Geoengineering Constraints on Foundation: Case Study from Queens, New York City, USA

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Abstract

This paper deals with regional geologic information coupled with Geoengineering and routine soil characterization aspects of a facility site to be developed by New York City Agency in Maspeth (40° 43' 23" North, 73° 54' 47" West), Queens, New York City. Soil and sediment core samples, collected from depths close to the surface to over 200 feet into the bedrock, near the Maspeth site, Queens, New York City, consist of a zone of non-compact fill materials (10 to 25 feet thick), underlain by a compressible peat and a partially decomposed highly plastic organic layer (Liquid Limit around 85) associated with calcareous clay and shell fragments (4 to 10 feet thick). The presence of the shell-bearing unit, close to the surface, may be indicative of a buried estuarine complex in this area. The organic clay and peat layer were underlain by loose to firm glacial sand with gravels often intercalated with thin silty clay lenses. This is in turn underlain by thick dark clay to black, and red, mottled, semi-plastic to highly plastic clay. The proposed building construction on this site poses a serious problem, considering the lack of soil strength. The current upper soil horizons are not sufficiently strong to withstand the required loading, estimated at near 1200kips for some locations. The foundation support system will therefore have to be established in the glacial sand, possessing N (blow count) around 50 and Liquid Limit close to 30 (low plasticity). When construction, particularly of high rise buildings, is planned near estuaries in or around older municipalities, the probability of encountering buried estuary deposits should be considered because of its possible effects on the load bearing ability of foundation soils.

Keywords

Compressible soil, Geoengineering, New York City

Introduction

Regional geologic information coupled with Geoengineering and routine soil characterization aspects related to a facility site to be developed by New York City Agency in Maspeth (40° 43' 23" North, 73° 54' 47" West), Queens, were critically assessed and recommendations obtained from the studies were provided to this agency for consideration (Figure 1 and Figure 2). The current investigation highlights the importance of regional geologic and sedimentologic investigation prior to undertaking geoengineering, design, and construction phases to build the facility for the New York City Agency. Maspeth (Figure 2) lies closely adjacent to Manhattan and the surficial geology is dominated by anthropogenic fill consisting of discarded construction materials, abandoned and demolished buildings (Figure 3), and other landfill materials. A comprehensive soil mapping program was initiated by the New York City Soil and Water Conservation District (NYCSWCD), and its most updated soil classification, (as recent as February 23, 2009), can be obtained [1] by visiting http://www.nycswcd.net/soil_survey.cfm. Surviving examples of these soils are not widely distributed. Much of the area is covered with glacial deposits. Wherever the bedrock is exposed, weathering and rapid erosion have also prevented large deposits from being accumulated in recent times. In Brooklyn, at one of the shaft sites of City Water Tunnel 2, the upper part of the bedrock was covered by the material called “concretionary sandstone”, believed to be a residual soil derived from the weathering of the underlying gneiss [2]. Residual soils were also found in some of the deep borings in Queens and Brooklyn, advanced for the proposed City Water Tunnel 3. In the eastern part of the Bronx, explorations for the Cross Bronx Expressway revealed some deep weathering of the Manhattan Schists [3].

Maspeth sits in close proximity to Newtown Creek (Figure 2) which has been partially filled in by humans, and is not in its original configuration. Newtown Creek, one of the still-existing estuaries, is a 3.5 mile waterway between Brooklyn and Queens. It empties into the East River near Long Island City. The current beginning of Newtown Creek is at Grand and 47th streets in Queens, though the creek once ran for far longer. Newtown Creek is large enough to have tributaries of its own, and at one time had small islands within it. Today, Newtown Creek is best known for the pollution that has plagued it for decades. Another prominent still-existing stream is Flushing Creek, which meanders through salt marshes in central northern Queens before emptying into the East River at Flushing Bay [4] & [5]. The fresh water aquifer beneath Kings and Queens Counties in NYC (Figure 2) is bounded on the top by the water table and on the bottom by relatively impermeable crystalline bedrock. The southern, western, and northern lateral boundaries of the freshwater are bodies of saline ground water and the saline tidal water that surround Long Island [6], [7], [8], & [9].

Laboratory Investigations and Geoengineering Interpretations

In order to assess the significance for geoengineering, numerous shallow and intermediate-depth exploratory boring were carried out in Maspeth by the New York City Agency in collaboration with local sub-soil drilling company. Traditional split-spoon, cuttings, and sediment core samples were obtained to conduct various laboratory investigations and included thorough grain size analysis (mechanical sieving, both dry and wet), Atterberg Limits (Liquid Limit, Plastic Limit, Plasticity Index), unconfined compressive tests, pH, organic concentration, and moisture content. Standard Penetration Test or N (blow counts) and Recovery % (based on 2 feet recovery) were retrieved from the field data provided by the drillers. Surface elevation is slightly higher than 12 feet in sea-level and water table is found to be approximately 15 feet below ground. Boring depths ranged from 50 feet to more than 200 feet and crystalline late Precambrian to early Cambrian bedrock consisting primarily of schist, gneiss, and marble was recorded around this depth [2] & [10]. Overall, the subsurface geology below the anthropogenic fill (up to 10 feet) can be generally described based on Figure 6 and Figure 7.

An organic layer comprising decomposed woody and plant materials, rootlets, and leaves often resembling peat and amounting to a thickness of 8 to 12 feet underlies the anthropogenic fill (Figure 4 & Figure 5). Organic content and percent moisture distribution within this organic layer was analyzed by following ASTM 2974 and 2216 procedures. Representative samples used to determine moisture and organic content are recorded in Figure 11A & Figure 11B. There seems to be a wide variation in the distribution of moisture and organic content. Typically, moisture percentage is between 75 to 30, while organic content ranges from 85 to 20. ASTM D 4972 was used to determine pH (Figure 11B) of the collected samples and an overall alkaline condition was noticeable except in sample 3 (22 feet to 28 feet) where the soil is more acidic. Generally speaking, there is a good correlation with higher organic concentration with respect to higher pH; however local anomaly does exist as can be seen in sample 2. A silty clay to clay layer lies below the organic layer and reaches a maximum thickness of 20 feet. It is considered to be a highly compressible layer and contains partially decomposed mollusks of recent origin. SPT (standard penetration test) conducted on this compressible organic layer provided N (blow count) value to be between 5 and 12. It is thought that this layer perhaps originated when Newtown Creek was dominated by estuarine fauna. Below the compressible silty clay to clay layer, is a thick, massive, fine to medium-grained, well graded sand mixed with rock fragments largely containing medium to fine gravel-sized quartzite, basalt, and schist. In places massive sand is intercalated with a trace to subordinate amount of silty clay (Figure 9). This sandy unit is 60 to 80 feet thick (Figure 6 and Figure 7) and is presumed to be of glacial origin, of Wisconsinan age. N (blow count) values in this massive sandy unit range from 40 to 55 and recovery of sand is between 50-65% (Figure 12). Till composed of clay, sand, gravel, and boulders, forms the Harbor Hill and Ronkonkoma moraines. Outwash consisting mainly of brown fine to coarse sand and gravel, is stratified and interbedded with clays. The till has relatively poor permeability. The sand and gravel part of the outwash is highly permeable; yields of individual wells in it are as much as 1,700 gal/min. Specific capacities of wells are as much as 109 gal/min per foot of drawdown. Groundwater is fresh except near shorelines. Horizontal hydraulic conductivity is 20-80 ft/d and 200-300 ft/d in moraine and outwash deposits respectively. Horizontal to vertical anisotropy is 10:1. Specific yield is 0.25 and 0.3 in moraine and outwash deposits respectively.

The massive sandy unit is underlain by a thick, silty clay to clay layer, often reaching a maximum thickness of 120 feet (220 feet below sea-level). ASTM D 2487 and ASTM D 422 were utilized to determine grain size distribution of collected samples and sediment cores (Figure 9). Both dry and wet sieving techniques were followed. In-situ unconfined compressive strength investigation was conducted on few representative samples using pocket penetrometer to assess its mechanical strength (Table 1). Roughly, unconfined compressive strength of the clay layer recorded a moderate to medium strength (Figure 12) with N values ranging from 60 to 75 and total core recovery also ranged from 75 to almost 100 percent. Field investigations of in-situ sediment cores from this unit revealed clay-rich, variegated, dense, and in places pyritized zones and are suggestive of reduced/anoxic deposition presumably restricted from paludal to an aerially extensive lacustrine environment. This is often associated with saprolites displaying relict foliations, and evidence of kaolinitization and chloritization. Weathering of the parent rock, consisting mostly of schists, pegmatites, granites, schistose-gneiss, and marble of late Proterozoic to early Cambrian age, has apparently contributed to the development of the saprolitic units. The Grenville rocks (late Proterozoic) form the basement for all of New York State and lie buried unexposed under the younger rocks, over most of the state. However, they are exposed at places in the southeastern New York State, particularly in the Hudson Highlands. Evidences of extensive weathering of crystalline basement rock have been suggested by many researchers and generally linked with bedrock heterogeneity, structural weakness, degree of alteration, and lowering of sealevel associated with past glacial episode (Pleistocene Glaciation). Present day Hudson River Canyon is one of the primary examples of being largely affected by lowering sealevel due to glacial episode. Lowering sealevel in response to glacial episode contributed to subsequent drop in baselevel resulting in rapid downcutting and forming incised deep valleys, which were eventually filled in by younger sediments [5], [11], & [12]. Correlation of this clayey horizon with similar sedimentological characteristics is perhaps indicative of Raritan Clay (Upper Cretaceous) which is locally known to be associated with the laterally extensive Cretaceous aquifer called Llyod sand [11] & [12].   The Raritan unit is a relatively impermeable confining unit. Locally it is of lenticular type, with admixtures of sand and gravel displaying moderate to high permeability. Vertical hydraulic conductivity is 0.001 ft/d. Yields are as much as 2,000 gal/min to individual wells and have been recorded elsewhere. Specific capacities are as high as 44 gal/min per foot of drawdown typically characterize this unit. There is some evidence of artesian pressure in some wells. Water is of good quality except for high iron content. Horizontal hydraulic conductivity is 35-75 ft/d. Horizontal to vertical anisotropy is 10:1. Specific storage is 1 x 10-6 per ft [9], [24], & [25].

ASTM D 4318 was used to determine Atterberg Limits for Liquid Limit (LI), Plastic Limit (PL), and Plasticity Index (PI) in order to assess the geotechnical properties of various layers from 30 feet extending to 135 feet (Figure 10A, 10B, and 10C) considering their direct bearing with settling of foundation or consolidation factor [26] & [27]. Plasticity index displayed a general decreasing trend from being 19 at depths 135 feet to 2 at depth 30 feet; whereas, Plastic limit decreased from 31 at 135 feet to 14 at depth 30 feet. Liquid limit displayed a similar trend with 50 within samples collected from 135 feet and gradually diminishing to 30 when reaching a depth of 30 feet.

An extensive weathered zone resembling saprolitic type was found to underlie the silty clay to clay layer and its thickness is variable from a maximum of 60 feet to a minimum of 20 feet (Figure 6 & Figure 7). An abnormal lateral variation of bedrock weathering can be attributed to the mechanical strength of the crystalline rock and associated structural fabric. Another notable factor associated with extensive weathering of bedrock is the lowering sealevel that existed in this region during the last ice age (Pleistocene Glaciation) which in turn caused rapid erosion and forming incised valleys into the bedrock due to lowering of baselevel as well. Soft, clayey weathered zone at top of the crystalline basement belonging to the late Proterozoic to early Cambrian rocks, as thick as 100 feet has been known to occur in this region. Most of the bedrock (late Proterozoic to early Cambrian) in this geologic setting was subjected to at least two major tectonic events namely the late Ordovician Taconic and late Devonian Acadian episodes. These events were manifested in complex deformation, crumpling, medium to high-grade metamorphism, jointing, and secondary mineralization. Also, the authors observed a pronounced gradation in terms of bedrock composition particularly associated with schists. Often it grades from muscovite-biotite-chlorite schist to garnetiferous-sillimanite schist reflecting variable degree of metamorphism and variation in composition of protoliths [3], [8] & [19].

Conclusions

Several key sedimentological aspects such as association of compressible organic layer and silty clay to clayey layer at a depth reaching 30 feet must be considered as an important geoengineering challenge since any foundation design involving these two shallow layers will pose a threat to the stability of the foundation. Based on very low N value (between 5 and 12) determined by SPT (Standard Penetration Test) and compressible nature of the current upper ground horizons (-10 to -30 feet), these were not considered to be sufficiently strong enough to withstand the required loadings estimated at near 1200kips for some locations [13], [14], [15], & [24]. Calculation of Atterberg Limits including Liquid Limit, Plastic Limit, and Plasticity Index for organic-rich clayey layer provided very highly plastic designation (Liquid Limit ranging between 70 to 85%) and raised serious question as to the stability of foundation on organic and primarily cohesive clayey layer (Figure 10A, Figure 10B, and Figure 10C). Considering very highly plastic nature (LL being 70-85%) of this cohesive organic-rich clay layer, a serious dewatering phase can be envisioned during the construction phase and interference with high groundwater table, which is apparently in existence very close to the site, certainly will create a major problem. The foundation support system will therefore be established in the till comprising thick, primarily non-cohesive sandy horizon and registering N value between 40 and 55. Liquid Limit (25 to 30; low plasticity) and Plastic Limit (mostly confined to 20) associated with sandy unit (Figure 10A through Figure 10C) further corroborates the notion of nearly homogeneous lithological nature of glacial sand with insignificant association of any dominant silty or clayey unit. However, in places small lenses of silty clay are known to occur due to the effect of degree of weathering involving bedrock. The other significant geoengineering aspect of this sandy layer is the lesser likelihood of large-scale dewatering issue due to piling and overlying weight. It is considered to be mechanically strong enough to withstand a load amounting to 1200kips (Figure 13). A system of piles is planned to be used for foundation support. The placement of the piles may either be in clusters at each column location or through a distribution of piles over the site with rigid slabs and grade beams used to distribute the heavy loads among the pile supports (Figure 13). Furthermore, considering the shallow water table in close proximity to this facility site, pilings or a deep foundation will intersect the groundwater table and a dewatering phase should be considered once the construction begins [16], [17], &

[25]. The significance of the current study is that it blends anthropogenic and soil data with sedimentology, regional geology and geoengineering parameters to assist the design and construction team to come up with the best engineering practice in order to ensure a stable foundation for the proposed New York City Agency facility to be built in Maspeth. Finally, New York's overburden exhibits extreme variations in geotechnical parameters, as well as in the physical character of buried paleo-glacial and peri-glacial streams; these are a constant and ubiquitous challenge to construction. It is quite well-known that the depth of the overburden deposits (mainly Pleistocene glacial and few instances early Cretaceous lacustrine deposits) in close proximity to this site was largely constrained by the mechanical strength of the bedrock and inherent structural weaknesses associated with bedrock. Based on this consideration, weathered zones over the basement rocks (late Precambrian to early Cambrian) were found to vary extensively (50 feet to plus 250 feet) and certainly warranting detailed geoengineering consideration in order to arrive at a plausible and economically feasible construction design. Locked-in paleo-tectonic bedrock stresses have been observed and encountered during construction. Evidence has been found of pre-historic liquefaction and ground-rupture motions related to the major regional paleo-earthquakes. The presence of compressible soils, in pockets of glacio-lacustrine origin, has been encountered. Anthropogenic interference including uncontrolled dumping of unconsolidated fills and toxic wastes have altered the natural physiography. When undertaking any new and large-scale capital construction projects in this area, one must address anthropogenic fill and resculpturing of surface topography [18], [19], [20], [21], & [24]. Geoengineering data of the soil samples including ASTM classification, Atterberg limits, unconfined compressive strength, moisture content, organic constituents, and pH of the representative soil samples were evaluated prior to submitting a feasible design plan for foundation facility in this area. When construction, particularly of high rise buildings, is planned near estuaries in or around older municipalities, the probability of encountering buried estuary deposits should be considered because of its possible effects on the load bearing ability of foundation soils.

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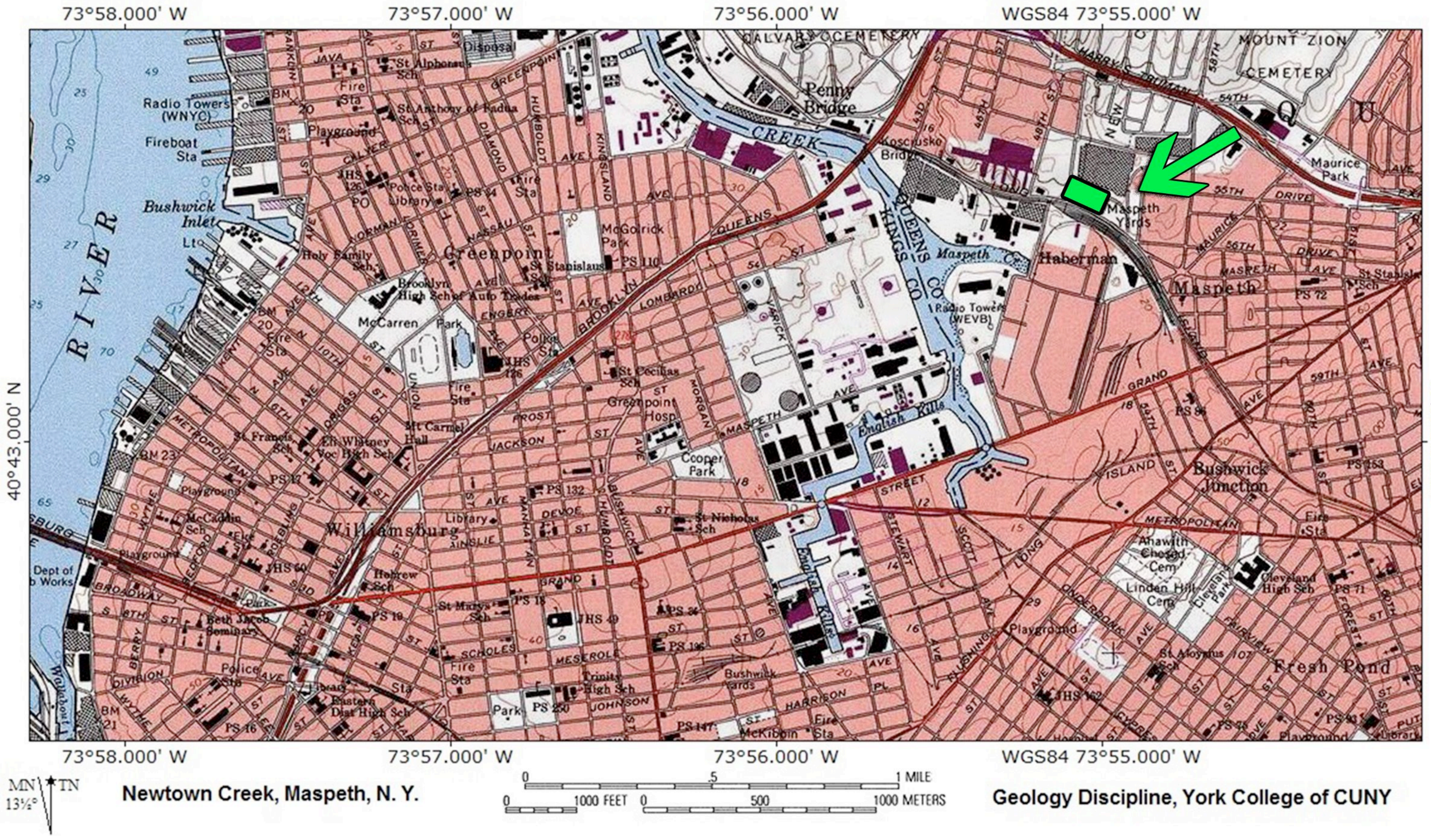


Fig. 1 Location map showing Maspeth, Queens, New York City.

Fig. 2 Newtown Creek.

Fig. 3 Shallow excavation showing fills comprising discarded construction materials.

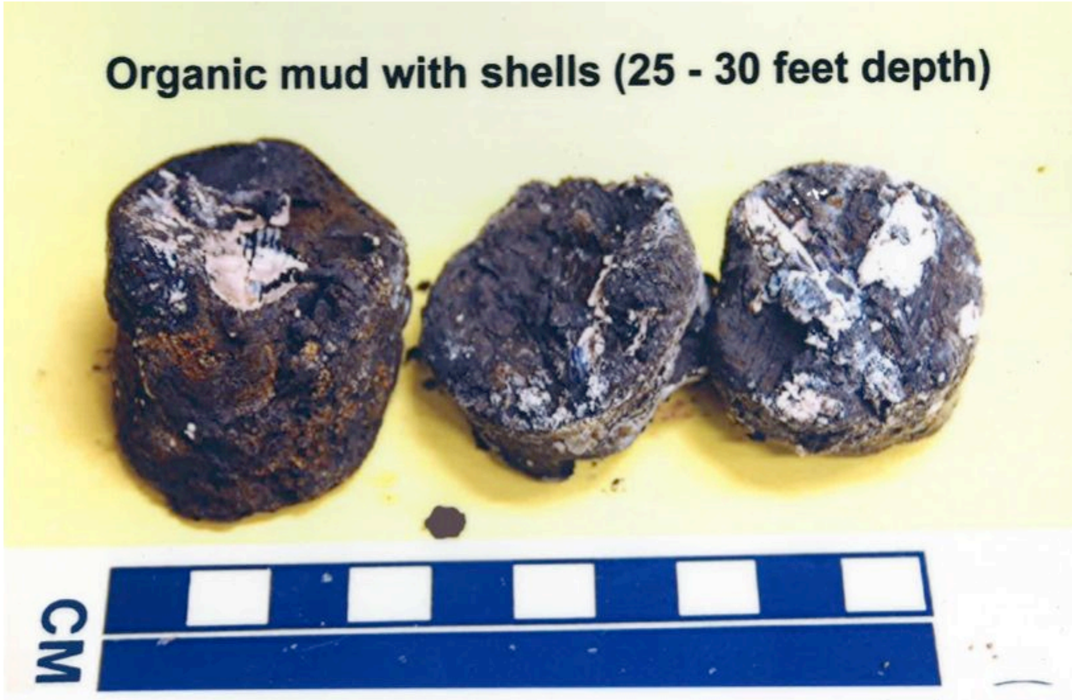


Fig. 4 Suggested buried estuary as evidenced by the presence of organic-rich, compressible peat-like materials with clam shells. (25 to 30 feet below sealevel).

Fig. 5 A close inspection of well-preserved clam shells within the peat-like materials.

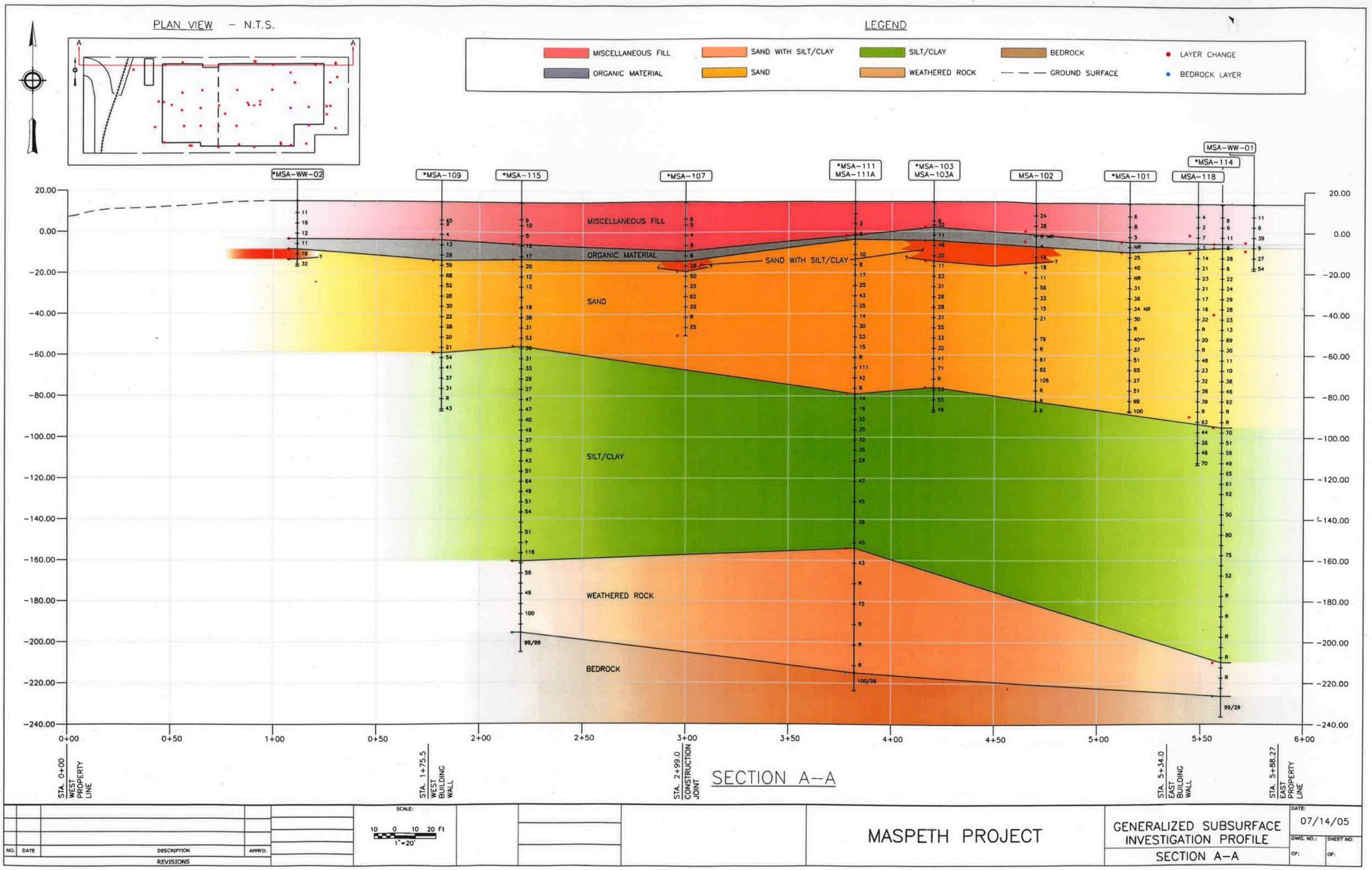


Fig. 6 Generalized subsurface investigation profile showing bore holes and encountered fills and dominant sedimentary rock types. Cross-section is drawn along A-A". Notice Organic-rich, highly compressible layer around -10 feet.

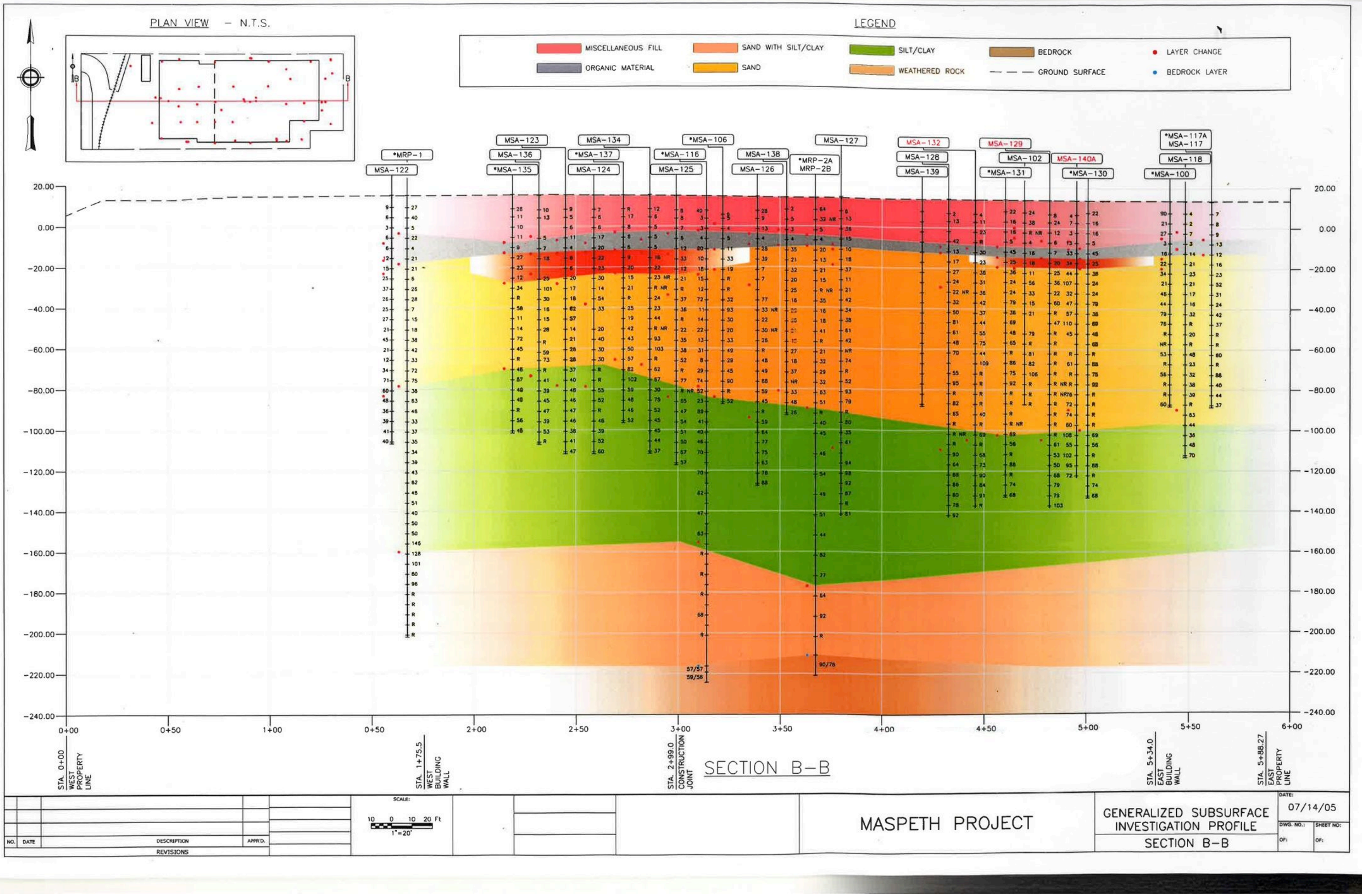
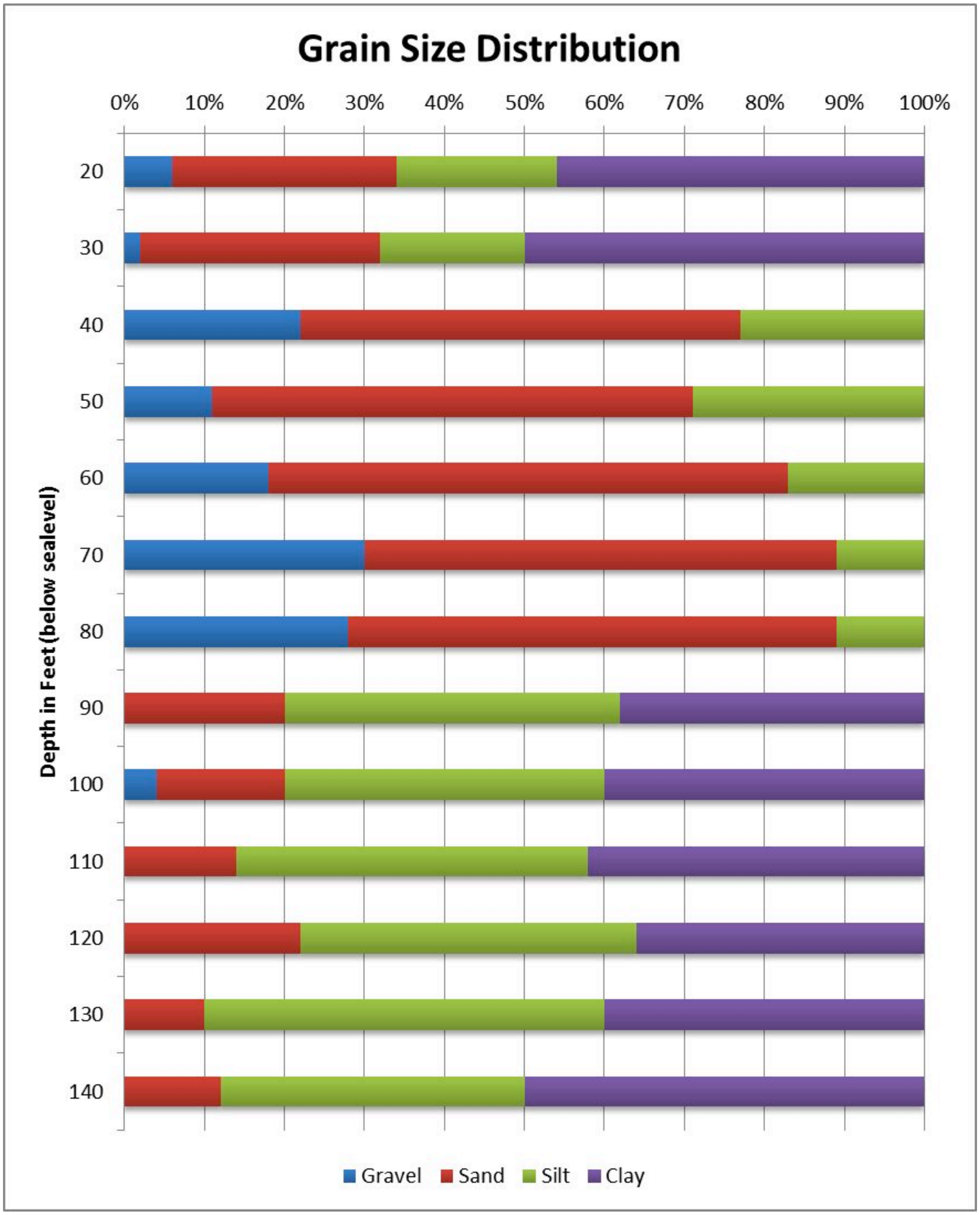


Fig. 7 Cross-section is drawn along B-B”. Representing additional bore holes and depth of the solid bedrock was encountered around -275 feet.

Fig. 8 Major lithologic unit above the solid bedrock is dominatly composed of variegated, moderately to highly compact silty clay; often recording higher N or SPT counts.

Fig. 9 An overall grain size analysis involving representative samples showing the distribution of gravel-sand-silt-clay with depth (- 20 to – 140 feet). Hydrometer tecnique was used to determine silt and clay fraction. Notice a general decrease of gravel and sand from – 90 to -140 feet.



Boring	Depth in Feet (below sealevel)	Measured Sediment Core Recovery (%)	UCT (unconfined compressive test, measured in tons per square feet)	Vane Shear Test (measured in tsf)	N (standard penetration test)
MSA126	115	95	4.5	1.25	64
	120	100	4	1.08	77
	125	100	3.6	2.5	75
	130	100	3.83	0.8	63
	135	100	4.5	0.4	78
	140	100	4	0.38	88
MSA127	125	100	4.01	0.93	68
	135	90	4.5	0.87	98
	140	100	4.5	0.78	92
	145	95	4.43	0.94	87
	155	100	4.08	0.82	81
MSA128	125	92	1.2	0.41	90
	130	85	4.13	0.84	64
	135	90	4.07	1.03	88
	140	100	4.5	0.7	86
	145	100	3.23	0.4	80
	150	100	4.26	0.82	78
	155	92	4.5	0.83	72
MSA129	120	85	2.77	0.53	61
	125	100	3.87	0.9	53
	130	80	3.9	0.98	50
	135	82	4.1	0.64	68
	140	100	4.5	0.34	79
	145	100	4.2	0.57	79
	150	95	4.01	0.36	103
MSA130	120	47	3.9	0.6	52
	130	75	3.5	0.85	74
	135	85	4.5	0.57	79
	140	75	4.25	0.65	61
	145	85	3.8	0.85	75
MSA131	115	90	3.3	0.8	69
	120	95	3.3	0.75	56
	125	70	3.3	0.78	55
	130	75	4.2	0.82	88
	135	62	4.5	0.7	77
	140	77	4.2	0.6	74
	145	85	4.3	0.75	68

Table 1 Representative borehole data displaying Recovery (in %), Unconfined Compressive Test (UCT), Vane Shear Test (VCT), and Standard Penetration Test (N or blow counts) belonging to the silty clay layer underlying the glacial sand. Weight of the thicker glacial sandy horizon above exerted pressure and caused greater compaction and subsequent increase in blow counts (N). Depth in feet (below sealevel).

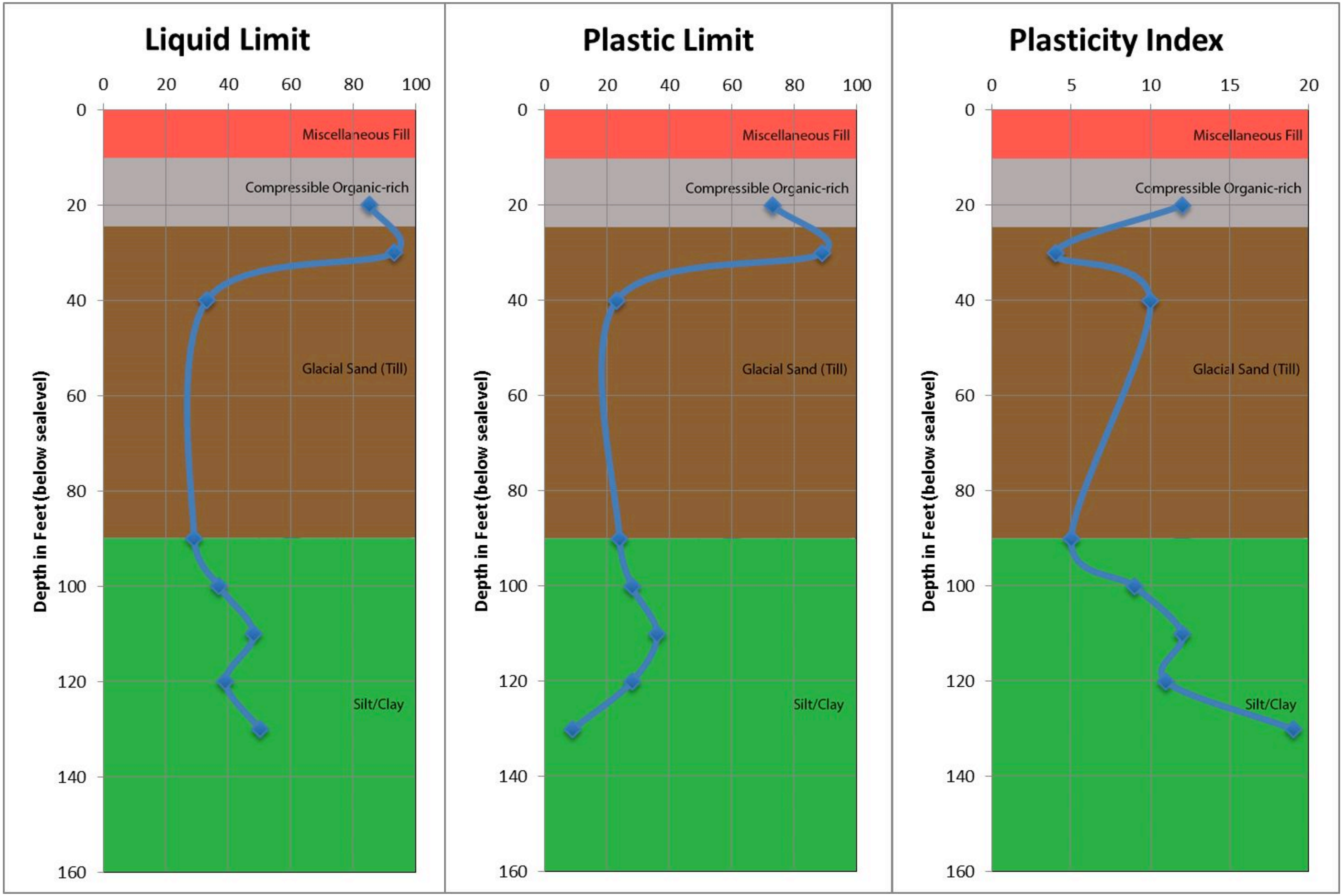


Fig. 10A Liquid Limits were calculated for organic-rich clay, silty clay, and glacial sand. Notice higher Liquid Limit (greater than 85; very highly plastic) for Organic-rich zone below the Miscellaneous Fill. Liquid Limit for Glacial Sand is around 30 (low plasticity).

Fig. 10B Plastic Limit showing greater number for Organic-rich zone located around -10 to -25 feet below the Miscellaneous Fill.

Fig. 10C Plasticity Index markedly varied being higher in Organic-rich zone compared to Glacial Sand.

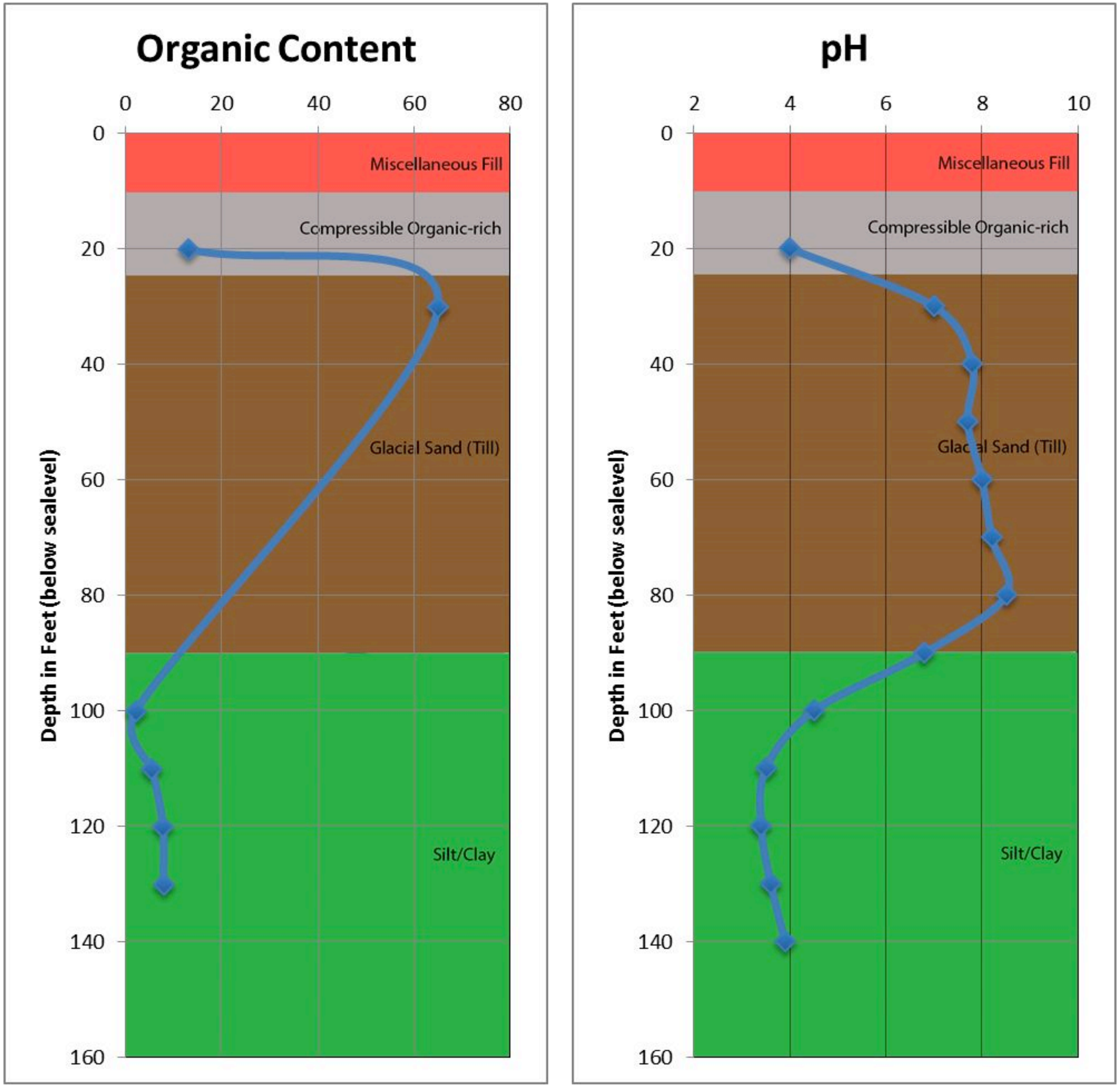


Fig. 11A The amount of organic content registered a higher number in Organic zone and displayed a dramatic decline within the Glacial Till.
Fig. 11B Measured pH values indicated acidic setting within the Organic-rich zone followed by being slightly alkaline with respect to Glacial Sand and becoming acidic within the Silty Clay unit encountered below – 90 feet.

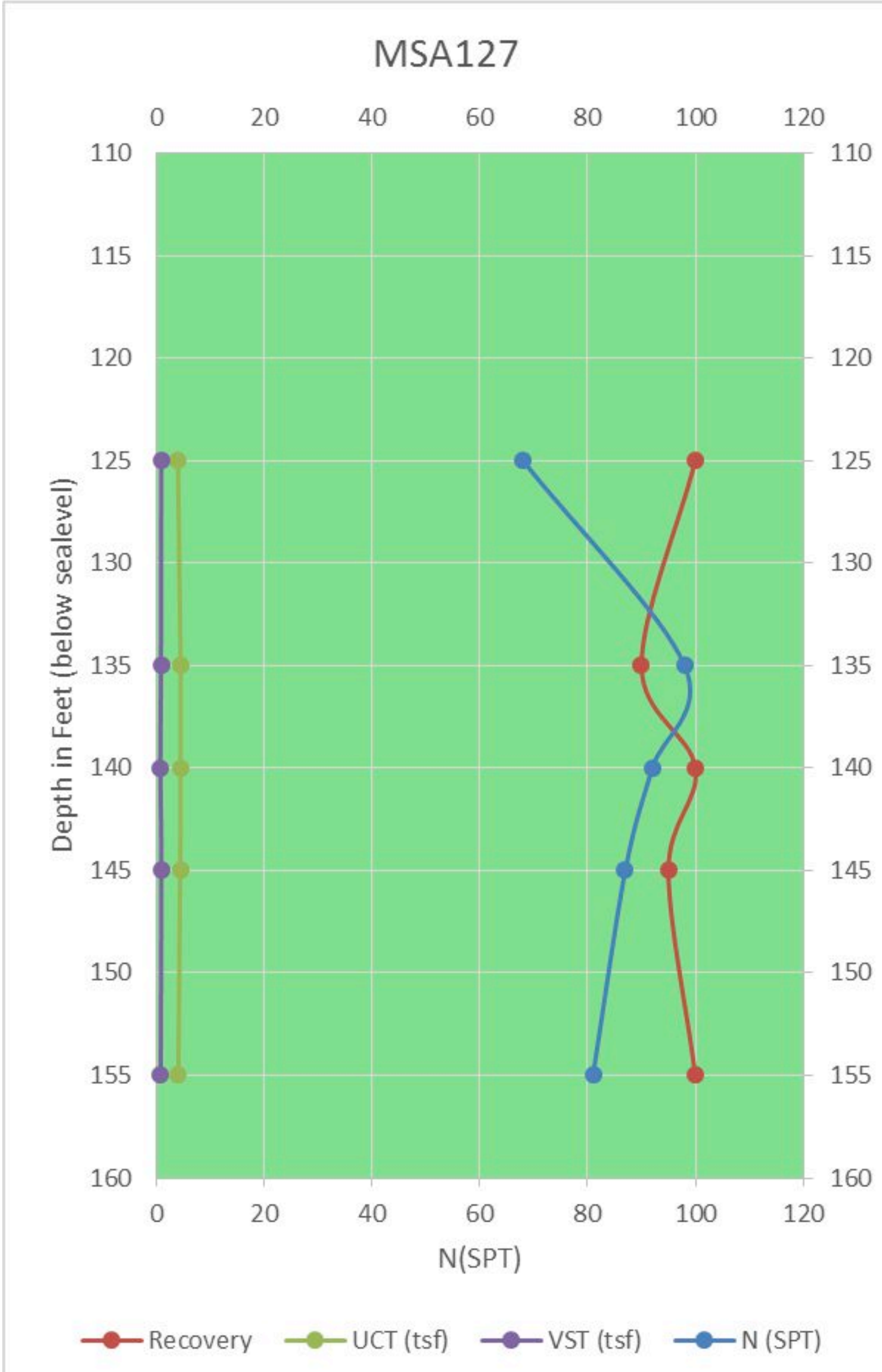


Fig. 12 A summary plot showing distribution of Recovery % (based on 2 feet of coring), UCT (unconfined compressive test, measured in tons per square feet), Vane Shear Test and N or SPT (standard penetration test or blow counts) conducted on Silty Clay layer below the Glacial Sand. Notice higher N or SPT for Silty Clay from – 135 feet suggesting more compaction and dewatering phenomena. Depth in feet (below sealevel).

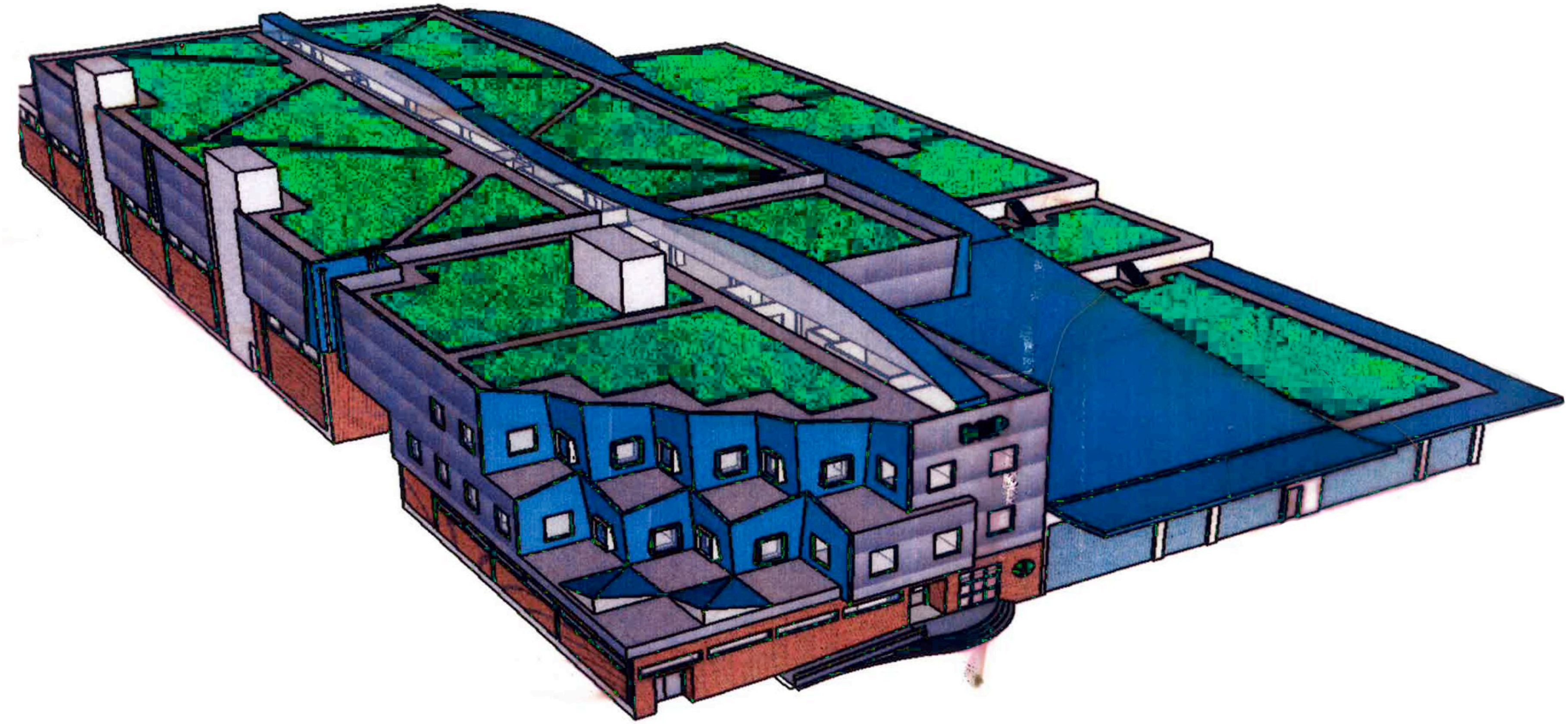


Fig. 13 It is proposed to use the above architectural design plan for construction based on subsurface conditions. Foundation needs to be on Glacial Sand located below the compressible Organic layer to avoid structural failure.