depth to bedrock, and the depths and thicknesses of the different soil layers are large; but they cannot be shown on a figure of this scale. For example, when considering the depth to bedrock at some of the locations shown in Fig. 3a, the following variations were recorded:

i) at Location 21, this depth varied from -32 ft MSL to -60 ft MSL

ii) at Location 61, this depth varied from -22 ft MSL to -51 ft MSL

and

iii) at Location 59, this depth varied from -65 ft MSL to -80 ft MSL

(The positions of the bedrock level as obtained from different boreholes at the same location are shown as the horizontally hatched short lines along the vertical line representing each location).

Thus, if a boundary for the bedrock surface is to be constructed, only one of these depths can be considered. Similarly, associated with the variations to the depth of bedrock are the variations of the thicknesses of the different soils, and again only the data from one of the boreholes at the site can be considered for the preparation of the Geotechnical Map. Therefore, it must be emphasised that these maps are no substitute for a detailed site investigation at any site, for a specific building project.

3.3.3 The Numerical Values of Engineering Parameters

The engineering parameters which should be presented numerically in the Geotechnical Map for Structural Building Purposes are those which should enable a civil engineer to evaluate the allowable bearing capacity of the soil at any depth.

This requires that, in general, information should be provided to compute both the ultimate bearing capacity of the soil and the settlements which take place. The necessary engineering parameters for this purpose will vary depending on the type of soil.

3.3.3.1 Sandy soils -

In the case of sands, the 'N' - value as obtained from the Standard Penetration Test can be used for computing both the ultimate bearing capacity and the settlement. This has been determined at most of the locations at every 5 ft. depths, and hence these are shown against their locations and depths in Figs. 3a, 3b, 3c and 3d.

It is this 'N'-value which can be used to differentiate between the loose and the dense (the 'new' and the 'old') sands. The 'N'-value can also be used to locate sandstone layers in the sand. For example, at Location 59 in Fig. 3a, at a depth of about 35 ft. very high 'N'-values have been recorded. These were subsequently identified as sandstone. Similar sandstone layers were obtained at Locations 20 and 51 of Fig. 3a.

3.3.3.2 Alluviums -

A knowledge of the geology of the area, the visual examination of the soil, and the small 'N'-values; they all help to identify an alluvium. For example, small 'N'-values have been recorded at Locations 1 and 58 of Fig. 3c. The visual examination of this soil showed it as a greyish fine silty soil with organic matter present in it. When the locations of 1 and 58 were transferred to the 2 foot contour map of Colombo, it was found that these two points were located in a valley which is shown dotted in Fig. 2. It is, therefore, conceivable that this valley has got filled up with alluvium when the Beira Lake spilt over. Similarly, alluviums were found to be present beneath the sandy soils in Figs. 3b and 3d.

Although the 'N'-values are useful for the identification of alluviums, they are not very reliable for predicting the ultimate bearing capacity of these soils. Therefore, when such soils are met, it is necessary to obtain undisturbed samples of these soils, which should be tested in the laboratory for their shear strength and consolidation properties.

3.3.3.3 Peaty soils -

Peat is such a poor engineering material (with low shear strength and very high compressibility) that building in areas where peat exists could be very costly. MacFarlane (1969) has noted that the two commonly used methods for building foundations in peaty soils consist of

i) complete removal of peat and backfilling with granular fill;
and
ii) use of piles going down to a stratum beneath the peat.

Peat is also an extremely difficult material to sample in an undisturbed state because of its very high water content. Considering all this, it is recommended that for the purpose of preparing a Geotechnical Map for Structural Building Purposes, it is absolutely essential to identify the peaty areas; but it is not necessary to assign numerical values for its strength and compressibility. However, it is necessary to determine the thickness of the peat layer, and the properties of the soils which lie beneath the peat.

Fig. 3C shows a peat deposit found at Location 32 - Maligawatte. In this case a lateritic soil formation is found beneath the peat, and buildings have been constructed at this site on piles-both friction piles terminating in the lateritic soil, and end bearing piles taken down to rock.

Some of the possible areas of peat in and around the Colombo District have been identified by Ray et. at. (1986); and these include areas such as Orugodawatte, Peliyagoda, Nawala, Maligawatte, Kotte and Muthurajawela. The high water contents, low specific gravities and dry densities, high ash contents; all of which are typical characteristics of peaty soils are evident in the measurements made by Ray et al. and shown in Table 1.

Sample Location	Ash Content (%)	Specific Gravity	Water Content (%)	Dry Density (Mg/m^3)
Orugodawatte	31.5	1.85	150	0.503
Peliyagoda	35.6	2.12	258	0.350
Nawala	28.1	1.69	362	0.260
Maligawatte	9.15	2.11	145	0.540
Kotte	22.0	2.29	138	0.560
Muthurajawela	36.2	1.72	233	0.333

TABLE 1

Typical values of some engineering properties of peat in and around Colombo. (Ref. Ray et al. (1986)

(It should also be mentioned that there are other engineering structures, notably roads and embankments, which are constructed on peat. In such cases it would be necessary to determine the strength and compressibility characteristics of the peat so as to determine the most economic design).

3.3.3.4 Residual soils -

The residual soils which are formed as the weathered product of the parent rock may be found lying beneath a transported soil (e.g. in Fig. 3a where the marine deposits overlie the residual soil), or they may appear at the surface (e.g. the lateritic 'hill' as shown in Fig. 3c, and more generally in Fig. 1).

The bearing capacity of lateritic soils has been studied by Ramanatha Iyer and John (1975) who carried out plate load tests on lateritic formations. They reported that the failure mechanism of the laterite in the two cases given above are quite different.

The laterite when it appears at the surface is characteristically desiccated and partly saturated. These soils have considerable shearing resistance partly due to the desiccation bonds generated by alternate wetting and drying, and partly due to the negative pore water pressures arising out of partial saturation. When these soils become saturated either due to rains or due to the rise in the water table, the negative pore water pressures tend to become negligible whereas the contribution to shearing resistance by the deciccation bonds persists.

From the results of plate load tests on thick beds of surface laterite Ramanatha Iyer and John concluded that the type of failure is similar to that which occurs in rocks such as granite, sandstone and limestone, where the crushing of the material controls the load-deflection behaviour of the foundation. The resistance to failure was higher than $3q_u$ (where q_u is the unconfined compressive strength), and the stress at yield ranged between 4 to 6 times q_u. It is therefore recommended that the bearing capacity of these lateritic soils be computed on the basis of its unconfined compressive strength (q_u). In the case of the settlements of these soils, Ramanatha Iyer and John recommend the use of elastic theory for the prediction of settlements under light load (prior to crushing), and the use of Ladanyi (1966) theory for larger loads (post-yield curves).

When the laterites are found at larger depths, the higher confining pressures found at these depths tend to make the laterite more plastic, and hence the plastic theories are found to be more appropriate. Therefore, it is recommended that the Mohr-Coulomb failure theory be used to evaluate the ultimate bearing capacity of these soils. The settlements of these soils were studied by Tennekoon (1987) who showed that

i) The primary consolidation of these soils take place very rapidly because it is only the pore air which moves through the soil, (there is no movement of the pore water through the soil); and
ii) considerable secondary compression settlements occur as a result of the breaking down of the concretionary structure of these soils under the effect of applied stress.

The oedometer test can be carried out to determine these characteristics, but the results need special techniques of analysis as shown by Tennekoon.

In the boreholes studied only the 'N'-values had been recorded and, therefore, these are shown at their respective locations and depths in Figs. 3a, 3b, 3c and 3d.

04. Conclusions

A Special Purpose Geotechnical Map is one which is developed for a specific purpose. In this paper, an attempt is made to develop such a map for structural building purposes, with an example from the City of Colombo. The data for the preparation of this map has been carried collected from several of the site investigations that have been carried out by various organisations over the past 10 years.

A Geotechnical Map for Structural Building Purposes should show the position of groundwater, the various soil strata and their properties which influence the design of the foundations, the position of bedrock, etc. The scale of such a map, although much larger than that of a geological map, cannot show the detailed site conditions at a specific site. But it can assist the civil engineer by informing him of the approximate site conditions and the types of foundation problems that might be encountered, so that he could make a preliminary assessment of the best type of foundation for the structure, and then plan the detailed site investigation in a more efficient manner. As information from more and more site investigations become available, it is possible to make refinements to the map, and also produce the maps to a larger scale.

In the preparation of the Geotechnical Map for Colombo, its soils have been divided into four main types; these being the sandy soils, the alluviums, the peaty soils, and the residual soils. Each of these soils has a distinct behaviour under the effect of structural load, and hence they have been used to demarcate the boundaries of the Geotechnical Map. The sandy soil could be further sub-divided into the 'new' sands which are loose and of recent origin, and the 'old' sands which are consolidated and are geologically much older. However, their spatial distribution appears to be quite varied, and the available data is insufficient to demarcate the boundaries between these two types of sandy soils.

The present practice in the site investigations for buildings in this country often consists of advancing a borehole, noting the level of groundwater, logging the type of soil encountered by visual examination, and measuring the resistance to penetration of the Standard Penetration Tube. Whilst the measured SPT value 'N' is adequate for determining the bearing capacity of the sandy soils, it is not so for the other types of soils encountered. In the latter case, undisturbed samples of soil should be taken and tested in the laboratory for the determination of their shear strength and compressibility characteristics. (Sometimes when very soft soils are encountered where undisturbed sampling is difficult and expensive, alternative field measurements may be made). In the case of peaty soils (which is an example of a very weak soil which is difficult and expensive to sample), the present practice is to discourage structural buildings on it unless the foundation loads are taken down to a layer beneath the peat. Therefore in this case it is recommended that at present it is sufficient to identify a peat, and determine the location and the thickness of the peat layer.

Using the above principles, a Geotechnical Map has been prepared for Structural Building Purposes for a part of the City of Colombo. Although the shear strength characteristics and the consolidation characteristics of the alluviums and th residual soils should also be included in such a map for completeness, this information was not available in the boreholes which were studied.

05. Acknowledgements

The Authors wish to express their sincere thanks to the following organisations which readily made available the records of their site investigations in Colombo for this study.

i) Foundation Engineering Consortium Limited,

ii) Group Engineering Laboratories Limited,
iii) Geotech Limited,
iv) Irrigation Department and
v) State Engineering Corporation.

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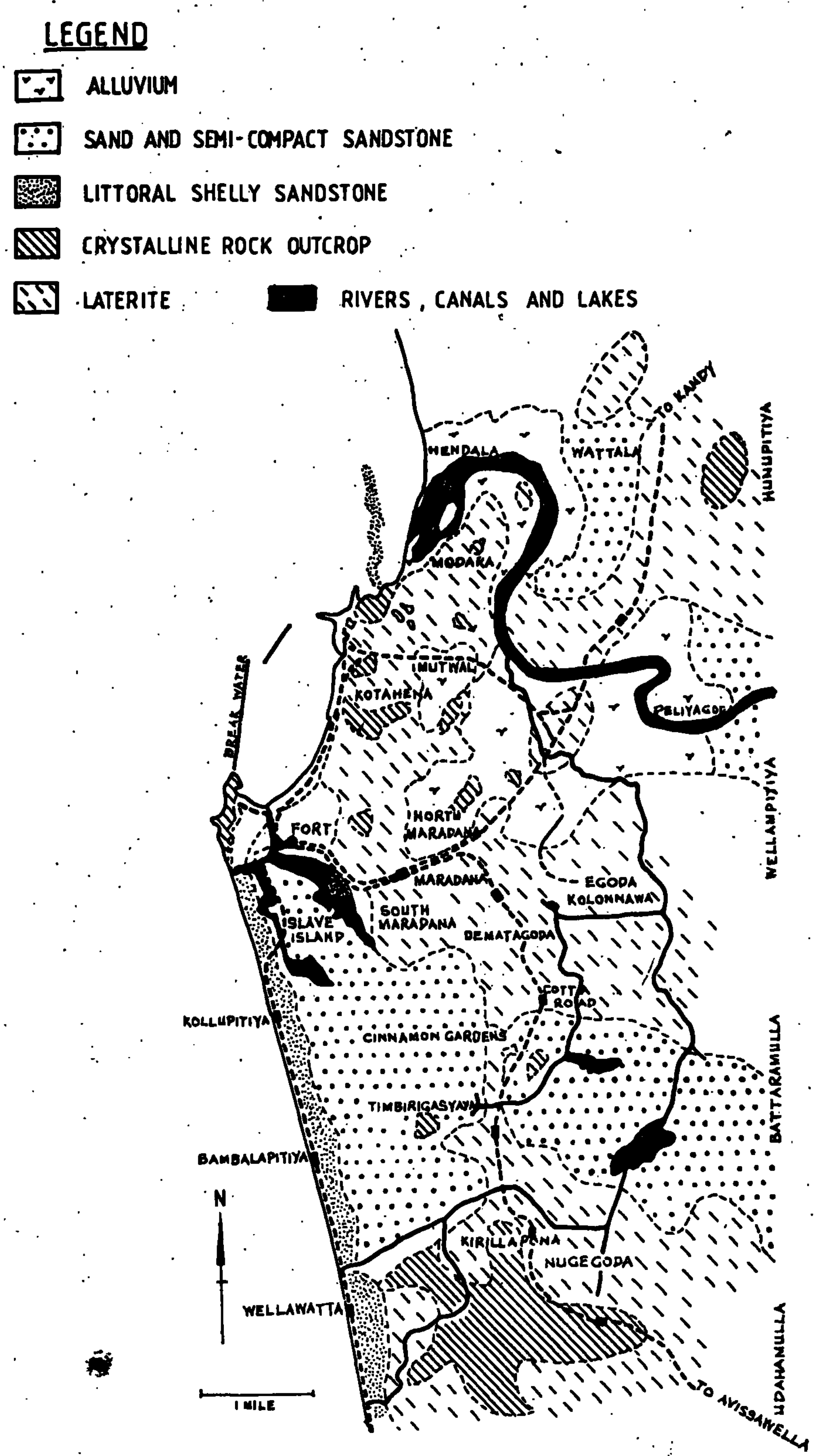

Fig. 1 - Geological map of the Colombo District.
[Ref. Cooray (1967)]

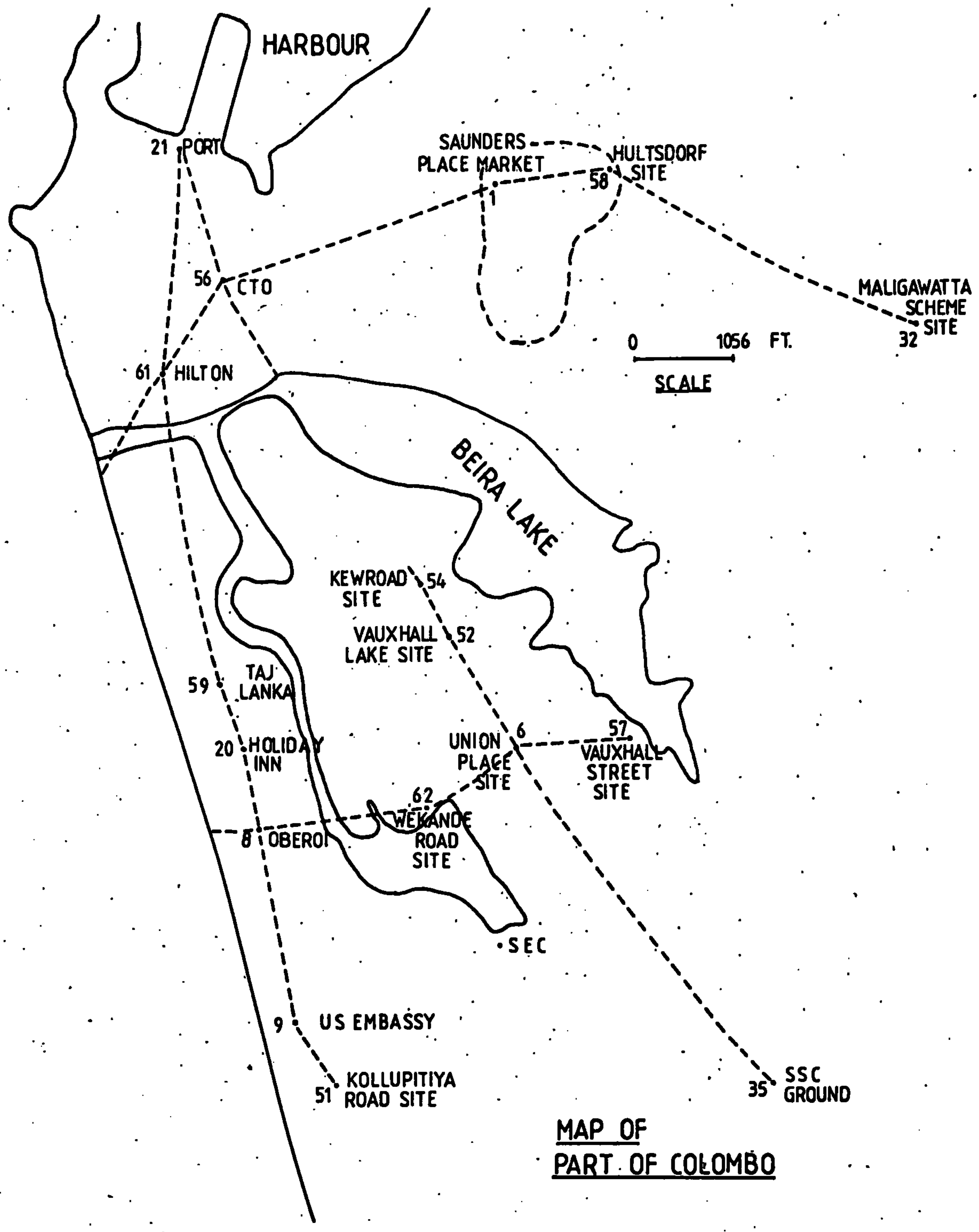

Fig. 2 - Map showing some of the Borehole Locations and the positions of the cross-sections used for study.

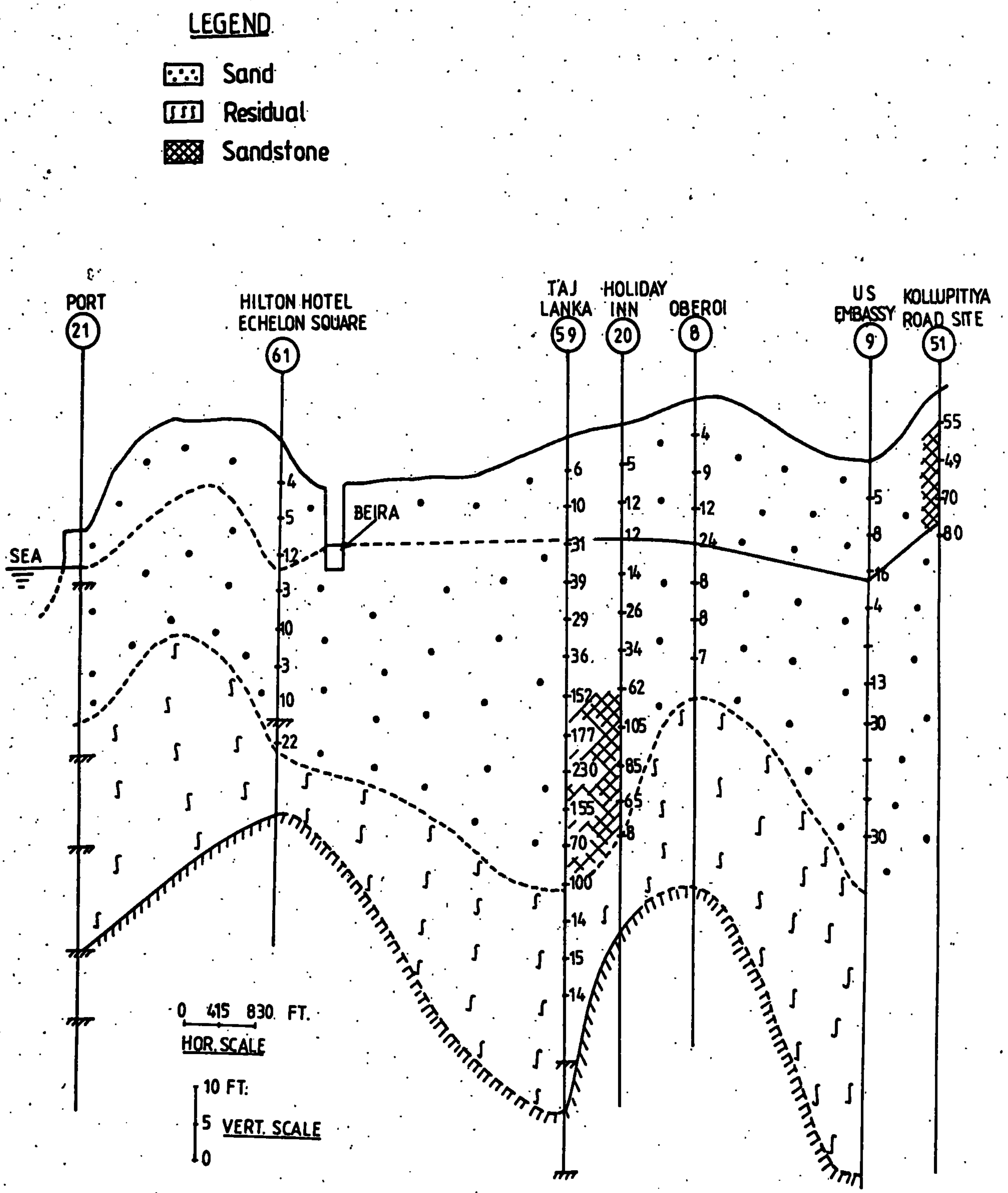

Fig. 3a - Cross-Section 21-61-59-20-8-9-51.

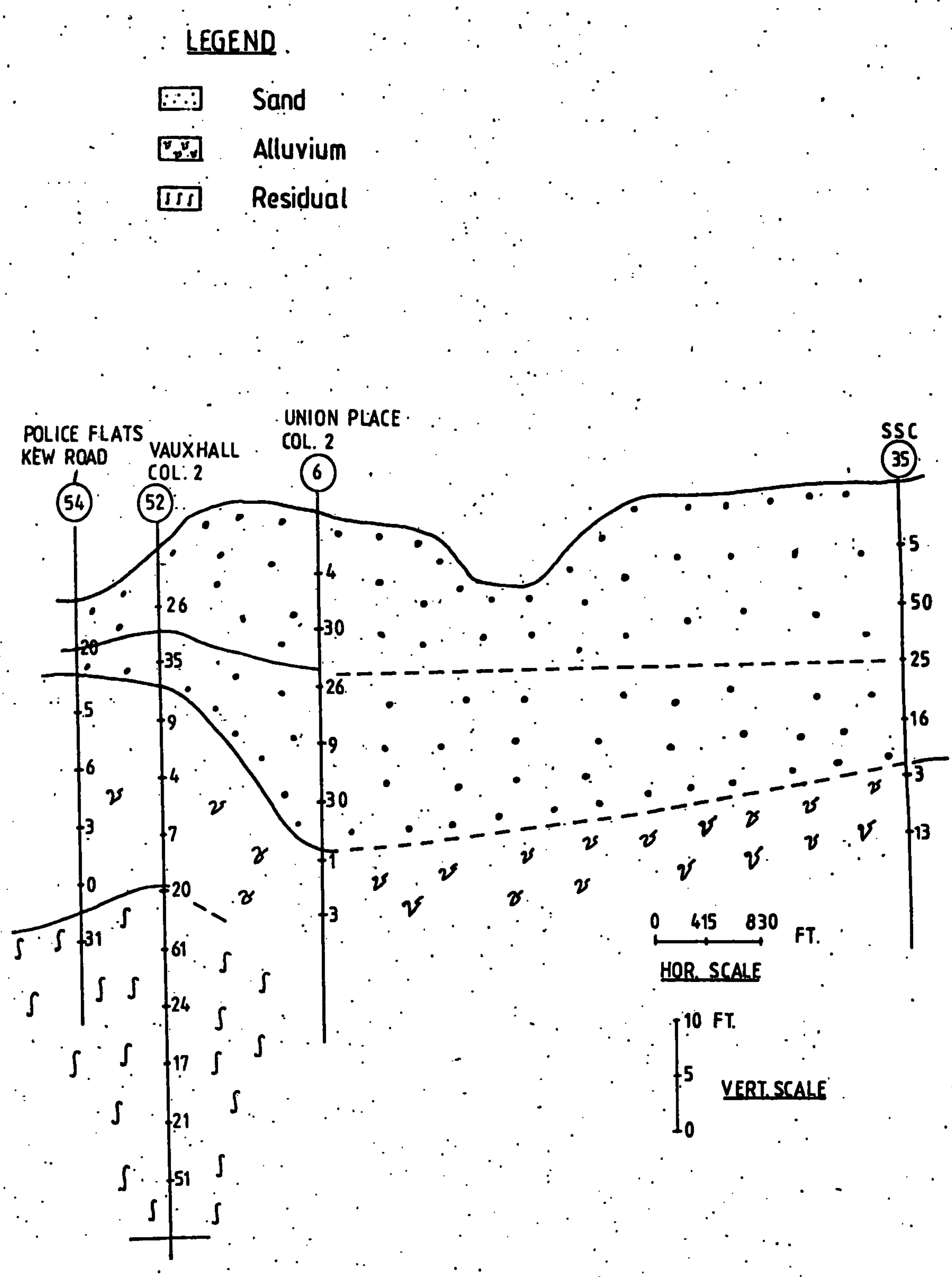

Fig. 3b - Cross-Section 54-52-6-35

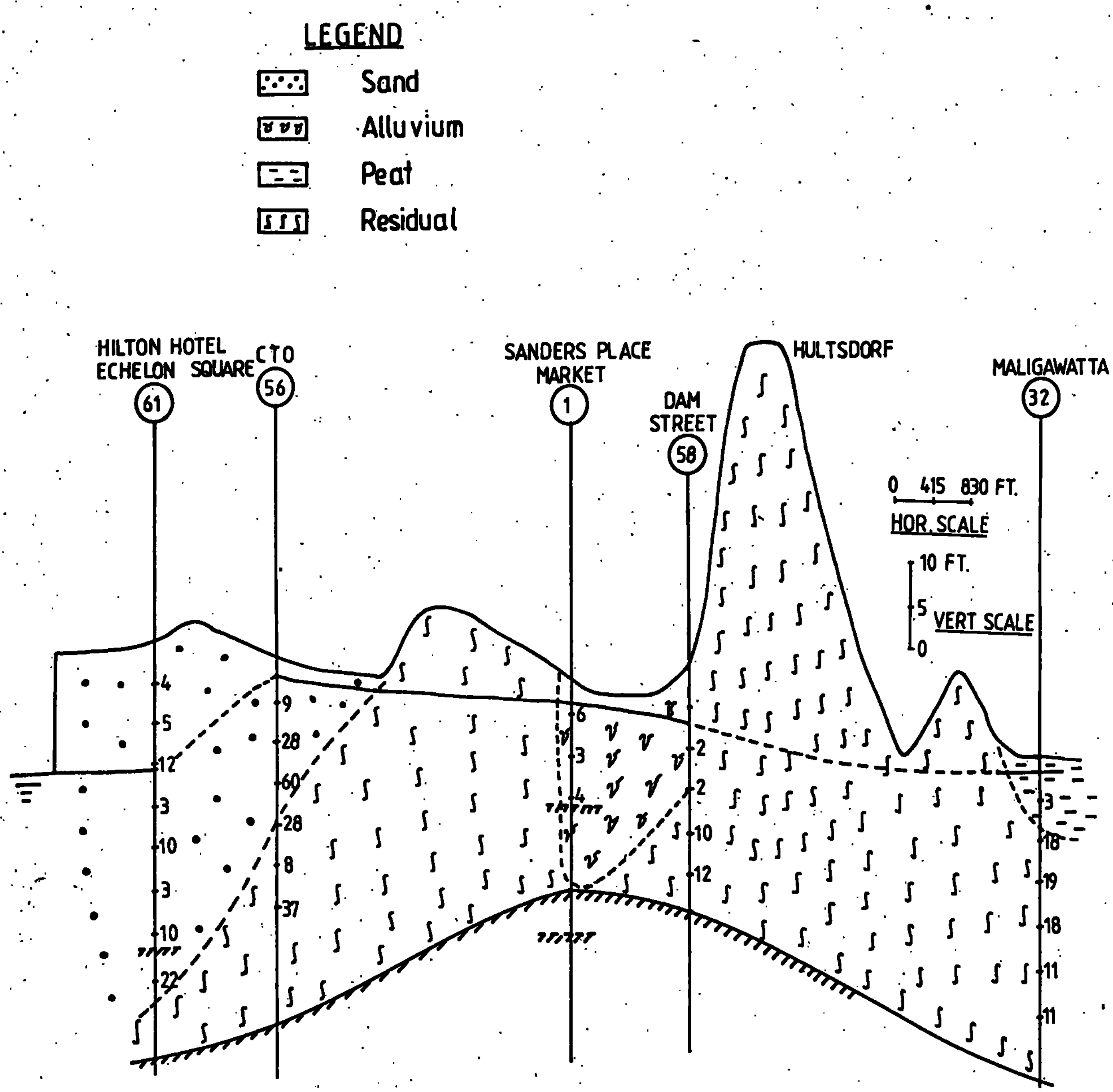

Fig. 3c - Cross-Section 61 - 56 - 1 - 58 - 32

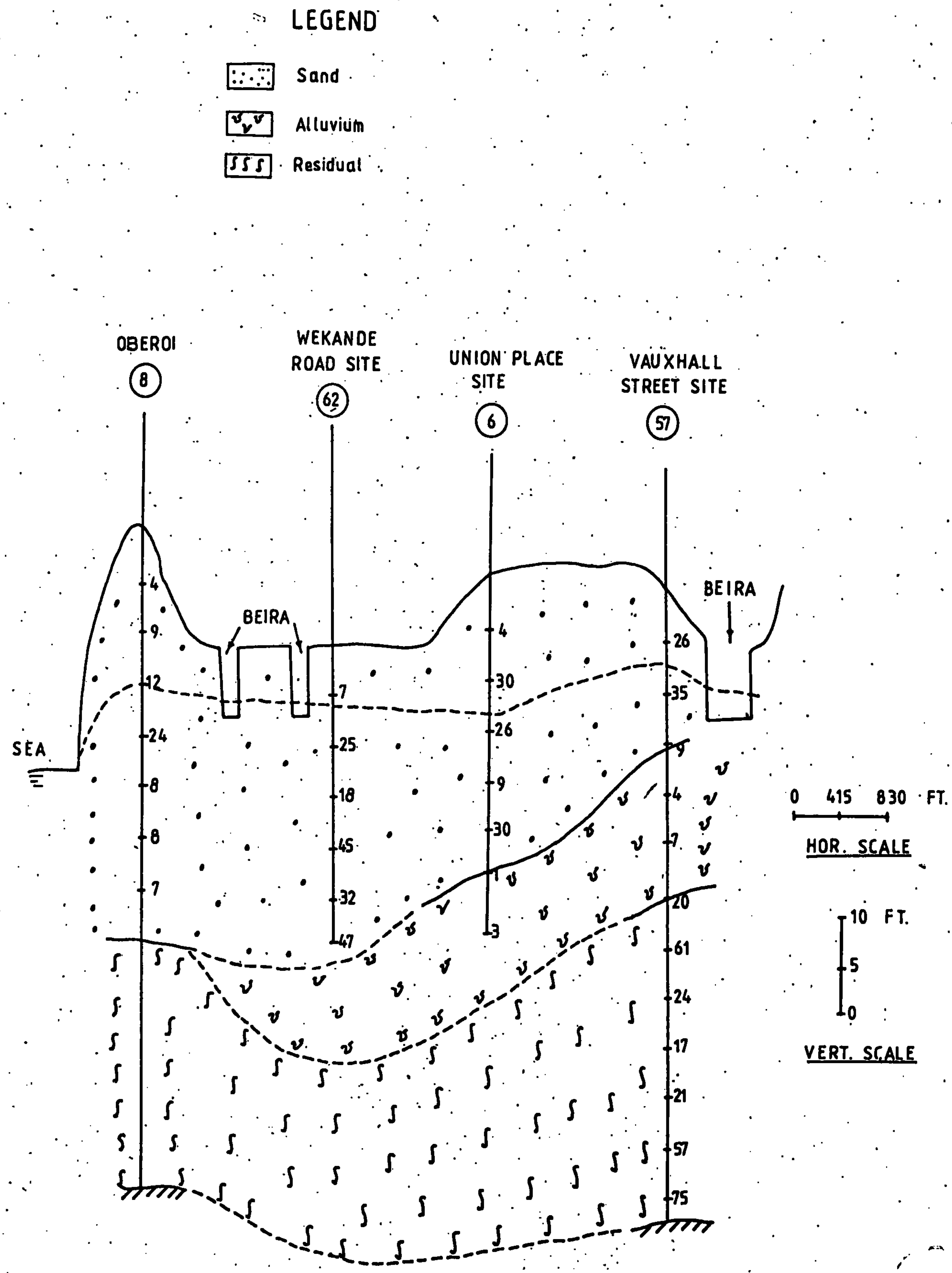

Fig. 3d - Cross Section 8 - 62 - 6 - 57