SURFICIAL GEOLOGY OF THE
BOSTON BASIN, MA.

by

MARTIN HAWKES,


Submitted in Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE
IN CIVIL ENGINEERING
at the
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(C)Massachusetts Institute of Technology.

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Submitted to the department of Civil Engineering on January 23, 1987 in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

ABSTRACT

A summary of the present state of knowledge concerning the history of the natural surficial deposits within the Boston basin is presented. Correlations between different assumptions concerning the pleistocene history of the basin are derived.

A method is developed to store in digital form the borehole descriptions published by the Boston Society of Civil Engineers. The method is based on the database operations contained in the software package Lotus 1-2-3.

A method is also developed which uses the borehole database to generate a comprehensive system of intersecting soil profiles for the Boston basin. The soil profiles are presented and summarized with respect to the assumed geologic history of the basin.

The engineering properties of the surficial deposits are not available for many locations within the basin. The borehole database and the soil profiles presented in this thesis will enable the development of criteria based on geology for the extrapolation of engineering properties to these locations.

Thesis Supervisor: Dr. Herbert H. Einstein
Professor of Civil Engineering.
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The author acknowledges with gratitude the valuable comments, encouragement and supervision provided by Professor Herbert Einstein during the course of our many meetings. It has also been a pleasure to work under his guidance.

The author also wishes to acknowledge the United States Geological Survey for providing the funds for this research.

Most of all the author would like to express his gratitude to his wife, Elizabeth, who has produced the cups of tea and the deadline necessary for the completion of this thesis. For this reason I dedicate every page and every figure of this thesis to Elizabeth.
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CHAPTER 1

INTRODUCTION

PURPOSE AND SCOPE

This report is concerned with surficial geology of the Boston basin in eastern Massachusetts. The report is the first in a series of reports for the project "Liquefaction Risk map of the Boston Area", Sponsored by the United States Geological Society (USGS) under grant number 14-08-0001-G1188.

The purposes of this report are:

1. to provide the geologic background required for the interpolation and extrapolation of engineering properties of soil in similar stratigraphic units within the Boston basin.

2. to develop a methodology for organizing and analysing the published borehole data.

3. to present the published borehole data for the Boston basin in a format in which the stratigraphy can be readily identified.

Almost the entire stratigraphy of the natural surficial deposits in the Boston basin can be attributed to the glaciation of the region during the Early and Late Wisconsin age. Chapter 2 reviews the currently available geologic information and summarizes the most probable series of events that may have led to the basin's complex stratigraphy.

The many boreholes that have resulted from subsoil investigations for construction in the City of Boston and its environs have been compiled by the
Boston Society of Civil Engineers (BSCE). Chapter 3 presents a methodology for the development of a computer database to store and manage the borehole records. The database has been used to generate a series of subsoil profiles from which the stratigraphy can be readily obtained. A number of profiles for the Boston Basin are presented in chapter 4 and are summarized in chapter 5.

BACKGROUND

This study is a portion of a larger study which is concerned with the development of a liquefaction susceptibility map for the Boston basin area. Liquefaction occurs in saturated, cohesionless soils during earthquake loading and can cause damaging ground deformations. The approach to be followed in determining the liquefaction potential is to determine the liquefaction opportunity and the liquefaction susceptibility and then to combine this information to yield a probabilistic assessment of the liquefaction potential.

Liquefaction opportunity is a measure of the seismicity of the area and considers factors such as the distance from the source, attenuation of the seismic waves with distance, and modifications for local conditions. The assessment of liquefaction opportunity is not discussed any further in this report.

Liquefaction susceptibility is a measure of the relative likelihood of the subsurface materials to liquefy during seismic shaking. The liquefaction susceptibility will be governed by the mechanical properties of the soils at a given location. Relevant properties are grain size distribution, soil fabric, relative density and depth below the water table. The liquefaction
susceptibility map will consist of zone boundaries that enclose materials that are similar in terms of these mechanical properties. In some locations within the basin the available data are insufficient to allow the zone boundaries to be drawn with certainty. It is therefore necessary to develop other criteria to allow one to extrapolate the available data to other locations throughout the basin.

Extrapolation of the available data is to be accomplished by reference to geology in the case of the natural soils and to historical information in the case of artificial fills. Extrapolation on the basis of geology assumes that materials that are similar in their composition and mode of deposition will also have similar mechanical behavior. A similar argument can be made for the fills where the factors may be age, rate of filling, mode of deposition and type of fill.

This report summarizes the geology of the Boston basin with the goal of identifying areas with similar geology. The information contained in this report will form the basis for the geologic extrapolations that will be required in order to develop the liquefaction susceptibility map for the Boston basin.

A parallel report (Ty, 1987) treats the fills which make up a large portion of the near surface deposits in the Boston basin.
CHAPTER 2

FRAMEWORK FOR THE GEOLOGICAL INTERPRETATION OF SURFICIAL DEPOSITS IN THE BOSTON BASIN, MA.

INTRODUCTION

The goal of this chapter is not to present any new findings or interpretations but to summarize work which has been done by others and bring to light any of the discrepancies which are still unresolved. The Boston area has undergone many stages of geological evolution leading to an extremely complex local stratigraphy. A typical geological paper seems to consists of a set of observations followed by an interpretation of the observations in the light of the writers previous experience. In this chapter the observations have been separated as much as possible from the many geological interpretations. The goal is to produce a comprehensive set of facts which can be used as a framework for future geologic interpretations.

The reader is first familiarized with the basin through a discussion of the topography. A brief description of the geology of the bedrock is then presented. This is followed by a discussion of the late glacial ocean levels, which play an important role in the deposition of surficial deposits within the basin both during the glacial and post glacial times. The surficial geology is then presented. For the bedrock and surficial geology sections the observational aspects are presented in isolation from the interpretations. The interpretations are presented last.
The glacial stratigraphy presented in this chapter is based largely on the observations of C. Kaye (1982). As the title of the chapter indicates, this stratigraphy is presented as a framework within which to interpret the surficial deposits of the basin. As the reader will find, not all the interpretations of glacial deposition in the basin are in agreement with the entire framework presented.

**TOPOGRAPHY**

The Boston Basin, is the low lying near coastal area bound on the north and south by the higher regions of the Middlesex Fells and the Blue Hills respectively as illustrated in figure 2.1. The borders of the basin are roughly defined by the North Border fault to the north and the Mt. Hope and Blue Hills faults to the south. The main drainage of the Basin are the Charles and Mystic Rivers which merge to form the Inner Harbor. The relief of the Basin is rarely greater than 15 m. except for several drumlins which reach elevations up to 60 m. The drumlins are randomly located throughout the basin and the harbor, and appear to bear no general relationship to the underlying bedrock.

The main geologic factors which control the topography of the basin include the bedrock type and orogeny, surface drainage prior to glaciation, erosion prior to glaciation, various stages of the glaciation and deglaciation, surface drainage after glaciation and coastal erosion and deposition. The basin's general geomorphology can be attributed to the Ordovician and Permian orogenies. Erosion of the preglacial surface was mainly due to rivers winding their way across the surface. The drainage was controlled by the resistance of the rocks to erosion.
and the level of the sea with respect to the land surface. During the glaciation of the region the forces between the onshore and the offshore ice lobes would have a large effect on the direction of ice flow within the basin. The level of the ocean controlled the impact of the ice flow on the existing topography and also the deposition of the glacially related material. The surficial topography of the Boston Basin has been complicated by local fluctuations in the ice front leading to a complex system of sub and supraglacial deposits, outwash plains, eskers, drumlins and kettle holes. Many of the landforms associated with widespread glacial phenomena may be anticipated along with the complications associated with trying to characterize them into a comprehensive set of events.

The topography of the basin has been greatly modified in recent years by the presence of man. Many of the hills have been cut down to use as fill to reclaim the mud flats and salt marshes that used to abound in the basin.

BEDROCK

As this chapter is primarily concerned with the surficial deposits in the Boston basin only a summary of the bedrock geology will be given.

The Boston Basin is a graben type structure consisting of wedge shaped, down faulted metamorphosed sedimentary and volcanic rock flanked by various granitic rocks. The weakly metamorphosed sedimentary rocks of the Basin can be divided into three main facies: coarse grained (conglomerate and sandstone), fine grained (argillite) and a mixed facies consisting of maroon and green tuffaceous siltstone and sandstone. These formations are known locally as: the Roxbury conglomerate (Puddingstone), the Squantum tillite (Dorchester member) and the
Cambridge argillite (Cambridge slate) in stratigraphic order. A large scale bedrock geology map of northeastern Massachusetts (after Skehan, 1979) is presented in figure 2.2. Figure 2.3 presents a more detailed (smaller scale) map of the bedrock geology of the Boston basin (after Billings, 1976). The ages of the sedimentary rocks which comprise the Boston basin have long been a matter of conjecture. The different time scales presented in figure 2.2 after Skehan (1979) and figure 2.3 after Billings (1976) illustrate the differing opinions of two well known geologists regarding the age of the Boston Basin rocks. Billings, presumably of the opinion that the basin was an analogue of the nearby Norfolk and Naragansett Basins, dates the sedimentary rocks as Carboniferous in age. Kaye and Zartman (1980) and Lenk et Al. (1982) report more recent geological mapping of the basin including radiometric dating and the finding of microfossils in the argillite. This new evidence suggests that the entire basin ranges in age from the very late Precambrian to middle or late Cambrian. The time scale presented by Skehan (1979) figure 2.2(a) is therefore in agreement with recent findings.

Structure

The bedrock geologic map of the Boston area is shown in figures 2.2 and 2.3. Figure 2.5 presents a portion of a detailed bedrock map of central Boston presented by C. Kaye 1982. The bedrock structure sections presented in figure 2.4 illustrate the complex bedrock structure of the Boston basin formed by folding and faulting within the basin. Figures 2.4 (a) through (d) also show various interpretations of the bedrock structure of the basin. The entire rock formation of the Basin plunges easterly (see figure 2.4(d) ). The Basin is deformed by compression into roughly east-west trending folds which are
overturned to the south (see figure 2.4(a), (b) & (c) ). Faulting has resulted in a shingle-block structure, these blocks are traversed by occasional normal faults. Furthermore there is a extensive network of dikes and sills penetrating all the rocks these range in width from a few cm to 50 m.

**Bedrock Surface**

Figure 2.6 shows shows contours on the surface of the bedrock in Boston (after C.A.Kaye, 1982). From consideration of bedrock contours it seems probable that a continuous ridge of rock passes beneath the present Charles river north and northwest of Beacon Hill. It has been suggested (Crosby, W.O 1903; LaForge, 1932; Chute, 1959; Upson and Spencer, 1969) that the preglacial Charles river valley followed the deep southeast trending trough, which passes under Andrew Square in South Boston then out into Dorchester Bay (see figure 2.6). The gorge at the mouth of the preglacial Charles is from 100 to 200 feet deep (Upson & Spencer, 1969). Kaye (1982) has pointed out that offshore seismic profiling has shown that this valley turns south and eventually ends in a cul-de-sac, thereby suggesting this feature may not be a buried river valley as presumed. A similar deepened river valley has been found beneath the Mystic Lakes- Fresh Pond area (Chute, 1959). Figure 2.7 presents a sketch map showing the locations of buried bedrock valleys in the Boston area (after Upson & Spencer, 1969).

The controlling factor in the bedrock topography is the rock hardness, integrity, and the resistance to glacial ice forces. The drift-bedrock interface may be transitional grading through weathered rock or may be distinct depending on the above listed rock properties prior to glaciation. Large blocks and slabs of the bedrock may have in places been removed in mass from what is normally
termed the bedrock surface by large glacial drag forces. These blocks may have been transported away or may now be suspended in the overlying till. The till/rock interface has been found to be in places highly permeable.

**Soft-Rock Alteration**

Weathering by the process of kaolinization has in many places altered the normally hard Basin bedrock into a whitish plastic clay. This alteration was first noted in the Cambridge Argillite which lies beneath MIT in East Cambridge but since then has been observed in many places throughout the Basin in all types of sedimentary rocks. The weathering may prefer certain stratigraphic beds and fault zones although this has not been confirmed. The effect of the weathering on the rock structure varies as one would expect with degree of weathering. The origin of the soft-rock alteration is at present conjectural.

**Orogeny of the Boston Basin**

Although the following description of the orogeny of the Boston Basin will probably always remain conjectural it does offer an enlightening view.

The Squantum formations of the Boston Basin were formed from the detritus eroded from the surrounding highlands and fault scarps during the late Precambrian to middle or late Cambrian (C.A.Kaye 1982). Volcanic activity was widespread at this time and accounts for the volcanic rock formations which surround most of the Basin. During the Permian time the strata of the Basin were subjected to strong compressive forces from the south (M. Billings 1929). These forces resulted in the gentle folding of the strata. As the compressive forces increased faults created a shingle-block structure in the southern parts of the
Basin. The central part developed a broad easterly plunging anticline and the northern portion developed broad open folds with occasional thrust faults. At this time the maximum thrust was located south-west of Boston on the north-east end of a tectonic arc which migrated north-west creating north-south tear faults (M. Billings 1929). It has been suggested (C.Kaye 1982) that the forces causing the major folding and faulting in the Basin were the result of plate-collision and subduction in the Ordovician and the Appalachian (Permian) orogeny. The compressive force acting at a lower depth then resulted in the rotation of the shingle block structures in the Basin. Finally in the Triassic-Jurassic time the region was subjected to tensional forces and the normal faults were created.

It has been postulated (Clapp, F.G. 1901) that during the Cretaceous period the land was several hundred feet lower than at present, the sea eroded the land and deposited sediments forming a Cretaceous peneplain. At the close of the Cretaceous period the land was lifted. Streams running off this new surface quickly eroded the unconsolidated Cretaceous sediments and eroded the solid rocks beneath. Near the close of the tertiary period a great elevation of the land occurred and resulted in the rivers cutting deep gorges in the bottom of their valleys. While the land was elevated the glacial epoch began which filled in all the existing river valleys with surficial deposits through which the rivers have had to readjust their paths.
LATE GLACIAL OCEAN LEVELS

The level of the sea can have an apparent change due to up or downwarping of the earth's crust caused by tectonic mechanisms and by changes in loading from the sea, ice, rock or surficial deposits. There may also be rises and drops of the sea level relative to a fixed point mostly due to fluctuations of the amount of water stored in the great ice caps. The latter changes in sea level are called eustatic changes, and affect all ocean shores on the Earth. During the glacial periods sea level changes due to loading and eustatic changes were occurring simultaneously in New England resulting in what has been termed the relative sea level change. The resulting sea level changes during the post glacial period along the eastern Massachusetts coast have been studied by Kaye and Barghoorn (1964) by considering the level and carbon dates of silt and peat deposits. The general trend observed these studies may be summarized as follows:

According to Kaye (1982) at the end of the glacial epoch (14-13,000 years B.P.) the sea reached its high altitude of 16 m with respect to present sea level. The sea level then started dropping and reached a low of about -23 m about 10,500 years B.P. After an interval of relative sea-level stability that lasted approximately 2,000 years, sea level began a slow rise to its present level.

Kenney (1964) summarizes data from Europe and North America, and establishes an internally consistent sea level and past glacial crustal movements plot. Figure 2.8 summarizes the sea-level and post-glacial crustal movements in the Boston area. The figure shows a relative sea level drop from +23 m to -31 m 12,000 years B.P. and a further oscillation, up to -8 m, and down to -18 m about 11,000 years B.P.. Note that there are some contradictions between Kaye and Kenney.
Recent correlations by Stone and Borns (1986) indicate that parts of the glaciomarine "Boston Blue Clay" in Boston and beneath the Fresh Pond moraine may older than was once believed. This may change the interpretation of the relative sea levels presented above.

**SURFICIAL GEOLOGY**

The surficial geologic map for the Boston Basin is presented in figure 2.10. This figure is a "touched" up version of the hand drawn map presented by C.A.Kaye (1978). The features illustrated on this map will be discussed in detail in this section.

The stratigraphic sequence of the surficial deposits of New England can be attributed mainly to the last great ice advance over the region. This glaciation attributed to the Laurentide ice sheet has been correlated to the Wisconsinan stage in western North America. The extent of the last glaciation and direction of ice flow in New England is illustrated in figure 2.9 (after Stone & Borns, 1986). The direction of ice flow in the basin as indicated by drumlin orientations and rock striations suggest a predominant south-east orientation, although this is found to vary through an azimuth of about 60° indicating as many as 4 possible distinct and different ice flows. The effect of earlier glaciations in the Boston Basin has however been almost obliterated by the impact of the last of the great ice advances. Due to the complexity of the deposits of the last glaciation the problems associated with deciphering multiple glacial events in the Basin have been largely unsuccessful. The deposits in the Basin which include till, sand, gravel, silt, clay and peat, are interrelated to form a complicated puzzle which contains the geologic history of
the Basin.

**Landforms**

In this section the landforms that may be present in the Boston basin are discussed without much reference to where they may occur. In a later section of this chapter the presence of some of the landforms is discussed in more detail. Also later in this chapter an attempt is made to correlate the creation of the landforms with the glacially related events that are known to have occurred in the basin.

Figure 2.11 illustrates the principal deposits related to the retreat of the late Wisconsin glaciation. The figure shows that on the coast south of Boston there are glacio-lacustrine land-forms while to the north of Boston there are glacio-marine deposits. 20 miles south of Boston there is no evidence of the sea ever being higher than its present day stand. At Lynn, 15 miles north of Boston, there is evidence of a marine incursion up to +50 ft. msl. In Maine, there is evidence of marine incursion +120 ft. msl (Horner 1929, Crosby, I.B., and Lougee 1934). Lougee (1953) describes a wave of permanent uplift which progressed northward following the receding ice.

West of the Basin, there are signs of large glacial lakes which formed in the northwest sloping and ice blocked valleys. These lakes (Bourne, Neponset, Charles and Sudbury), drained from one to another or sometime coalesced. Released water rushed along the ice margin forming kame terraces and eventually drained through the Basin.
Due to the passage of ice through the lowlands of the Boston Basin we may expect the floor of the Boston Basin to be overlain by a *ground moraine* consisting of a greenish-gray to blue, well graded compact, unsorted generally non-stratified mixture of rock fragments and minerals of all sizes varying from cobbles to boulders with approximately 15% cohesive sandy clay and silt matrix. When weathered the till has an over-all rusty, buff color. The ground moraine may contain more pervious strata of sand and gravel resulting from the outwash deposits of subglacial streams. Because the ground moraine was in most places buried beneath glacial clay a short period of time after deposition, weathering is restricted largely to the drumlins and topographic highs.

The presence of a *drumlin field* in the Basin has long been recognized although the origin of the drumlins is still subject to debate. There are about 180 drumlins in the Boston Basin, the distribution of these drumlins can be seen in figure 2.10. Typically the drumlins consist of a till similar to that of the ground moraine. The drumlins are discontinuously stratified with thin layers (cm to m) of sandy, silty or gravelly till. From cliff exposures it has been observed that the drumlins exhibit a well defined layering which generally conforms to the drumlin shape (anticlinal). These layers consist of parallel partings, generally marked by very thin silty zones (Kaye 1967b). Many of the drumlins composed predominately of till have been found to rest directly on the bedrock surface and grade laterally into the extensive clay deposits. It is interesting to note that none are known to be resting on the clay, which indicates that the deposition of the clay postdates the formation of the drumlins.

Recent soil investigations have shown that some of the hills in the Basin may be
End moraines from glacial readvances in the Basin. (Kaye, 1982; Chute, 1959). These hills which are sketched in figure 2.10 apparently are comprised of the pile up of large plates of sand, gravel and clay with smaller amounts of till. It has been postulated that these materials may have been possibly transported englacially and deposited at the final termination of the readvance (Kaye 1976). According to Kaye (1976) the large hill on the Boston peninsula originally known as Trimont and now called Beacon Hill is no longer recognized as a drumlin but as part of a late glacial readvance end moraine. This later point however is still conjectural. End moraines present a highly variable and hence very complicated stratigraphic sequence as illustrated in figure 2.12 which is the cross section of the Beacon Hill end moraine as interpreted by C. Kaye (1976). This figure also illustrates some of the type of events that may have to be considered in creating a land form of this type.

In other areas of the Basin we may expect to find kame and kettle terrain consisting of gravel and medium coarse sand, well stratified but very irregular with cross bedding and lenses of finer material. These features are the result of deposits accumulating on the stagnant ice which filled the Basin during the deglaciation. Some of these deposits slumped as the ice melted forming an irregular surface. The kames typically grade into the till moraines, kame terraces and outwash plains. The kettle holes or low spots may contain irregular patches of Pleistocene lacustrine or recent alluvial deposits.

Eskers, although probably rare in the Basin may be buried under later deposits. These will consist of clean coarse gravely soil deposited in subglacial streams to form long winding ridges.
Hartshorn (1958) discusses the possibilities of flowtills as a possible landform when trying to interpret local areas of till over sand and gravel. Ablation moraine, formed on the surface of the retreating ice sheet is almost identical to superglacial till, and when saturated from the melting ice it will flow down hill as a mudslide spreading out over the outwash deposits.

Material washed out from the glaciers as they withdrew was deposited in large outwash plains throughout the Boston Basin. These will consist of delta material deposited in lakes or brackish water and of alluvial fans where the soil is deposited on the land. The deposits will typically contain fine gravel, sand and silt. Boulders will be rare in these bedded deposits.

As the glaciers withdrew the meltwaters deposited lacustrine and marine deposits, consisting of fine sand, silt and clay which have had chance to settle out in the calmer environment of larger water bodies which occupied the Basin. These will occasionally contain peat. The coarser deposits will generally consist of a medium compact to compact gray well graded gravelly sand; the finer outwash which is found to great thickness throughout the Boston basin consists of a silty clay of medium plasticity which is blue-gray to an olive-green in color.

More recent alluvial deposits are to be found in the Basin ranging in thickness from a few cm to 2 m. These consist of flood plain deposits of sand and silt or swamp and marsh deposits of silt, muck and fresh water peat. The latter are more extensive.
Recent marine deposits consisting of wave formed beaches of sand and gravel, and tidal marshes of silt muck and salt marsh peat are also to be found within the Basin. The silt varies from a non-plastic silty fine sand to a plastic peaty clayey silt with shells.

The final chapter of the stratigraphy of the Basin has been the changing of the landforms by man. The surface of the Basin has been modified significantly by the cutting and filling of the hills and tidal plains that used to surround the peninsula, the dredging of the basins and the damming of the Charles River.

Pleistocene Stratigraphy

The main complications in deciphering of the glacial history of the Basin may be summarized as follows. There have been 2 (possibly 3) separate glacial events that have modified the deposits within the basin. There have been possibly 4 separate and distinct ice flow directions affecting the deposits. The sea level has been moving up and down relative to a fixed point. The different stratigraphic horizons are difficult to identify. There is a distinct lack of accurate dates with which to correlate the deposits with glacial activity elsewhere.

Considerable confusion seems to surround the terms 'boulderclay', 'till', 'moraine', or 'ground moraine' which tend to have been used indiscriminately for any poorly sorted mixture of gravel, sand and clay deposited by a glacier. In this paper the term 'till' will be used as a specific genetic definition and refers to 'an aggregate whose particles have been brought into contact by the
direct agency of glacial ice and which, though it may have undergone glacial-induced flow, has not been significantly disaggregated’ (Boulton, 1972).

The most complete (and most recent) summary of the glacial deposits which make up the Basin was given by C.Kaye (1982) who identified four sets of till coupled with glacial outwash, summarized as follows:

Till I: Overlies bedrock directly, this is one of the main components of the drumlins. This till is described as a greenish gray to slightly bluish gray to a light buff color where oxidized; compact fine sandy silt, with a little fine to coarse gravel, and a trace of clay with cobbles and boulders. (i.e. plastic well graded till). The deposit displays all the characteristics of a ground moraine. The "lower" till in the drumlins of the Boston Bay area contains the shells of numerous marine species indicating a non-glacial climate (Crosby & Ballard, 1894, Kaye, 1961). This soil may have dated from the Saganom age before being incorporated into the drumlins. Till I is described as Event 1: deposition of ground moraine by Chute (1959) and the Boston Till by Judson (1949). Based on amino acid racemization estimated (AARE) ages on shells from the Peddocks Island drumlin in the Boston bay, Stone & Borns correlate the "drumlin till" of the Boston basin with Montauk Till of Long Island and thus date the drumlins from an Early Wisconsin Glaciation (79 to 65,000 years B.P).

Outwash I: Coarse gravel interbedded sand and clay to well-bedded silty clay and silt. The Gravel delta on eastern part of Beacon hill as described by C.Kaye (1982) possibly belongs to this category. This deposit may be the finer layer which is found sheared and sandwiched between the till in drumlins.
Till II: Overlies outwash I, slightly more greenish and coarser than till I otherwise very similar. This is also a component of the drumlins in the basin.

Outwash II: Almost entirely sand and gravel. Sand is light-greenish, silty and compact. In Beacon Hill this sand is massive and intercalated with fine to coarse gravels. This deposit was also described by Kaye (1961) in the Boston Common garage excavation as Drift II, a brown, well oxidized coarse gravel, interbedded with lesser amounts of fine gravel and sand and relatively sparse layers of compact yellow silt. In the higher lands around the basin this outwash deposit may be related to the Event 2: Deposition of outwash 1*, kame terraces described by Chute (1959). The argillite gravel in much of this outwash shows signs of prolonged weathering, possibly from a long interstadial period that separated the early and late parts of the Wisconsin Glaciation (Kaye, 1982).

Till III: This is a discontinuous till observed in the eastern part of Beacon Hill as a thin (< 3m) bluish to greenish till overlying outwash II. With respect to the uncertain geologic history of the Beacon Hill deposits the inclusion of this deposit as a viable category throughout the basin is questionable.

Outwash III: This is the deposit known throughout the world as the Boston Blue Clay. The deposit consists of a well-stratified clay, little silt with

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Note: The Arabic and Roman numerals are used on purpose to distinguish between categorization by different authors.
occasional interbedded fine sand. Outwash III underlies most of the Boston lowlands and is up to 75 m thick. The clay grades into littoral sand then into fluvial sand and gravel when traced up the Charles river. The Boston Basin apparently was the main drainage trough for glacial meltwater, subsequently

Boston is now located at the apex of a submarine delta. The deposit correlates with the glacial lake sediments of Lake Hitchcock from the Connecticut valley ice lobe (see figure 2.9). Outwash III is probably related to Event 3: Deposition of Clay as described by Chute (1959).

Kaye (1982), describes three levels of "rhythmic" bedding as observed by offshore profiling of the clay beds beneath Boston Harbor. Rhythm 1 which consists of about 1 cm thick is alternating beds of clay and silt or laminated fine sand. Rhythm 2, about 50 cm represents an alternation of more clayey and more sandy deposition within the cycles of the first rhythm. The third rhythm consists of strong sand zones separated by more clayey material with a cycle of about 3-5 m in the upper part of the clay deposit. This structure is illustrated schematically in figure 2.13.

The upper surface of the clay is disturbed in places with thrust faulting and folding. An early description of the disturbance was given by Stodder (1852) when onserving the excavation of a cut in East Boston; "The drift deposit there consists of a layer of gravel with an undulating surface of uniform thickness, underlying a deposit of clay. At the place recently exposed cracks in the clay are seen from 6 to 3-4 inches width and some 15 feet deep, filled with the drift
overlying it. What was the origin of these cracks? ".

**Till IV:** Up to 10 m of till overlie the clay at the margins of Back Bay and between Fresh Pond and Harvard Square deposited by a local readvance of the ice called the Fresh Pond readvance. This deposit is described as Event 4: Fresh pond moraine and Outwash by Chute (1959) and Lexington Till by Judson (1949). Kaye (1961) correlated outwash gravels in the Commonwealth Garage excavation with poorly compacted Tills that are on the uplands surrounding the basin. Judson describes the Lexington Till as an ablation till that is widely distributed over the western and northern rim of the Boston basin and even possibly over much of southern New England. The later speculation however seems unlikely because the ice-marginal deposits and history of glacial lake deposits indicate a systematic northward retreat of the ice-lobe margins (Stone & Borns, 1986).

**Outwash IV:** This deposit consists of current bedded, fine to coarse sand, gravelly sand and occasional fine to medium gravel, usually underlain by the clay of outwash III. This deposit is described as Event 7: Outwash 4 deposition of large alluvial fan southward over clay by Chute (1959). The deposit is described as the Lexington Outwash by Judson (1949). Most of Cambridge is underlain by this outwash on a plain sloping towards the east. It is not well developed east of Back Bay. In the lower parts of the outwash there is a higher percentage shale fragments presumably split by ice action (Kaye, 1982). The outwash lies disconformably over the eroded and weathered surface of the Boston Blue Clay (Judson, 1949).

This description presents an extensive framework for the Pleistocene soil
stratigraphy that may be expected within the Basin. Not all the above Pleistocene deposits may be encountered at any one location but all the deposits encountered should fit somewhere into the above framework. Complicating the structure of this framework will be local effects such as gravel deltas on the lee side of drumlins, slumps, slides, local melting of stranded ice blocks etc. all of which will create large variations in the characteristic deposits. To make matters worse many of the deposits are very similar and without the highly detailed observations of a local geologist the different deposits can not be easily distinguished.

Postglacial stratigraphy

The advent of glaciation in geological time has been very recent and many of the associated landforms still remain in their near original condition. Erosion of the Pleistocene deposits has not yet advanced very far. The postglacial deposits include the reworked outwash III clay in the estuary systems of the lower Charles, Mystic and Malden rivers. Marine silts have been accumulating in the tidal estuaries that abound in the Basin. The postglacial clay is also found in the lowlands separating Fresh Pond and Spy Pond in North Cambridge. Studies for the new subway excavation (Red Line Extension Northwest) through this deposit have shown it to be highly sensitive and to have a higher natural water content than the older Outwash III clays. Alluvial deposits in the Basin consist of flood plain deposits of sand and silts along the borders of the river basins. Peat deposits in the Basin appear to have followed the advancing strand line of the rising sea (Judson 1949). These consist of fresh and salt-water facies.
Artificial fill

In the last 200 years the surface topography of the Basin has been changing rapidly due to the cuttings and fillings required for the expansion of the city of Boston. Many of the hills have been entirely removed, and the tidal basins entirely filled. Figure 2.10 depicts the strand line as it probably existed at the time of arrival of the Puritans, superposed on the modern topographic map of the city. Much of the early filling was by hand using horse drawn carts to haul the material, later steam shovel and trains were introduced in Boston and at the turn of the century the hydraulic dredge made an appearance in the Basin (refer to the parallel report by Ty for a more in depth discussion of chronology of artificial filling in the Boston basin).

GLACIAL HISTORY

Like the bedrock orogeny, the history of surficial deposition in the Boston Basin will probably always remain conjectural. The deposits from glacial events are very variable and the occurrence of substantial ice withdrawals and readvances in different directions within the basin has resulted in a very complex history of deposition, erosion and displacement. The number of glacial events which have resulted in the deposition of surficial soils in the Boston basin is still subject to debate. Kaye (1961), considered evidence for four advances dating from Kansan or Nebraskan to late Wisconsin each associated with a drift deposit. In a later paper (1982) Kaye still considers that there had to be four separate and distinct ice currents but has changed the chronology to range from Early to Late Wisconsin. Stone and Borns (1986) have attempted to correlate dates from the glacial deposits throughout New England to arrive at a regionally consistent
chronology of events. Their conclusions suggest two general glaciations dated Late and Early Wisconsin and possibly one local readvance after the late Wisconsin glaciation. The deposits in the terminal moraine of Long Island, N.Y. also suggest in addition to the above two glacial events the possibility of at least two earlier glaciations dated tentatively as early and late Illinoian age (Stone & Borns, 1986). One possible interpretation of the glacial history in the Boston basin is presented in table 2.1, while an alternative interpretation is shown in table 2.2. Unless noted elsewhere the correlations shown on these tables are very tentative. The following discussions will follow the sequence of events listed in tabel 2.1, however inconsistencies and other possible interpretations will be pointed out with proper reference to appropriate figures and tables.

The earliest deposits in the Boston basin which date from the Sangamon (79 to 132,000 years B.P.) (Stone & Borns, 1986) are located in the drumlins in the central and southern portions of the basin, and overlapping the southern but not the northern margin. The shells of 55 marine species have been identified in the "lower" till of these drumlins (Judson, 1949). The drumlins in which fossils have been found are indicated by asterisks in figure 2.10. Presumably these deposits were scraped up by glacial ice and incorporated in the resulting drumlins. Till I is the principal till from which the drumlins were formed. Till I is also the lodgement till from the general glaciation of the region. This till known elsewhere as the "lower till" or informally as the "drumlin till" has been correlated with the Montauk Till on Long Island (Schafer & Hartshorn, 1965; Stone & Borns, 1986) and is hence Early Wisconsin in age.
Table 2.1 shows the Till I correlated with Event 1 as described by Chute (1969), Boston Till described by Judson (1949) and the Glacial Till described by Aldrich (1970). This correlation is tentative. The ages shown in table 2.1 are based mostly on the opinion of C. Kaye (1982). Contrasting opinions are those of Chute, Aldrich and Judson. Chute (1969) is of the opinion that all the glacial deposits in the Mystic Lakes-Fresh Pond area were formed by the last ice sheet (late Wisconsin ?) that covered the area. Judson (1949) and Aldrich (1970) are also of the opinion that the till and the clay were formed during the last glaciation (late Wisconsin ?). Table 2.2 is essentially based on these interpretations. Another opinion is that of Stone and Boms (1986) which indicates two major tills, the "Lower Till" and the "Upper Till", deposited throughout eastern Massachusetts; this is also included in table 2.2. It is thus uncertain how many different lodgement tills exist in the basin. The ages and the correlations of the tills are uncertain due to difficulties in distinguishing the different tills.

Returning back to table 2.1, the origin of the next two deposits, Outwash I and Till II described by Kaye (1982) is unclear. Both of these deposits are probably associated with some local variations in ice movement within the Basin. As stated previously Kaye considers the foreset gravel delta in the eastern part of Beacon Hill as belonging to Outwash I. Till II is found in many of the drumlins and is identified as a distinct deposit in the Beacon Hill moraine by Kaye (1982).

The genetic origins of the drumlins are numerous, ranging from erosional to depositional forms of growth. As the drumlins in the Boston Basin are formed predominately of the same till which covers most of the bedrock, a depositional
mode of formation is indicated. There is however evidence that entire drumlins have undergone intense deformation after deposition, suggesting that the Boston drumlins were formed in at least two different ice currents (Kaye 1982). The shapes of the drumlins are then the result of glacial flow subsequent to their deposition. Bedrock striae indicate that the flow directions of the ice varied substantially in the basin. If the drumlins were initiated by accretion of basal debris in the initial stages of the glaciation, and the flow directions then varied, then the observations are what we would expect. Under these conditions the drumlins are a result of depositional and erosional stages (or post depositional deformation).

The retreat of the glacial ice from the south-eastern Massachusetts to just north of the Boston Basin resulted in the deposition of outwash II. This outwash described as Event 2 by Chute is represented by the kames and kame terraces of Mount Auburn Cemetery (Chute 1959). Most of the Basin at this time was probably still occupied by stagnant ice. The sands and gravels were deposited around these ice blocks and later slumped when the ice melted. The resulting stratigraphy can be highly variable. Some of the finer outwash may have settled out in the bodies of water that would have occupied the lowlands of the Basin. Outwash II shows signs of prolonged weathering suggesting an interstadial break in the glacial activity at this time. This would allow time for the erosion and redeposition of the preceding deposits and may account for the discontinuous nature of these deposits and confusion in identifying them in their correct stratigraphic position.

About 18,000(?) years ago the ice from the Late Wisconsin glaciation reached its
southern extreme limit in New England, as indicated by the glacial terminal moraines of Long Island, Martha's Vineyard and Nantucket Island (see figure 2.9). At this time the Cape Cod region was covered by three distinct ice lobes (see figure 2.9). The imbalances in movement and pressures within these lobes, particularly the onshore and offshore lobes is probably the cause of the highly variable ice flow directions in the Boston Basin. These flow directions as stated previously range from southerly to south-easterly and possibly south-westerly.

It would appear that Till III described by Kaye (1982) is the lodgement till from this glaciation. Kaye states that this till is missing in many excavations in the Boston Peninsula. Table 2.1 shows the correlation based on the assumption that the general lodgement till observed throughout the basin is the same as Till I described by Kaye. Table 2.2 presents the alternative opinion without the complicating factors of the multiple tills shown in table 2.1. Whether the till from the last glaciation is all from the Late Wisconsin stage or contains remnants from earlier glaciations is undetermined. The deposits of older ice sheets may exist particularly in the buried valleys and in the harbor drumlins.

About this time according to C.Kaye (1976) the glacier formed a pile up of Outwash I, Till II and Outwash II over an undeformed core of thick Till I and a large foreset delta of coarse gravel. This pile up is Beacon Hill. The deciphering of the geology of Beacon Hill, which for a long time was considered to be a drumlin, has provided the urban geologist with a challenging problem. The deviation of the deposits in Beacon Hill from the deposits of the remaining drumlins in the Basin was first noted by I.B. Crosby (1934) who described the hill as an "abnormally shaped drumlin or a drumlin crowned with kames". C. Kaye
who has probably had the opportunity to observe more foundation excavations for large buildings in the Boston Basin than anybody else, has written an excellent paper which summarizes his views on the geology of the Beacon Hill (Kaye 1976). It suffices to say that according to this paper the stratigraphy of the hill is extremely complex (see figure 2.12) and is probably best described as some form of end moraine, subglacial squeezing, or some other glacial or glaciotectonic process from an the advance or readvance of the ice in the early part of the Late Wisconsin glaciation.

As the ice melted from the Boston Basin, clay with some interbedded silt and fine sand (Outwash III) was deposited in the central area. This clay forms the bulk of the clay deposits in the Boston Basin. Although no fossil mollusks have been found in this clay the general consensus is that the clay was deposited in a marine environment. Shells of cold water fauna have been found in the clays at West Lynn, 9.6 km north of Boston. Dates from these fossils average 13,925 ± 300 yr B.P. (Kaye and Barghoorn, 1964). The absence of fossils at Boston is possibly due to low salinity (brackish) and excessive turbity of the water at the mouth of a major outwash river. At this time the sea was at its high altitude of 16 m above present sea level in Boston. The clays of this outwash are found up to altitudes of approximately 9 m BCB in Boston, 16 m BCB in Salem but rarely above sea level south of Boston (see figure 2.11).

As stated previously the upper surface of the clay is disturbed in places with thrust faulting and folding. Kaye (1982) describes another type of deformation that shows up on the offshore seismic profiles, "large", funnel-shaped downfolds that involve the entire thickness of clay and generally are 100-200 m across".
These structures represent some form of kettle hole formed around stagnant ice that must have been weighted to the bottom of the marine waters by englacial rock debris.

At an elevation of 9 m (i.e the level of the sea relative to the land at this time, see note 3 on figure 2.8) is a widespread erosional beach, consisting of undeformed beach sands which are also of Outwash III origin.

As the sea level relative to land began to drop from its high of approximately 50 ft above present sea level about 12,600 years B.P. ago due to the isostatic rise of the land surface as depicted in figure 2.8, the marine unit emerged from beneath the water. The outwash deposits were thus subject to erosion, deposition and oxidation. The upper 1-3 m of the clay in the Basin is generally oxidized as a result of this subaerial exposure.

In a last gasp the ice advanced over parts of the Boston Basin for the last time overriding the deposits below and depositing as much as 10 m of Till IV. This last readvance consisted of three separate ice lobes, the Charles River Lobe, Mystic Lakes-Fresh Pond Lobe, and Back Bay Lobe, which descended the valleys of the Charles River, Mystic Lakes-Fresh Pond area, and the Malden River (Kaye, 1982) (See end moraines depicted on figure 2.10 for location of the lobes). Each of these local readvances is associated with low morainic ridges, push structures, disturbances, and overconsolidation of the underlying deposits. Figure 2.10 depicts the end moraines from these readvances as interpreted by C. Kaye, 1978.

The Back Bay Lobe advanced down the Malden area and probably also involved ice
moving down the Charles River. This lobe stopped against the lower slope of Beacon Hill. Pushed ridges of clay were formed, as observed in excavations for the Boston Common parking garage (Kaye 1961). Powder House Hill (in the center of the Common) is interpreted as another push ridge as is the Boston Neck, the narrow clay isthmus that connected Boston to mainland in colonial times. West of Back Bay, Outwash III and older deposits have been observed to have been thrusted, folded and faulted (Kaye 1982).

The Charles River Lobe moved east along the Charles river valley and spread north over Cambridge to produce the morainic ridges which include Mount Auburn Cemetery, Harvard Observatory Hill, Shady Hill and Dana Hill. These hills consist of clay push ridges similar to those observed from the Back Bay Lobe.

The Mystic Lakes-Fresh Pond Lobe has been well documented by Chute (1959). Its moraine which encircles Fresh Pond on the south and south-west is composed of a clayey till scraped up by the glacier from the low lands to the north of the moraine. Lane (1928) observed 1.6-2.3 m of till overlying horizontally bedded sand and gravel and presents an excellent photograph in which the thrust faulting in the sand and gravels due to glacial overriding is clearly visible. These faults correlate with a direction of ice flow of about S30 E.

The glaciation was followed by a warmer climate during which the glacier retreated from the Boston area. The relative sea level rose rapidly from its low of approximately 95 feet below present level, 11,800 years B.P. (see figure 2.8). There followed a deposition of current-bedded, fine to coarse sand and
occasionally gravel (Outwash IV) *, while the clay was presumably being deposited further out in the bay. Outwash IV includes the deposition of kames, kame terraces, and outwash plains (described by Chute 1959 as Event 5 *: deposition of Outwash 3). Large, remnant ice blocks remained in the Basin located in the lowlands of the Charles downstream of Harvard University, Back Bay, and in the lowlands between Fresh Pond and the Mystic Lakes. An ice block still covered the site of Spy Pond (Chute 1959). In addition there were numerous smaller remaining bodies of ice to form kettle holes and kame terraces particularly in the Fresh Pond-Mystic Lakes area. This stage is described as the Lexington substage, sands and gravels by Judson (1949).

Following the deposition of Outwash IV as described above (Outwash 3 in Event 5 according to Chute), Chute (1959), describes a deposit * of clay with some interbedded sand and gravel (Event 6) spread over the lowland between the Fresh Pond moraine and the Mystic Lakes. This deposit reaches a thickness of about 50 feet, 0.2 miles northeast of Fresh Pond and is underlain by till. Chute considers that these clays must have been deposited before the ice blocks that occupied the basins of Fresh Pond, Little Pond, Spy Pond and the Mystic Lakes had melted. Chute (1959) wrote:

Evidence has been presented for the existence of clays of at least three different ages in the [Mystic Lakes-Fresh Pond area]. The oldest clay known in the area was deposited before the readvance of the ice that formed the moraine; next in age is the clay interbedded with Outwash 2 [deposited with the Event 4: formation of the Fresh Pond moraine] the youngest is the clay that underlies the surface north of the Fresh Pond moraine, which has been worked extensively for brick and pottery clay. All these

* For reconciliation of apparent inconsistencies in table 2.1 see comments on the following page.
clays are probably of marine or brackish-water origin and represent deposition which took place each time the ice retreated from the Boston basin. The readvance of the ice stopped clay deposition in the area of the ice lobe, but it was resumed again as soon as the ice had melted sufficiently for the water body to resupply the lowland.

The deposition of the clay of the sixth event came to an end when the water body covering the lowlands of the Fresh Pond area was drained.

In the Boston lowlands there is only one widespread deposit of clay (Outwash III), in the Mystic Lake-Fresh Pond area there are two widespread deposits of clay (Event 3 and Event 6). If all these clays are associated, it would imply that clay was being deposited in the lowlands during the Fresh Pond readvance. This implication seems not to be compatible with what is known about glacial mechanisms in which a readvancing glacier would have deposited increasingly coarser material in the lowlands; the deposit of Outwash III would have to contain outwash sands and gravels from the readvancing glacier which is not the case. For this reason it is uncertain if the youngest clay deposit described by Chute (Event 6) is associated with the clays deposited in central Boston and described in this report as Outwash III (see table 2.1).

To explain the apparent inconsistency between the events described by Chute and those observed in the Boston basin lowlands, Event 6 and Outwash III are considered to be separate deposits. The following hypothesis is presented as a possible scenario:

Outwash III and Event 3 clays are deposited throughout the Boston basin as the ice from the Late Wisconsin glaciation retreats from the Boston area. The ice then readvances into the Boston basin in three distinct lobes as described
previously in this report and as indicated in figure 2.10. During this readvance the Fresh Pond moraine is formed and Outwash IV, Lexington Substage Outwash, and Event 5 outwash is deposited throughout the basin. As the ice lobes retreated a separate body of water was formed bound to the south by the Fresh Pond moraine, to the east by the retreating Back Bay lobe and to the west by the higher land. It was in this separate water body that the clay of Event 6 was deposited while Outwash IV may have still have been deposited in the central basin region or glacial deposition may have ceased by this time. According to Chute (1969) the deposition of the clay of event 6 came to an end when the water body covering the lowlands of the Fresh Pond area was drained.

Finally Chute (1969) describes Event 7: Deposition of Outwash 4 as a deposit of sand and gravel in a large alluvial fan southward over the clay of Event 6. This deposit may be correlated with the last deposits of Outwash IV throughout the highlands surrounding the basin (the Lexington Substage, sands and gravels described by Judson, 1949). This deposit is considered part of the glacial sequence because it must have formed while the ice block that was located at Spy Pond was still present, or else the depression in the clay left by the melted block would have been filled with sands and gravels of Event 7.

**POSTGLACIAL HISTORY**

Approximately 11,000 years B.P., at the close of the last glaciation the sea level fell for the last time (see figure 2.8), possibly related to the Valders Glacial substage and the continued isostatic rebound. The remnant ice blocks of the basin continued to melt and the surrounding deposits slumped into the resulting voids. As the sea level dropped the deposits of Outwash IV and III...
became progressively exposed to erosion and weathering, first by waves then later by streams and subaerial erosion. (This would have been the second time since deposition that some of these deposits have emerged from the sea due to the relative sea level changes). Subbottom seismic profiles of the Boston Harbor clearly show the redeposited clay resting unconformably on the earlier deposits of clay (Kaye 1982). Erosion channels in the Clay deposits have been observed to a depth of -30 m (Crosby 1934) filled with Outwash IV. Kaye also postulates that it is this reworked clay deposit that was found to be highly sensitive in the excavation for the new Red Line extension of the subway in North Cambridge. It seems probable that the drainage of the area north of Fresh Pond at this time would be similar to that observed today, i.e north-eastely via the Alewife Brook into the Mystic River at the Medford-Arlington-Somerville border. This would have been the direction in which the sea would have receded from the north of Fresh Pond basin during the post glacial sea level decline. The drop in the relative level of the sea in the north of Fresh Bond area would give a possible explanation for the reworking of the clay in the area as postulated by Kaye or some other mechanism leading to a higher sensitivity.

The sea level reached its low point about 10,500 years ago exposing many of the outwash plains and terraces of the Boston Basin (see figure 2.8). Erosion continued and the poorly drained marsh lands began to collect postglacial organic deposits consisting of pond deposits and woody peat. Along the shore in the sheltered parts of the basin salt marshes flourished.

About 8,500 years B.P. the sea level began a long gradual increase to its present level. Marine silts rich in organics were deposited throughout the submerged portions of the Basin. The formation of a salt water peat kept pace
with the advancing sea, in places it has been destroyed by the action of waves. The salt water peat in places is separated from earlier deposits of fresh and salt water peats by the deposits of marine silts. The thickness of these deposits varies throughout the Basin from 0 to a maximum of 13 m but is generally less than 7 m.

Finally with the advent of modern man came the requirement for expansion and the lowlands of the Basin were drastically changed through the process of cutting down the hills to fill in the tidal basins. Figure 2.14 illustrates the strandline as it probably appeared in 1630 when the first puritans settled in the basin. The fill is thickest over former tidal basins such as the Back Bay where it averages 5 m and increases to as much as 9.5 m in places (Aldrich, 1970).

**SUMMARY**

The Boston Basin is a low lying sedimentary basin which lies in a coastal zone close to the margins of the Pleistocene ice sheets. It was repeatedly glaciated and deglaciated as the ice front fluctuated in a manner which is still conjectural.

The sea level was some 23 m higher after the last glaciation, and dropped thereafter before rising to the present day level (with a possible oscillation in between). Clay outwash was deposited during the seas high stand followed by outwash sands as the sea dropped, and peat and silt as the sea slowly rose to its present level.
The topography has been significantly altered by the expansion of the city of Boston.

As pointed out by Clifford Kaye (1976B);

"The geologic picture would have been much simpler and easier to arrange in logical sequence if it were not for the overabundance of data - a realization that raises the question of just how much data is sufficient, or is there no limit to the clues necessary for the unravelling of the geologic past?"

This chapter presented an overview of the landforms and surficial deposits which are to be found within the Boston basin, and the relationships between them. The true detailed picture of these deposits is contained within the thousands of boring logs which have been summarized by the Boston Society of Civil Engineers (BSCE) since 1914. The remainder of this report is concerned with the organization and interpretation of these data with the goal of gaining a more detailed picture of the surficial soil deposits in the Boston Basin.
SOME TEXT ON THE FOLLOWING PAGE(S) IS ILLEGIBLE ON THE ORIGINAL MATERIAL.
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<th>TIME DIVISION</th>
<th>EASTERN GLENN</th>
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<th>WEST BOSTON</th>
<th>N.W. GLENN</th>
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<td>&quot;Lower&quot; Till at Sankaty Head, on Nantucket Island. (Stone &amp; Borns, 1986).</td>
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<td>&quot;Terminal Moraine&quot; on Ronkonkoma-Block Island- Martha’s Vineyard-Nantucket end moraine belt. C dates indicate that Martha’s Vineyard was deglaciated earlier than 15,300 B.P. (Stone &amp; Borns 1986).</td>
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<td>&quot;Event 5&quot;: Deposition of outwash 3, Kames &amp; Kame terraces, (Chute, 1959).</td>
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<td>&quot;Event 7&quot;: Outwash 4, large alluvial fan southward over the clay, (Chute, 1959).</td>
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Fig 2.1 OUTLINE OF BOSTON BASIN SHOWING MAJOR FAULTS
(After Kaye, 1976)
**Fig 2.2(a) LEGEND FOR FIG 2.2(b) BEDROCK GEOLOGIC MAP OF N.E. MASSACHUSETTS**

*(After Skehan 1979)*

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<td>Alkalic-series rocks: Q-Quincy, P-Peabody, and C-Cape Ann Granites</td>
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<td>Cambridge Argillite</td>
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<td>Roxbury Conglomerate (Quaquam Member)</td>
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<td>Mattapan Volcanic Complex</td>
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| Upper Precambrian? | Dedham Plutonic Complex including older Gabbro and Gabbro Diorite |
|                   | Lynn Volcanics |
|                   | Middlesex Fells Volcanics |
|                   | Westboro Formation |
|                   | Tadmuck Brook Schist |
|                   | Nashoba Formation |
|                   | Beaver Brook Member nb |
|                   | Spencer Brook Member ns |
|                   | Long Pond Member nl |
|                   | Billerica Schist Member nbs |
|                   | Fort Pond Member nf |
|                   | Bellows Hill Member nbb |
|                   | Nagog Pond Member nn |
|                   | Boxford Member nba |
|                   | Nashoba Brook Member nmb |
|                   | Nashoba, member not identified nu |
|                   | Tophet Swamp Member nt |
|                   | Fish Brook Gneiss |
|                   | Shawsheen Gneiss |
|                   | Marlboro Formation |
|                   | Sandy Pond Member |
|                   | Contact of stratified rocks |
|                   | Intrusive contact |
|                   | Concealed contact |
|                   | Fault |
Fig. 2.3(a)  LEGEND FOR Fig. 2.3(b)  BEDROCK GEOLOGIC MAP OF THE  BOSTON BASIN  (after Billings 1976)
Fig 2.4 (a)  TWO INTERPRETATIONS OF THE BEDROCK GEOLOGY ALONG
SECTION A-B  FIG. 2.2(b) (After Skehan 1979)

Thrust faults thus indicated:

BF Northern Border
W Watertown
MH Mount Hope
SB Stony Brook
N Neponset
BH Blue Hills

Wamsutta Fm.
Roxbury Conglomerate
Pondville Fm.
Squanto Member
Alkalic-series rocks: Quincy
Mattapan Volcanic Complex
Cambridge Argillite
Dedham Plutonic Complex inc. older Gabbro and Gabbro Diorite
Fig 2.4(b) **SECTION A-B FIGURE 2.3(b) SHOWING WESTERN NORTH-SOUTH STRUCTURE OF THE BOSTON BASIN** (After Billings, 1976)
Fig 2.4(c) SECTION C-D FIGURE 2.3(b) SHOWING EASTERN NORTH-SOUTH STRUCTURE OF THE BOSTON BASIN (After Billings, 1976)
Fig. 2.4(a) SECTION E-F FIGURE 2.3(b) SHOWING WEST-EAST STRUCTURE OF THE BOSTON BASIN

(After Billings, 1976)
Fig. 2.5  PORTION OF BEDROCK GEOLOGIC MAP (USGS MF-124) SHOWING FAULTS AND BOUNDARIES FOR CENTRAL BOSTON AREA (After Kaye 1982)
Fig. 2.6  PORTION OF BEDROCK SURFACE MAP
(USGS OF-?)
Contour interval is 50 ft. Datum is mean sea level.
(After C. Kaye 1980)
Fig. 2.7  SKETCH MAP OF BOSTON AREA SHOWING LOCATIONS OF BEDROCK VALLEYS

(After Upson & Spencer 1969)
Elevation of point located today at sea level.

Eustatic sea level.

Figure 2.8  **SEA LEVEL AND POST-GLACIAL CRUSTAL MOVEMENTS IN BOSTON, MA.**
(Modified after Kenney, 1964)
Fig 2.9 Map showing extent and direction of ice flow for the late Wisconsin ice sheet in northern New England. (After Stone and Barns, 1986)
Fig 2.10
Surface Geologic Map of Basin Basin 1:100,000
EXPLANATION

MADE LAND; t.s. over salt marsh and
subaqueous offshore.

BEACH DEPOSITS

SALT MARSH

ESKER; sand and gravel.

WISCONSIN GLACIATION:

STRATIFIED DRIFT; sand, gravel, and
clay, morain I.H., in places
overlain by surf.

DRUMLIN; mostly I.H.
(some drumlins leveled to provide land fill).
8 Drumlns with surficial fill have been observed
with Cross Island, 1946.

END MORAIN; mostly dislplaced stratified
drift but also fill.

GROUND MORAIN; mostly I.H.
some bedrock outcrops.

ROCKY TERRAIN; many bedrock
outcrops, thin stratified
drift.

Approximate moraine limit in late Pliocene
and early Pleistocene. Eoward of this, marine
clays and sands dominate stratified drift particularly
at depth.

A. Fresh Pond and moraine
B. Beacon Hill deformation
C. Boston Neck
D. Fresh Pond ice lobe
E. Charles River ice lobe
F. Back Bay ice lobe
G. Peddocks Island drumlin

GEOLOGIC MAP OF THE BOSTON AREA, MASSACHUSETTS
modified after
Clifford A. Kaye
USGS OF 78-111
Fig 2.10
Fig 2.11  MAP SHOWING THE LATE WISCONSIN MORAINES
SECTIONS AND MELTWATER DEPOSITS OF EASTERN
MASSACHUSETTS. (After Stone & Pepper 1980)
Fig. 2.12  GEOLOGIC CROSS SECTION THROUGH BEACON HILL

SHOWING COMPLEXITY OF DEPOSITS

(After C.A. Kaye, 1976)
Fig. 2.13 Schematic illustration of rhythmic bedding in Outwash III.
Fig. 2.14 CENTRAL BOSTON SHOWING THE STRANDLINE AS IT PROBABLY APPEARED IN 1630 (AFTER C. WISE, 1936).
CHAPTER 3

METHOD OF INTERPRETING THE BSCE BORING DATA

INTRODUCTION

For the past century, the surficial deposits in the Greater Boston area have been probed for the purpose of foundation explorations. Fortunately, much of the information has been compiled into compact volumes by the Boston Society of Civil Engineers’ Committee on the Subsoils of Boston. The compiled data dates back to 1914 and consists of four sets of data collections which cover the entire Greater Boston area. Appendix I contains a complete listing and examples of the format of the BSCE Boring data. A plan is provided with each set of borings showing the city streets and the borehole locations. These borehole plans are also presented in Appendix I.

One of the goals of this report is to present the data in a form in which the soil stratigraphy can be readily identified. The method pursued is to graphically present the information from boreholes which are approximately located along a straight profile. The soil deposits can then be linearly interpreted between the boreholes to provide a cross section profile (as shown in figure 3.10).

To perform this task use has been made of the microcomputer, and ‘off the shelf software’. This chapter describes the steps used to digitize the BSCE boring data and to develop the cross section profiles. Figure 3.1 presents a schematic of the system developed in this study.
Perhaps the most important contribution of this study will be the set of files that have been created by the worksheet DATAEDIT. The files contain the digitized BSCE boring compilations. The boring data in these files form a database for all subsequent studies involving the BSCE boring compilations.

The following sections of this chapter describe the steps required for creating the database and generating profiles from the database. The actual programs and detailed descriptions of the operations are contained in the appendices of this report. By referring back to figure 3.1 it can be seen how the steps fit into the general system, where the input files originated and where the output files are going.

BOREHOLE LOCATIONS

The raw data contained in the BSCE compilations present the locations of the boreholes as a plan map referenced to the city streets. Appendix I contains a summary of all the BSCE borehole compilations published to date. This appendix also contains the borehole location plans which were used in this study. Superimposed on each plan is a grid (see figures in appendix I). The borehole locations have been given global cartesian coordinates, X and Y, with reference to this grid. The origin of the coordinate system is arbitrarily chosen as the lower left hand corner of each borehole plan, as shown on the plans in appendix I. This latter point is very important to keep in mind, because it means that the boreholes from different location plans are referenced to different cartesian coordinate systems and should therefore be combined carefully. The data in this format can be readily accessed by computer, allowing easy
manipulation and reorganization. This latter point is illustrated by the program BHOFFSET which uses the digitized data to select the borings to be shown on the cross section profiles.

The BSCE boring data is digitized using a HiPad Digitizer, driven by software titled BHDIGIT.BAS. The reference grid is based on 1000 foot increments, so the digitizing procedure results in X,Y coordinates in units of 1000 ft.. The digitized data is stored as a text file with a single borehole number, X-coordinate and Y-coordinate on each line. Figure 3.2 shows the structure of the output file generated by the program BHDIGIT. The first line of the file is the title of the data, the second line is the number of boreholes contained in the file and the remainder of the lines contain the borehole reference number and coordinates.

The borehole locations may be digitized in sections and each section saved in a separate file, or each section may be appended to the end of an already existing file. Separate files have been used to store the borehole locations from the different sets of BSCE borehole compilations which cover different areas or years. In some areas, such as Boston Peninsula two or more files have been used in order to keep the amount of data in any one file to an easily manageable amount. Files are appended to the end of previously created ones when the borehole locations are not all digitized in one sitting. This enables borehole locations to be digitized at a later time and added to the end of the existing file. It is recommended that the boreholes be digitized in small areas at a time and then appended to a file, such that in the event of a device fault a minimum amount of data will be lost.
The program BHDIGIT is written in Advanced Basic (BASICA) for the IBM PC or compatible. The procedure for digitizing the data, and a complete listing of the program BHDIGIT is presented in Appendix II.

BOREHOLE DESCRIPTIONS

The goal is to organize borehole descriptions into a computer file so that each stratum described in a borehole is an entry in a database management system. A database management system is a program that organizes information, extracts selected information, allows for the addition of new information and updating of the information already in the computer.

For this project the software package Lotus 1-2-3 has been utilized. 1-2-3 is an integrated software package containing a combination of a spreadsheet program with database management and graphics capabilities. This software can readily be used to organize the borehole descriptions and plot the profiles. Some of the operations that are particularly useful in the 1-2-3 software is the ability to easily combine, extract and edit information from different files. These operations are incorporated in the 1-2-3 software and are easily performed using menu driven commands. A more complete description of the Lotus environment and the worksheets described in this section is presented in appendix IV.

In this section a Lotus 1-2-3 worksheet called DATAEDIT is described. The worksheet DATAEDIT contains a set of Lotus command language programs called macros (or keystroke commands). Each macro performs a specific task. Collectively the macros allow for a high degree of automation, with little knowledge of 1-2-3 required.
The worksheet DATAEDIT contains all the column headings for the borehole database. Figure 3.3(a) shows how the empty database would look on the computer monitor. The output file created by the program BHDIGIT is combined with the worksheet by invoking a macro (for a more detailed description of the steps involved refer to appendix IV.). The information from BHDIGIT will be automatically placed in the correct columns in the worksheet. The data is then sorted in order of increasing borehole reference number. Figure 3.3(b) shows what the database would look like after the output file from BHDIGIT has been imported and sorted. The macros in the worksheet DATAEDIT allow for the systematic input of the strata descriptions, depths and the surface elevations for each borehole. This information is contained in the BSCE boring compilations.

Macros are available in the worksheet DATAEDIT to search the data for the borehole the user has selected to enter, and to insert the appropriate number of rows to make space for the strata descriptions. Macros are also available to copy the appropriate borehole reference number and coordinates onto the inserted rows. After these two steps the user must enter the borehole descriptions from the BSCE compilation. A macro in the worksheet is available to calculate and enter the strata elevations from the strata depths and surface elevations (or vice versa). The final database structure after completing the above steps is shown in figure 3.3.(c). A close comparison of fig 3.3(b) and (c) shows why the steps of inserting rows and copying information onto the inserted rows is required. Additional macros are incorporated in the worksheet which allow for editing, saving and retrieving the database files created by DATAEDIT. Refer
to Appendix IV for a more detailed description of the steps involved for the entry and manipulation of data in the database.

In order to reduce the size of the database, the BSCE compilations covering different locations or years are saved in different database files. When the macro stores the database table in the file of the user's choice, it only stores the digitized data, not the entire worksheet DATAEDIT (i.e., not the macros, menu and formatting). This latter point may seem very confusing, but it is important to realize that the 1-2-3 worksheets are in effect a single huge sheet of "electronic paper" onto which everything (almost everything) unique to the worksheet application must be written. This means that the macros and the macro menu must be written on the same piece of "electronic paper" as the database. In order not to save the macros and macro menu in the same file as the database it is necessary to provide a macro for saving only the database.

When the worksheet DATAEDIT is first loaded onto the computer the worksheet will contain no digitized borehole data. A database file must be imported into the worksheet, or a new one can be created (as described in the previous paragraph). This methodology which may seem rather confusing at first, saves a lot of storage space by not repeatedly storing the worksheet DATAEDIT's macros, menu and formatting. There are other reasons for saving the database in separate worksheets to the macros. These are more easily explained when considering further programs that utilize the database (such as worksheet PROFILE).

All of the operations which have been described above are initiated by pressing a combination of two keys which invoke a 1-2-3 command macro. It is important to
note that the worksheet contains only the macros for editing and formatting the data and not any digitized data. The digitized data is stored in separate database files. The files described in this report are usable only by 1-2-3, although facilities are available in the 1-2-3 environment for interfacing the files with other software applications. A complete description of the DATAEDIT worksheet and some notes on how to use it is presented in appendix IV (some knowledge of the LOTUS 123 environment may help).

ALIGNMENT OF BOREHOLES

In order to present a cross-section profile of the soil stratigraphy it is necessary to isolate the boreholes which roughly lie in a straight line along the alignment of the profile. These boreholes drawn to scale in the correct locations will display a slice of the soil stratigraphy. Program BHOFFSET has been developed to select the boreholes to be presented on the soil profile. This program uses the borehole reference number and coordinates to make this selection. The file containing the borehole reference number and coordinates is created by program BHDIGIT (see fig. 3.1 and fig. 3.2). BHOFFSET creates a file of boreholes and their locations with respect to the profile alignment. It does not handle any soil description or elevation data. A Lotus 1-2-3 worksheet is presented in a later section which combines all this information to create the actual soil profile.

A line along which the soil profile is to be plotted is chosen. The coordinates at the start and end of the section must be determined. This can be done either using the digitizer or by scaling from the plan. These coordinates will define the alignment of the profile. The maximum deviation in borehole location
perpendicular to the alignment, the offset, must also be selected. The criteria for borehole selection are illustrated in fig. 3.4. The factors governing the selection of the profile alignment and maximum offset, are the locations of the surrounding profiles, the locations of the boreholes, and the soil stratigraphy. Typically a distance of 150 feet has been selected for the maximum offset.

The program BHOFFSET reads the digitized data file created by the program BHDIGIT. BHOFFSET asks for the start and end coordinates, and maximum offset of the profile line. The program selects all the boreholes in the file that fall within the maximum offset of the alignment (ie. the shaded region in fig. 3.4). The distance of the borehole from the start along the alignment and the perpendicular offset is calculated for each borehole selected (see fig 3.4). The boreholes are then arranged in order of increasing distance from the start of the section. The program displays, allows for modification and saves the borehole number, distance along the section, and offset in a file of the operators choice. Figure 3.1(b) shows the format of the output data from program BHOFFSET. The output file is saved in a format which is suitable for input into a LOTUS 123 spread sheet.

The program BHOFFSET is written in TURBO PASCAL and will run on the IBM PC and compatibles. The program is interactive and contains error trapping. A description and listing of BHOFFSET is presented in Appendix III.
PROFILES

Up to this point a database containing the digitized form of the BSCE borehole compilations and a method of selecting the boreholes along a given alignment has been described. In this section the Lotus 1-2-3 worksheet PROFILE is presented. The goal of this worksheet is to combine the files created by BHOFFSET and DATAEDIT in such a way that the soil stratigraphy along the chosen alignment can be readily identified.

Worksheet PROFILE has been built around the database management commands that are contained in the 1-2-3 program. This worksheet like the DATAEDIT worksheet contains a set of macros, each with a specific task. A menu of macros and the keystrokes necessary to initiate them is contained within the worksheet.* The operation of the worksheet is described briefly in the following paragraphs. Further information and complete listing of the macros is presented in appendix IV.

By invoking a 1-2-3 command macro the borehole database file is imported into worksheet PROFILE. This data is placed in a section of the worksheet named the "Data" range. The output from BHOFFSET containing the borehole numbers, distance and offset is also imported into the worksheet. These data are placed within a section of the worksheet named the "Criterion" range. A macro is initiated which extracts all the digitized borehole descriptions from the Data range which satisfy the listed criteria, the criteria for extraction being the borehole reference numbers listed in the Criterion range. The extracted descriptions are placed within a section of the worksheet named the "Output"
range. The Output range will now contain a table of boreholes which are to be presented as a soil profile.

The next step is to replace the X and Y coordinates for each borehole with the distance and offset information. This has to be done so the location of the borehole with respect to the alignment can be realized. The distance and offset information is calculated by program BHOFFSET and will be in the criterion range. A macro within the worksheet PROFILE copies all the information into the appropriate locations.

In order to graphically present the data using the graphics capabilities contained in the 1-2-3 program, each of the boreholes must be separated by a blank row. The graphics program is then able to distinguish different boreholes by the presence of null data. (If this is not done then the bottom of the previous borehole on a section is connected to the top of the next borehole). A macro is available that inserts blank rows between all the boreholes in the output range.

The graphics settings are already prepared in the worksheet PROFILE. By simply depressing one "magic" key all the boreholes are displayed as vertical lines with ticks at the change of strata. All the boreholes are plotted at the appropriate location and elevation along the section. The borehole data in the output range and the profile plot may be printed to allow for interpretation and recording. Figure 3.5 shows the format of the output range which can be printed. An example of the type of graphical display created by PROFILE is shown in figure 3.6.
A complete description of the PROFILE worksheet and some notes on how to use it is contained in appendix IV.

INTERPRETATION

The soil profiles as represented by the boring data, and displayed by the PROFILE plot are not always simple to interpret. For example attempts to get the computer to connect strata of clay in one borehole with those in an adjacent borehole are generally not possible without resorting to an intelligent system. Such an interpretation system would have to be able to distinguish intermediate layers of sand which were not observed in one of the boreholes. The general geology would have to be known before the profiles were drawn so the system could have a basis for deciding how to connect the soils identified in each borehole. It is hard to imagine a program that would be capable of performing decisions which even a geologist with years of experience may not be capable of. Such a system has not been pursued in this study. In many cases there simply is not enough information to know how to connect the strata between borings. In all cases the nature of the soil between the boreholes remains to some extent uncertain.

Anybody who has had the task of drawing soil profiles across a one block building site can readily appreciate the hardships involved with interpreting soil descriptions along a 1 mile section. To ease the task the soil descriptions contained in the PROFILE output range have been manually added to the PROFILE graph. The result is a graphical representation of the boring information along a straight line with soil descriptions. The data from the different BSCE compilations can be processed using the system described. The
result will be a set of soil plots that can be compared and compiled by overlaying them on a light table. With a little knowledge of the 1-2-3 environment the separate boring compilations may be combined to form one plot of all the data. This combined plot usually contains too many boreholes on one plot to work with. (A larger scale could be used).

With careful scrutinizing of the data, an interface between the different soil horizons can be determined for the length of the section where there are sufficient boreholes. An example of the type of soil profile plot that has been produced with the above process is illustrated in figure 3.7. This figure shows the soil stratigraphy indicated by the boreholes from one set of BSCE borehole compilations. The same process is repeated for the other sets of borehole compilations.

For this study the soil profiles have been further processed. The PROFILE plots for each alignment for all the BSCE compilations considered have been combined in a worksheet named SUMMARY. This worksheet contains no macros, only graph settings and table headings. The elevations of the interfaces between the different soil types for the boreholes on the alignment are entered into the SUMMARY table. The summary table which has been manually created for the Stuart street profile is shown in figure 3.8. The elevations are identified from the edited PROFILE plots (fig. 3.7). The worksheet SUMMARY creates a plot using different symbols for the different interfaces. The summary plot for the Stuart street profile is presented in figure 3.9. The symbols are joined up and edited to create the final soil profile. The final soil profile is presented in figure 3.10. This final plot could be overlayed with the edited PROFILE plot for
additional information.

The worksheet SUMMARY step may at this point seem a bit redundant. This process was used because the data from the different BSCE compilations (same area but different years) was considered independently. It was then necessary to combine all the information in one final plot. Hence the worksheet SUMMARY.

The worksheet SUMMARY is described in detail in appendix IV.

SUMMARY

This chapter described a methodology for generating soil profiles from the BSCE boring compilations. The method uses a digitized version of the BSCE boring compilations from which the data pertaining to a specified alignment can be extracted and edited. The method described in this chapter is summarized as follows (see figure 3.1 also);

i) Program BHDIGIT is used in conjunction with a Hipad Digitizer, to digitize the BSCE borehole location plans.

ii) The BHDIGIT output file is input into worksheet DATAEDIT.

iii) The borehole descriptions contained in the BSCE compilations are added into the DATAEDIT worksheet.

iv) Program BHOFFSET is used to select the boreholes to be presented on the profile. The selected boreholes are stored in a file of the users choice.

v) The BHOFFSET output file is imported into the "Criterion Range" of Lotus 1-2-3 worksheet PROFILE.
vi) The database file containing the borehole descriptions to be presented on the profile is imported into the "Data range" of worksheet PROFILE (The database files are created by the worksheet DATAEDIT).

vii) The boreholes in the "Criterion Range" are extracted from the "Data Range" and placed in the "Output range".

viii) The profiles are plotted and soil descriptions printed.

ix) The soil interfaces are determined from the soil descriptions. All the data considered are edited and combined into the final plot using 1-2-3 worksheet SUMMARY.

x) The plots are further edited by hand.

The next chapter of this report presents the complete set of profiles generated in this study using the system described in this chapter.
Hipad Digitizer
BSCE borehole location plan.

Program BHDIGIT
Controls digitizer, creates borehole location file.

Profile alignment
start coordinates, end coordinates, maximum offset.

Program BHOFFSET

Worksheet DATAEDIT

BSCE borehole compilation.

Fig. 3.1a SCHEMATIC OF DATA PROCESSING SYSTEM.
### Worksheet PROFILE

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<th>Hole</th>
<th>Distance From Arlington (ft.)</th>
<th>Depth at Bottom of Strat (ft.)</th>
<th>n-Value</th>
<th>Strat Name</th>
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<td>Surface</td>
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<td>0</td>
<td>13.6</td>
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<td>Very Stiff Y Clay</td>
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<tr>
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<td>13.6</td>
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<td>13.6</td>
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<td>0</td>
<td>13.6</td>
<td>M Silt &amp; L Gravel</td>
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<td>0</td>
<td>13.6</td>
<td>Silty Sand</td>
</tr>
<tr>
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<td>0</td>
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<td>0</td>
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<td>M Sand &amp; L Gravel</td>
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---

**Soil Profile Along STUART Street**

*Arlington St. to Channel (ESCE 1949)*

---

![Distance from Arlington St. (1000 ft.)](image)

**Fig. 3.1b SCHEMATIC OF DATA PROCESSING SYSTEM**

84
<table>
<thead>
<tr>
<th>BOREHOLE REFERENCE NUMBER</th>
<th>X CO-ORDINATE</th>
<th>Y CO-ORDINATE</th>
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**Fig. 3.3(a)**  **BOREHOLE DATABASE TABLE HEADING IN WORKSHEET**
**DATEREDIT (AND WORKSHEET PROFILE).**

<table>
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<tr>
<th>Entry</th>
<th>Strata Description</th>
<th>Strata Category</th>
<th>Strata Legation</th>
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</thead>
<tbody>
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**Fig. 3.3 (b)**  **BOREHOLE DATABASE AFTER USING THE (ALT) 1**
**MACRO TO IMPORT THE BHDIGIT DATA FILE.**

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**Cursor Location to start data entry for borehole # 154**
(S macro).
**Fig. 3.3(c)** EXCERPT FROM THE BOREHOLE DATABASE AFTER ENTERING ALL THE INFORMATION USING THE WORKSHEET DATAEDIT.

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Boreholes located within the shaded region will be stored by BHOFFSET in a data file.

Criteria to define the shaded region are shown in bold.
Fig. 3.5 PRINT OUT OF OUTPUT RANGE FROM WORKSHEET PROFILE SHOWING A PORTION OF THE DATA FOR THE PROFILE ALONG STUART STREET, (BSCE 1949)

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Soil Profile Along STUART Street
Arlington St. to Channel (BSCE 1949)

Fig. 3.6 UNEDITED OUTPUT PLOT FROM WORKSHEET PROFILE
Soil Profile Along STUART Street

Arlington St. to Channel (BSCE 1949)

Distance from Arlington St. (1000 ft.)

Fig 3.7  EDITED PLOT FROM WORKSHEET PROFILE
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FOR SOIL PROFILE NEAR STUART STREET

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Soil Profile Along STUART Street

Arlington St. to Channel (BSCE Data)

Elevation BCB (ft.)

Distance from Arlington St. (1000 ft.)

Fig 3.9  UNEDITED OUTPUT PLOT FROM WORKSHEET SUMMARY
Soil Profile Along STUART Street
Arlington St. to Channel (BSCE Data)

Distance from Arlington St. (1000 ft.)

Fig 3.10 FINAL SOIL PROFILE PLOT
CHAPTER 4

BOSTON BASIN SOIL PROFILES.

The previous chapter of this report describes a methodology for generating soil profiles from the BSCE boring compilations. The method uses a digitized version of the BSCE boring compilations which has been created specifically for this purpose. The method was described in chapter 3 and is summarized at the end of that chapter.

Using the methods described in chapter 3 a series of intersecting soil profiles covering the following areas have been created:

i) Boston Peninsula.
ii) South Boston.
iii) Cambridge.
iv) East Boston
v) Charlestown.

A plan map for each of these areas is contained at the end of this chapter showing the location of each of the soil profiles (figure 4.1 through 4.6). The soil profiles are referenced using the name of the street which is most closely associated with the alignment of the profile. The soil profiles are presented in appendix VI.

The soil profiles are based on the boring data from the last two compilations of the Boston Society of Civil Engineers (1931 -1984). These data contain the boreholes from the 1931 compilation. The data in the 1914 compilation is not presented in a form that can be readily digitized and have therefore not been considered in this analysis.
The stratification elevations contained in the BSCE compilations represent the approximate boundary between the soil types, it must be realized that in many of the cases the soil transition may be gradual and the elevation reported may be subjective. The boring logs depict the subsurface condition only at the specific location of the borehole. Soil conditions at other locations may differ from the conditions occurring at these boring locations. The soil interfaces depicted in the profiles of Appendix VI are based upon interpolation between borings and may not represent the actual subsurface conditions.

Comments on the stratigraphy revealed by these profiles and the relation to the geology discussed in the second chapter of this report are made in the following chapter.
CHAPTER 5

GEOLOGICAL INTERPRETATION OF THE SOIL PROFILES

INTRODUCTION

This chapter summarizes the soil profiles that have been created by the methods described in chapter 3. The soil profiles are presented in alphabetical order in appendix VI.

The soil stratigraphy illustrated in the profiles has been simplified due to the scale at which the profiles have been presented. Many of the local anomalies have been smoothed out. The problem of recognizing and separating the different drifts based on the descriptions in the BSCE borehole compilations is often extremely difficult. Often the deposit beneath the Clay has been described as "Till" or "Hardpan" and the possible different drifts that it may contain are indistinguishable.

SOIL STRATIGRAPHY

The profiles shown in the figures in this chapter are made up from the individual profiles discussed in chapter 4 and presented in appendix VI. The legend for all the profiles is presented in figure 5.1(a). The general stratigraphy which is indicated from the profiles for most of the basin is presented in the following sections, described from the bottom to the top.

Bedrock: The bedrock is usually described as "Bedrock", sometimes as Argillite, Slate or Siltstone. More often the boreholes will simply end in "Refusal" which could be bedrock, a boulder or hard till. Very few of the boreholes considered
penetrate into the bedrock. The result is a very disjointed picture of the bedrock surface. However, even from this disjointed picture it can be seen that nowhere is the bedrock surface even. The surface is very undulated attaining peaks and valleys in many of the profiles.

There may be a step in the bedrock surface striking about N40° E located just west of Leverett Circle to just west of Stuart and Washington Street running under the northeast side of Beacon Hill. Figure 5.1(b) shows this step as indicated by the Embankment, Causeway and Cambridge Street profiles. The step, which rises at least 40 feet on the south east side, is not clearly apparent from Kaye's bedrock map (figure 2.6). It is also interesting to note that the normal faults shown in the figure 2.5 which flank each side of the peninsula also strike approximately N40°E.

Till, (Till I ?); The till is usually described as "Till", "Hardpan" or Clay, Sand, Gravel and Boulders (hard). This drift overlies bedrock in almost all boreholes in the basin. It appears to have formed a fairly uniform blanket ranging from 5 to about 30 feet in thickness. Under many of the hills in the basin this till increases in thickness, and may even outcrop (see figure 5.2). This till forms the core or "lower" till of the drumlins in the Boston basin.

On the lee side of Fort Hill drumlin (with respect to the South-easterly flow of ice) there appears to be a separate drift of till which is below the above described drift. This till which is depicted on the Fort Point Channel profile in figure 5.3, is typically described as a Sandy Silty Clay. The drift is approximately 35 feet thick overlying bedrock, and is buried beneath 5 to 25 feet of Sand, Gravel, Clay with some Boulders. In the Dorchester Avenue profile
also shown in figure 5.3, 2 boreholes are plotted which penetrate over 100 feet of Clay, Silt and fine Sand (to a minimum elevation of -224.8 ft BCB) without encountering bedrock. It is uncertain from the BSCE data whether this drift is the ground moraine from an earlier glaciation than that which deposited the general drift which blankets most of the basin (shown as Till I, Event 1 and Boston Till in table 2.1). This older deposit could be the "lower till" described by Stone & Borns (1986) dating from the early Wisconsin glaciation (see table 2.2) or could be remnants of the ground moraine from the Illinoian glaciation and the source of the material which formed the harbor drumlins.

The easterly side of the Fort Hill drumlin appears to have a slope of approximately 30° towards the Boston harbor. This slope is shown in the Purchase Street profile (fig. 5.2(a)) and also in the Atlantic Avenue profile (fig. 5.2(b)) which is located immediately east of the slope. The Origin of this slope is speculative at this time.

Yellow and Blue Clay, Sand and Gravel (Till II?); The Blue Clay discussed in the next section appears to grade laterally into this "Clay, Sand and Gravel" in the vicinity of the drumlins. This is depicted on the Beacon (fig. 5.2(c)), Cambridge (fig. 5.1(b)), Federal (fig. 5.4(a)) and Washington Street (fig 5.4(b)) profiles. This deposit appears to comprise part of the upper till of the drumlins in the basin and it probably corresponds to Till II as illustrated in table 2.1. The deposit is at least 50 feet thick on Beacon Hill (see fig 5.2(c)) and 40 feet in the Copps Hill drumlin (see fig 5.2(b)).

The upper portion of this till contains Yellow Clay while the lower portion is
often described as Blue Clay. The Yellow Clay is presumably colored by weathering of the Blue Clay on exposed surfaces, as discussed in the chapter 2 of this report.

Blue Clay (Outwash III); This is the most widespread deposit in the basin. In most places it is described as Sandy Blue Clay or Blue Clay with fine Sand lenses. The Clay reaches thicknesses of well over 100 feet in many of the profiles in the central portion of the basin (see figures 5.2 and 5.5). Clays interbedded with Sand and Sands interbedded with Clay constitute the Sandy phase of the deposit as depicted in figure 2.13. The elevation of the surface of the Blue Clay rarely exceeds 10 feet BCB in the areas considered in this report and ranges typically from elevation -30 to 0 feet BCB.

Yellow Clay (Outwash III); Yellow Clay overlies the Blue Clay in most areas of the basin although the thickness seems to be very variable. As stated above the yellowing is probably due to oxidizing from subaerial exposure when the sea level fell after deposition of the Clay. The Yellow Clay is generally 3 to 10 feet thick and is usually described as stiff relative to the Blue Clay below which is typically described as soft.

Outwash Sands And Gravel (Outwash IV ?); This material is deposited discontinuously throughout the Boston basin. A large patch is present in the westerly portion of the Back Bay area (see the Boylston and Hereford Street profiles shown in figure 5.5(a) ). The Sands and Gravels also form a low lying terrace on both sides of the lower Charles River (see Embankment profile in figure 5.1(b) and MIT Campus profile shown in figure 5.5(b) ). In the vicinity of the Boston University bridge and projecting under the Charles river basin in the vicinity of the BU
bridge the Sands and Gravels with interbedded Clays reach a thickness of over 70 feet (see the BU bridge, Morse School and Magazine Beach profiles shown in figure 5.6). In this area these deposits may lie directly over the ground moraine (till). This probably represents a filled stream channel caused by erosion at the beginning of the outwash sequence. More typically the Sands and Gravels are 5 to 25 feet thick and are underlain by the Clay. Most of Cambridge is underlain by these Sands and Gravels (see Main Street, MA. Avenue profiles shown in figure 5.7).

Recent Alluvium and Organic Deposits; These deposits are widely distributed in the central region of the Boston basin. They are typically described as fine Silty Sand, Silt and fine Sand or Silt with varying amounts of peat to just peat. This deposit reaches a maximum thickness of over 30 feet (see Causeway Street Profile shown in figure 5.1(b)). The lowest elevation is about -40 feet BCB in the lowlands surrounding the harbor. The maximum elevation is approximately +10 feet. The deposit is described as containing shells in numerous locations throughout the basin. In many areas there is evidence of marine Silts deposited over peat (see Boylston (fig 5.8), Dedham (fig 5.11), Haverhill (fig 5.4(a)), and Herald Street (fig 5.11) profiles. Elsewhere the opposite may be true (see Stuart (fig 5.8), Memorial (fig 5.6(b)) and Auburn Street (fig 5.10) profiles. In general the peat, Silt and fine Sand deposits are intermingled in a complex relationship.

The deposition of reworked Clays as described by Kaye (1982) is not obvious from the profiles.
Miscellaneous Fill; Almost every borehole considered penetrated fill of some description as the uppermost layer. This layer is usually described as "miscellaneous fill", sometimes Sand and Gravel or cinder fill. The thickness of the fill varies from about 20 feet in the Back Bay (fig 5.8), along the Embankment (fig 5.1(b)) and Atlantic Avenue (fig 5.2(b) to just a few feet representing man-made surface disturbance on the drumlins. Locally, however, the filling may reach thicknesses of upto 40 feet such as at the north end of the Haverhill Street profile (fig 5.4(a)) and in the old Clay pits on the North side of Fresh Pond profile (fig 5.12).

LANDFORMS

The following sections describe the landforms which are present in the Boston basin and which are identified on the profiles.

Beacon Hill Deformation; The internal structure of Beacon hill as depicted by Kaye (1976, see figure 2.12) is not apparent from the borehole descriptions considered in this report. The rise in the ground moraine till which presumably comprises the core of the hill can be seen on the surrounding profiles (see figure 5.2(c) and 5.4(b)). The relation between the Clay, Sand and Gravels which comprise Beacon Hill and the surrounding deposits is unclear from the profiles. Even if the deformations discussed by Kaye (1976 & 1982) are present they would be unrecognizable because not enough borings are considered on the profiles to pick up the type of detail depicted in figure 2.12.

The presence of Beacon Hill in the Boston Peninsula significantly complicates the geology of the basin. The stratigraphy as represented by the BSCE borehole
descriptions was reasonably easy to sketch along all the profiles until they approach the vicinity of Beacon hill where the Blue Clay apparently grades into fine Sand, Gravel and boulders and the Yellow Clay grades into Yellow Clay fine Sand and Gravel.

Glacial Readvance and The Fresh Pond Moraine; The evidence for the deposition of till over Clay as decribed by many geologists studying the Boston basin deposits (Kaye 1961,1982; Chute,1959; W.Crosby 1903) as indicated by the profiles in this report is very scanty. In the Boylston Street profile (fig 5.8) there appear to be two layers of till interfingered with the Blue Clay (similar to that described by W.O.Crosby, 1903). The upper most layer of till in this profile is located at .60 feet BCB. In Charlestown the profiles are very confusing, some of the boreholes may indicate till over Clay although the general stratigraphy as indicated by the BSCE boring data is inconclusive (see Front Street and Rutherford Avenue profiles in figure 5.9). The same comments can be made for the East Boston Profiles (see Border Street profile shown in figure 5.2(d)).

In Cambridge the profiles Huron Avenue and High Street shown in figure 5.10 illustrate the stratigraphy of the Fresh Pond Moraine. The Mount Auburn Profile, (also shown in figure 5.10) shows Sand and Gravels near the surface which would be more like outwash than till. The Massachusetts Avenue profile, (fig 5.7) shows an upper till that has approximately the same composition as that of the Fresh Pond Moraine and may be correlated with it. The north of Fresh Pond profile (fig 5.10) offers no new enlightenment on the subject.

Boston Neck Deposits; The Boston neck is the thin isthmus which connected
Beacon Hill and surrounding land to the mainland during low tide (see fig 2.10). The stratigraphy of the neck can be seen by the Shawmut and Washington Street profiles which are aligned with the neck (see figure 5.4(b) ) and the Worcester (fig 5.5(a) ), Dedham, Stuart Street (fig 5.8), and the Herald and Dedham Street (fig 5.11) profiles which traverse the neck. The Blue Clay passes under the neck forming a continuous deposit of Blue Clay from Back Bay to South Boston. The topography of the neck is due to the Yellow Clay and fine Sand which overlies the Blue Clay. Kaye (1982) describes thrusting and folding in this deposit and attributes the ridge to that of a glacial moraine which he apparently correlates with the Fresh Pond moraine. The data studied in this report are not of sufficient detail to indicate whether or not glacial overiding of the Clay as discussed by Kaye occurred.

SUMMARY

Not all the deposits shown in table 2.1 have been identified in the subsurface soil profiles of the Boston basin presented in this report. Clearly part of the problem is the interpolation between the boreholes of different BSCE boring compilations and the correlation between the borhole descriptions done by different personnel and different companies. Clearly only the most widespread deposits within the basin have been identified due to the distances between the boreholes and the lack of detailed consistent descriptions for the deposits.

The soil profiles illustrate the general stratigraphy of the basin and should give a useful indication of the subsurface conditions to be expected at any specific location. The profiles are particularly useful for determining the thickness and extent of the Sand and Gravel outwash deposit and the Silt
deposits. It is hoped that the profiles will be updated as more information becomes available in the database.
Fig. 5.1(a) LEGEND FOR THE BOSTON BASIN
SUBSURFACE SOIL PROFILES.
Soil Profile Along the EMBANKMENT

Soil Profile Along CAUSEWAY STREET

Soil Profile Along CAMBRIDGE Street

Fig 5.1(b)
STEP IN BEDROCK IN THE BOSTON PENINSULA AS INDICATED BY BSCE BOREHOLE DATA
Fig 5.2(a)  INCREASED THICKNESS OF TILL UNDER FORT HILL AS INDICATED BY THE BSCE BORING DATA.

(see also Federal St profile)

Soil Profile near PURCHASE STREET

Soil Profile Along I 93 SOUTH
Randolph to Essex St. (BSCE Data)

Distance from Randolph St. (1000 ft.)

Fig 5.2(a) Fig 5.7 Fig 5.8 Fig 5.4(a) Fig 5.2(b)
Fig 5.2(b) INCREASED THICKNESS OF TILL UNDER COPPS HILL AS INDICATED BY THE BSCE BORING DATA
Fig 5.2(c) INCREASED THICKNESS OF TILL UNDER BEACON HILL AS INDICATED BY THE BSCE BORING DATA.

Soil Profile Along BEACON Street
Arlington to Devonshire St. (BSCE Data)

Soil Profile Along Street
Devonshire to Harbor (BSCE Data)

Beacon Hill Deformation

Distance from Arlington St. (1000 ft.)

Distance from Devonshire St. (1000 ft.)
Fig 5.2(d) INCREASED THICKNESS OF TILL UNDER EAGLE HILL (EAST BOSTON) AS INDICATED

BY BSCE BORING DATA

Soil Profile near BORDER STREET

Soil Profile near CONDOR STREET

Harbor to Condor Street (BSCE Data)

Border to E. and Condor St. (BSCE Data)
Fig 5.3  THICK DEPOSITS OF TILL IN SOUTH BOSTON AS INDICATED BY BSCE BORING DATA

Soil Profile Along FORT POINT CHANNEL

Northern to Broadway St. (BSCE Data)

DORCHESTER AVENUE

Broadway St. to Expressway (BSCE Data)

Elevation MSL (ft.)

Distance from Northern St. (1000 ft.)

Distance from Broadway St. (1000 ft.)
Fig 54(a) SHOWING BLUE CLAY GRADING INTO CLAY, SAND AND GRAVEL IN THE VICINITY OF COPPS HILL, AS INDICATED BY BSCE BORING DATA.
Fig 5.4(b)  BLUE CLAY GRADING INTO CLAY, SAND AND GRAVEL IN THE VICINITY OF THE FLANK OF BEACON HILL.  
FIGURE ALSO SHOWS THE STRUCTURE OF THE BOSTON NECK ALONG SHAWMUT & WASHINGTON STREETS.

Soil Profile Along SHAWMUT AVE.

Mass. Ave to East Berkeley (BSCE Data)

WASHINGTON ST.

Mass. Ave to East Berkeley (BSCE Data)

Near Berkeley to Water St. (BSCE Data)

Distance from Mass. Ave. (1000 ft.)

Distance from East Berkeley (1000 ft.)

Fig 5.5(a)
Fig 5.11
Fig 5.11
Fig 5.8
Fig 5.26

Distance from Mass. Ave, to Govt. Ctr. (D.C. Data)

Distance from Mass. Ave, to Govt. Ctr. (D.C. Data)
Soil Profile near MEMORIAL DRIVE
MORSE SCHOOL
Grant & Atens to Magazine St (BSCF Data)

Fig 5.5(b)

Soil Profile near MAGAZINE-BEACH
Atison & Laynor St (BSCF Data)

Soil Profile near BU BRIDGE
Allston to Commonwealth (BSCF Data)

Fig 5.6
THICK DEPOSITS OF SAND AND GRAVELS WITH INTERBEDDED CLAYS
Fig 5.7  SOIL PROFILE IN CAMBRIDGE SHOWING EXTENT OF SAND & GRAVEL DEPOSITS AND POSSIBLY TWO TILL LAYERS.
Fig 5.8  SOIL PROFILE ALONG BOYLSTON STREET AND ACROSS THE BOSTON NECK SHOWING INTERFINGERED BLUE CLAY AND TILL (3 borings only), AND CONTINUOUS BLUE CLAY UNDER THE BOSTON NECK.
Fig 5.9 PROFILE IN CHARLESTOWN SHOWING A MIX OF TILL AND CLAY

Soil Profile near RUTHERFORD AVENUE FRONT STREET

South of Sullivan Square (BSCE Data) Rutherford to Warren Ave. (BSCE Data)

Elevation BCB (ft.)

Dist. from Sullivan Square (1000 ft.) Dist. from Rutherford Ave TP (1000 ft.)
Fig 5.10
SOIL STRATIGRAPHY OF
THE FRESH-POND
MORAINES AS INDICATED
BY BSCE BORING DATA
Fig 5.11 SOIL PROFILES WHICH
TRVERSE THE BOSTON
NECK SHOWING CONTINUOUS
CLAY UNDER THE NECK

see also Fig 5.8
Fig 5.12  DEEP DEPOSITS OF FILL IN THE OLD CLAY PITS NORTH OF FRESH POND
CHAPTER 6

SUMMARY

The goal of this report has been to summarize the geology and to gain a better understanding of the stratigraphy of the surficial deposits in the Boston basin. This study has been invoked by the need to gain a better understanding of the stratigraphy of the basin for the purpose of creating a liquefaction potential map for the Boston basin.

The first portion of this report summarized the present state of knowledge concerning the general geology of the Boston basin. Emphasis has been placed on the surficial geology because these deposits have the greatest effect on construction within the basin. From the review of the published geological papers it is noted that there have been only a few significant publications, mostly by USGS geologists. Each of these papers portrays a dynamic series of events leading to deposition which are not always easily correlated with other papers or even with the surficial deposits which are to be found throughout the basin. For example Kaye (1961) described what must be one of the most complicated stratigraphic sections in the basin (the Boston Common garage excavation) in a paper titled "Pleistocene Stratigraphy of Boston, Massachusetts". In a later paper (1982) a similar set of drifts is described but these are very difficult to correlate with the the 1961 drifts (for this reason Kaye, 1961 has not been added to table 2.1). Table 2.1 is presented in chapter 2 as a summary of the many views on the pleistocene geology of the Boston basin. The problem of correlating these deposits throughout the basin and fixing them in time is still largely unresolved. Probably the most important questions still remaining are;
1. How is the Fresh Pond readvance related to the deposition of the Blue Clay throughout the lowlands of the basin? Was the clay still being deposited in the basin during the Fresh Pond readvance? Were there other lobes advancing at the same time (Back Bay lobe and Charles river lobes as described by Kaye, 1982)?

2. Did the glacial ice over ride the Blue Clay?

3. Is the Boston Neck a moranic ridge from the Back Bay ice lobe?

4. What is the origin of Beacon Hill and how is it related to the rest of the surficial deposits in the basin?

5. How many different deposits are actually present in the basin and how can they be identified?

6. What were the conditions in the basin during the deposition of the Blue Clay? How is this clay related to the clays north of Fresh Pond and those that have been dated in the Salem Quadrangle?

The above questions represent only a few of the unanswered questions which have been raised during the attempted correlation of the geological events in this report. From an engineering point of view the answers may not be important, unless they help to predict the subsurface conditions.

The next section of this report (chapter 3) described a method in which the Boston Society of Civil Engineering (BSCE) borehole compilations could be stored.
in digital form in a computer. In this form the data could be reorganized such that the information contained by the data could be more easily recognized. Two separate, but related programs were developed based around the software package Lotus 1-2-3.

The first program enables one to store the BSCE boring data in digital form. This program uses a Lotus 1-2-3 worksheet named DATAEDIT to create a database containing the BSCE borehole descriptions. The borehole descriptions are contained within the database in numerical order. The location of the boreholes are described using cartesian coordinates relative to some defined origin. The worksheet automatically performs many of the operations required for the construction of the database.

The second program, actually two programs, makes use of the borehole database described above. The program plots the boreholes which are located approximately along a specified straight line as a series of vertical lines spaced at the appropriate distance along the line (i.e. a scaled plot of the boreholes). The subsoil interfaces described in the borehole descriptions are drawn on the plot as horizontal ticks on the vertical lines. The programs used to create the plots are BHOFFSET, which selects the boreholes to show on the plot and worksheet PROFILE which reorganizes the borehole database and creates the plot.

Using the methods and programs described in this report a comprehensive set of intersecting subsurface soil profiles have been created. From these plots it is concluded that the general stratigraphy of the basin is;
i) BEDROCK; argillite, siltstone or shale.

ii) TILL; Clay, sand, silt, gravel, cobbles, boulders, ranging typically from 5 to 30 feet thick. This deposit blankets the bedrock throughout almost the entire basin. This is possibly underlain by a finer till in some of the deeper bedrock valleys.

iii) YELLOW AND BLUE CLAY, SAND AND GRAVEL; This till appears to comprise part of the upper till of the drumlins in the basin. It reaches a maximum thickness of approximately 50 feet in the Beacon Hill deformation.

iv) CLAY; The Boston Blue Clay is over 150 feet thick in many locations in the basin. The clay is located throughout the basin to a maximum elevation of 10 feet BCB. The clay contains many lenses of fine sand. In many locations throughout the basin the upper 10 feet of the clay is oxidized to a yellowish color.

v) SAND AND GRAVEL; located in patches throughout the basin, and in terraces along the Charles river basin. The sands and gravels are usually underlain by the clay and are approximately 5 to 25 feet thick.

vi) SILT, FINE SAND AND PEAT; Located throughout the lowlands of the basin, this drift reaches a maximum thickness of approximately 30 feet.

vii) FILL; located almost everywhere in the basin consists of sand, gravel, cinders, or clay.
A more detailed summary of the stratigraphy revealed by the subsurface profiles is presented in chapter 5 of this report.

Future work should be done to modify the borehole database to include a simple soil classification for each stratum described in a borehole. Such a system may be modeled around the twin letter descriptions of the Unified Soil Classification scheme. If this were done, it would be possible for the computer to automatically identify similar soils and to manipulate them to create contours of the soil surfaces, or draw the soil interfaces on the profiles. Work is being done at this time to add codes to the fill descriptions to describe the historical sequence of filling. These codes include a code for age, material, mode of deposition and depth of water at time of deposition (see parallel report by Ty 1987).

Future work should be also done to ensure that the long history of compiling the borehole descriptions in the Boston basin is continued. The borehole descriptions published by the BSCE should be available in digitized form for the benefit of all those who are interested in gaining a better understanding of the subsurface conditions in the Boston basin. The compilations of borehole data since 1914 set an example in urban geology which is probably unsurpassed by any other city, but the quality of the data has to greatly improved if the full benefit of the database is to be realized.

It is hoped that the database and the profiles presented in this report will aid in the understanding of the stratigraphy of the basin and that this report will provide the foundation for future digitizing of borehole data into a database.
APPENDIX I
BOSTON SOCIETY OF CIVIL ENGINEERS'
PUBLISHED BORING DATA

In the first Volume of the BSCE Journal, 1914 J.R Worchester presented a collection of borings in Greater Boston as an appendix to his article "Boston Foundations". No Standard penetration Data is presented as the test had not yet been developed. The boring information is presented on a series of maps as follows:

1. Boston Peninsula
2. South Cove District
3. East Cambridge
4. South Boston
5. Backbay & Roxbury.
6. Brookline
7. Harvard Square District
8. East Boston and Chelsea
9. Charlestown

In 1921 the Committee on Boston Subsoils was formed to gather data regarding the character of the subsoils in Boston and hence carry on the work that J.R. Worchester started. The following is a list of the compilations that have been summarized and published in the BSCE Journal:


Contains 3,900 boreholes (no SPT-n value data) dating from 1924 to 1931, grouped together from the following areas;

1. Boston Peninsula
2. Roxbury.
3. South Boston
4. East Boston and Charlestown
5. Cambridge.
Reports of the Committee on Boston Subsoils published in the BSCE Journal summarizing boring data dating between 1931 and date of publication are as follows:

Section 1: Boston Peninsula, 1949, Oct., Vol. 36, No. 4. (1,556 boreholes, 6 excavations, no SPT-n value data).

Section 2: Roxbury & Brighton, 1950, Oct., Vol. 37, No. 4. (1,111 boreholes, 197 excavations, no SPT-n value data).

Section 3: South Boston & East Boston, 1951, Oct., Vol. 38, No. 4. (1,306 boreholes, no SPT-n value data).

Section 4: Cambridge & Charlestown, 1953, Jan., Vol. 40, No. 1. (1,137 boreholes, no SPT-n value data).


Section 6: Dorchester, Somerville & Everett, 1956, Oct., Vol. 43 No. 4 (347 boreholes, no SPT-n value data).

These six sections were reprinted and published by the BSCE in one volume in 1961.

Reports of the Committee on Boston Subsoil BSCE Journal summarizing the borings completed since the above listed compilations are as follows:

Section 1: Boston Peninsula, 1969, July-Oct., Vol. 56 No. 3-4. pp. 131-291. (1,623 boreholes including SPT-n value data).


Section 3: South Boston, 1971, Jan., Vol. 58 pp. 51-63. (792 boreholes including SPT-n value data).

In 1972 the committee on Subsoils was disbanded due to lack of funds. The committee was again organized and the task continued as follows:
Section 4: Cambridge, 1984, Vol. 70, No. 1-2. (1,360 boreholes including SPT-n value data).

The above is the last compilation of boring logs published. The committee on the Boston Subsoils is still organized and is working on the next compilation of boring data.

Each BSCE compilation has presented the locations of the boreholes via a plan map referenced to the city streets. The boreholes are cross-referenced to the descriptions by assigning each borehole a reference number.

At the back of this appendix are presented the following BSCE borehole location plans used to create the profiles presented in this report:

1969 Boston Peninsula
1949 Boston Peninsula
1931 Boton Peninsula
1914 Boston Peninsula
1971 South Boston
1951 South Boston
1984 Cambridge
1953 Cambridge
1953 Charlestown
1951 East Boston

The symbol, ★, is located at the origin of the cartesian coordinate axis used to digitize the borehole locations. The plans that do not have this symbol have not been digitized. For the maps that have been digitized every borehole shown on the map will have reference number and the X and Y coordinates stored in a file on floppy disk.
APPENDIX II
PROGRAM BHDIGIT

The program described in this appendix controls and interprets the data strings generated by a Hipad Digitizer. The objective of the program is to create a digital form of the BSCE borehole location plan. The digital form of the borehole locations consists of the borehole reference numbers and corresponding cartesian coordinates with reference to some origin. The BSCE borehole data was currently only available as a plan map referenced to the city streets. The digital form is required so the information can be readily accessed by computer. The fast selection of the boreholes to present on a given profile performed by the program BHOFFSET is just one example of the usefulness of the digital form of the data.

The transformation from the spatial location of the boreholes on the plan to a digital location reference in the computer is accomplished using a Hipad Digitizer. The digitizer communicates with the IBM PC through a RS 232 comunication connection. The digitizer requires computer software to drive it, it can not be operated by itself. For this study a custom Digitizer driver has been written. The program named BHDIGIT.BAS, is written in Advanced Basic (BASICA), version A 1.11 and needs to be run through the MicroSoft BASICA line compiler.

The main feature of the program is that each digitized borehole has a corresponding reference borehole number. The program reads a single data string from the digitizer, then prompts the user for the reference borehole number for
chart in figure A2.1. The program displays instructions and prompts the user for information when required. An error trapping subroutine is included which restores the program in the event of an error. Without the routine an error would usually prove fatal (ie. the program would crash with loss of all data). The subroutine, however can only handle the limited number of errors for which it was programmed. The types of errors anticipated are concerned with opening files and errors in the operation of the digitizer such as depressing the wrong buttons. Details of the program operations are presented in the following paragraphs, reference to figure A2.1 will help to get an over view of the program.

In order for the program to calculate the X and Y locations it is necessary that the X and Y directions and a scaling length be defined. The program BHDIGIT carries out these operations by requesting that the user digitize the origin and ends of the X and Y axis. It then asks the user for the minimum and maximum X and Y coordinates. Using this information the rotation of the coordinate axis away from the axis of the digitizer is calculated. This is an important step in the determination of the correct locations because the X and Y coordinates that the digitizer communicates to the computer are referenced to the axis of the digitizer not the coordinate axis of the plan. It is very unlikely that the axis of the plan will coincide with the axis of the digitizer.

Once all the boreholes have been digitized and processed the program allows the user to print out the data file. An example of the format of the data file is presented in figure A2.2. The program next allows the user to save the data. The user is prompted for a file name. The program checks to see if the name
already exists. This is done by trying to open the file. If the file opens then it exists. If the file doesn't exist then an error is given and the error trapping subroutine restores the program. If the file exists then the new digitized data is appended to the end of the old data. If the file doesn't exist then a new file is created and the title of the borehole data is written to the file followed by all the digitized data.

The above argument about new and old files may seem rather confusing but the final result is that the data may be digitized in small areas at a time and the data stored in the same file. This is important because although the program contains error checking subroutines, it is not infallible. There are many stray buttons on the digitizer and if some of them are accidently depressed and the error checking subroutine is unable to recover from the error, all the digitizing that has not been saved up to that point is lost forever. Hence it is best to digitize small areas at a time and append the data to the same file.

Specific instructions for the operation of the digitizer are as follows;

1. Use the communication connection (RS 232) pins 15,18,20,10,11 of the digitizer to 7 at the IBM (GND.) pin 22 output (serial) of the digitizer to 3 (receive) data at the IBM.

2. Run the BHDIGIT, wait for the 'READY' sign then reset the digitizer pad by pushing the reset button followed by pressing the pushbutton when the cursor's axes are united with the origin of the axes of the digitized area.
   NOTE : The origin does not have to be at (0,0) but must coincide with Xmin and Ymin.

3. If the first presented numbers on the screen are not "(ORIGIN) 0,0" press the Y key followed by enter, you will probably have to start over. Otherwise follow instructions.

4. The next two points must be at (Xmax,Ymin) and (Ymax,Xmin). Continue to feed information followed by the borehole reference number as prompted. Use position : POINT on the Hipad at all times.
NOTE: switching the Hipad to Stream by accident (easily done) might result in buffer overflow and loss of all data.

5. To stop entering data, press the cursor down down key (↓) followed by the enter key and the Hipad digitezer pushbutton, (this data point will not be considered).
The following is a complete listing, additional explanatory notes are added in Italics. Refer to figure A.2.1 for a clearer perspective of the program operation and additional comments.

```
10 REM =================================================
      B H D I G I T  original: DJD  05-27-1986
           modified: M.Hawkes 06-06-1986
20 REM =================================================
135 REM
150 CLS : FOR I = 1 TO 5 : PRINT : NEXT I
170 INPUT "INPUT DATA TITLE ";TITLE$
300 INPUT "INPUT X-COORD. OF YOUR AXES ORIGIN ";XMIN
320 INPUT "INPUT Y-COORD. OF YOUR AXES ORIGIN ";YMIN
340 INPUT "INPUT MAX X VALUE ";XMAX
360 INPUT "INPUT MAX Y VALUE ";YMAX

Interactive input of data title,(TITLE$), and coordinates of corners of area to be digitized.

380 PRINT "YOU HAVE JUST INPUT THE FOLLOWING:" : PRINT
390 PRINT "DATA TITLE: ";TITLE$
400 PRINT "ORIGIN AT X= ";XMIN," Y= ";YMIN
410 PRINT "X MAX = ";XMAX," Y MAX = ";YMAX
420 INPUT "DO YOU WANT TO MAKE ANY CHANGES? (Y/N) ";ANS$
440 IF ANS$="Y" GOTO 170
450 IF ANS$="N" GOTO 550 ELSE PRINT "TRY AGAIN"
460 GOTO 420

Gives user chance to check coordinates and make any changes.

550 PRINT " WAIT"
560 DIM X(1500), Y(1500), XY$ (1500), BH(1500)

Set maximum allocated memory space for arrays.

X array; X-coordinates of borehole locations.
Y array; Y-coordinates of borehole locations.
XY array; Hipad combined coordinates for Borehole locations.
BH array; Borehole reference numbers.

580 KEY(14) ON
600 OPEN "COM1:1200,M,7,1,CS,DS,CD" AS #1
610 PRINT : PRINT "   R E A D Y "

Turn on key trapping for key (↓). Open a file and allocate a
```
buffer for RS-232C communication with the Hipad digitizer.

625 CLS : FOR I = 1 TO 5 : PRINT : NEXT I
630 PRINT "PRESS RESET BUTTON ON DIGITIZER AND DIGITIZE ORIGIN
POINT"
640 PRINT "AFTERWARDS, DIGITIZE THE MAX VALUE ALONG THE X AXIS"
650 PRINT "THEN DIGITIZE THE MAX VALUE ALONG THE Y AXIS" : PRINT
670 PRINT "THEN START DIGITIZING":PRINT
680 PRINT "TO END DIGITIZING,PRESS THE CURSOR DOWN ( ) KEY ON
IBM KEYPAD"
690 PRINT "THEN PRESS ENTER KEY,AND DIGITIZE ANY ARBITRARY POINT"

Display instructions on the screen to start and end digitizing.

700 I = 1
705 ON ERROR GOTO 1600

Initialize counter. Enable error trapping and specify the first line of the error handling subroutine.

START PRIMARY DATA INPUT LOOP.

710 PRINT : PRINT "DIGITIZE";
715 INPUT #1, XY$(I)

Read data string from hipad digitizer.

720 IF I > 3 THEN INPUT "BOREHOLE #"; BH(I)

If origin, Xmax and Ymax have already been entered, then prompt, and read the borehole reference number.

725 XS=MID$(XY$(I),2,6) : YS=MID$(XY$(I),8,6)
730 X(I)=VAL(XS) : Y(I)=VAL(YS)

Set I'th value of arrays X & Y equal to the numerical value of the portion of the Hipad string which corresponds to the X & Y coordinates.

732 IF I = 1 THEN PRINT "( ORIGIN )" ";X(I)"", ";Y(I)
734 IF I = 2 THEN PRINT "( X-AXIS )" ";X(I)"", ";Y(I)
736 IF I = 3 THEN PRINT "( Y-AXIS )" ";X(I)"", ";Y(I)
740 IF I > 3 THEN PRINT "(";BH(I),")" ";X(I)"", ";Y(I)

Display the digitized point on the screen.

750 ON KEY(14) GOTO 860

If the cursor down ( ) key is pressed then skip out of data input loop.

760 IF I > 1 GOTO 840
770 PRINT : PRINT : PRINT "CHECK IF X,Y OF THE ORIGIN IS (0,0)."
IF NOT, PRESS CURSOR DOWN "; : PRINT CHR$(25) ;;PRINT " FOLLOWED BY THE ENTER KEY AND THE HIPAD PUSHBUTTON "

* Display message to check origin coordinates, skip if origin has already been entered.

840 IF I > 1500 GOTO 870
850 I=I+1 : GOTO 710

* If more than 1500 data points have been entered skip out of data input loop, else loop for the next data point.

END OF PRIMARY DATA INPUT LOOP.

860 INPUT DUMMY$
865 CLS: PRINT ; PRINT: PRINT
870 INPUT"END OF DATA INPUT; DO YOU WANT TO CONTINUE PROCESSING THE DATA? (Y/N)*;AN1$
880 PRINT: PRINT
890 IF AN1$="Y" GOTO 980
900 IF AN1$="N" GOTO 950 ELSE PRINT "TRY AGAIN"
920 GOTO 870
930 PRINT ; PRINT: PRINT " REMEMBER TO PRESS THE RESET BUTTON (* to reset the HIPAD to zero *) AFTER THE NEXT RUN COMMAND"
950 END

Interactively ask user if he/she wishes to continue processing the data. If no then display message to rest digitizer and end program.

START DATA REDUCTION

980 PRINT " DATA BEING PROCESSED. PLEASE WAIT."
1010 IF Y(2)<=0 THEN TH1=ATN(Y(2)/X(2)) ELSE TH1=0
1020 IF X(3)<=0 THEN TH2=ATN(X(3)/Y(3)) ELSE TH2=0
1030 THETA=(TH1+TH2)/2

Calculate rotation (THETA) of the map grid away from the Hipad axis.

1040 X2=X(2)*COS(THETA)+Y(2)*SIN(THETA)
1050 Y3=X(3)*SIN(THETA)+Y(3)*COS(THETA)

Calculate coordinates of map corners.

START PRIMARY DATA REDUCTION LOOP.

1060 FOR J=4 TO I-1
1070 XM=X(J)*COS(THETA)+Y(J)*SIN(THETA)
1075 YM=Y(J)*COS(THETA)-X(J)*SIN(THETA)
1080 X(J)=(XM*(XMAX-XMIN)/X2)+XMIN
1085 Y(J)=(YM*(YMAX-YMIN)/Y3)+YMIN
1090 NEXT J
END PRIMARY DATA REDUCTION LOOP.

1100 PRINT : PRINT
1115 INPUT "DO YOU WANT TO PRINT RESULTS ON PRINTER ? (Y/N) " ;AN2$
1120 IF AN2$= "N" GOTO 1360
1130 IF AN2$= "Y" GOTO 1180 ELSE PRINT "TRY AGAIN"
1150 GOTO 1100
1180 LPRINT CHR$(14);TITLE$
1190 LPRINT :LPRINT :LPRINT " NO. OF DATA POINTS = ";I-4;"
1240 LPRINT " SELECTED MINIMUNS AND MAXIMUNS: XMIN= ";XMIN;
1240 LPRINT " YMIN= ";YMIN;" XMAX= ";XMAX;" YMAX= ";YMAX
1250 LPRINT : LPRINT : LPRINT: "Borehole X Y "
1260 FOR J=4 TO I-1
1280 LPRINT :TAB(2) BH(J); : LPRINT TAB(8) USING
1280 "+#####.#####";X(J),Y(J)
1330 NEXT J
1340 LPRINT : LPRINT : LPRINT ;LPRINT "TH1 = ";TH1, "$H2 = ";TH2
1342 LPRINT "THETA = "; THETA

Interactively ask user if he/she wishes to printout the data. If yes then write headings on the printer and send all the formatted data to the printer.

1350 PRINT : PRINT
1360 INPUT "DO YOU WANT TO STORE THE DATA ? (Y/N)" ;AN3$
1380 CLOSE
1390 IF AN3$="N" GOTO 1480
1400 IF AN3$="Y" GOTO 1430 ELSE PRINT "TRY AGAIN"
1420 GOTO 1360
1425 PRINT : PRINT
1430 INPUT "PRINT THE FILE NAME UNDER WHICH YOU WANT THE DATA TO BE STORED" ;FILE$

Interactively ask user if he/she wishes to save the data. If yes ask the user for the name of the data file to be used.

1435 OPEN FILE$ FOR INPUT AS #1
1500 CLOSE
1510 OPEN FILE$ FOR APPEND AS #1
1515 PRINT:PRINT " OLD FILE"

If the file doesn't exist then line 1435 will cause error number 53 and control will be transferred to line 1600. If the file exists then close file and open for appending.

1530 FOR M=4 TO I-1
1540 PRINT #1, BH(M),X(M),Y(M)
1550 NEXT M
1560 PRINT : PRINT " END OF PROCESS "
1570 END

155
Write data to the file.

The following section of the program is an error trapping routine. In the event that an error is initiated in any section of the main program, control will be passed to to the subprogram starting on line 1600.

1600 CLS :PRINT:PRINT:PRINT
1610 BEEP: FOR J = 1 TO 100: NEXT J: BEEP
1630 IF ERR = 69 OR ERR = 57 THEN 1730 ELSE 1900

Error 69 : Communication Buffer overflow
Error 57 : Device I/O Error

Both these errors are associated with errors on the HIPAD control buttons. The following steps halt the program and allow for resetting the HIPAD buttons.

1730 PRINT " ***** ERROR ON HIPAD *****":PRINT
1735 PRINT " CHECK THE BUTTONS ON THE HIPAD":PRINT
1737 IF ERR = 57 THEN 1800

If the error is a communication buffer overflow then some extra data may have been read.

1738 PRINT " ALSO CHECK DATA WHEN FINISHED":PRINT
1740 IF I > 3 THEN I = I-1
1750 INPUT " ***** PRESS ANY KEY TO CONTINUE *****";D$
1760 CLOSE
1770 OPEN " COM1:1200,M,7,1,CS,DS,CD" AS # 1
1790 RESUME 710

Open and close communication buffer required to clear the buffer.

1800 CLOSE
1810 INPUT " ***** PRESS ANY KEY TO CONTINUE *****";D$
1820 RESUME 600

For I/O error start the communication procedure over again at line 600.

1900 IF ERR = 53 THEN 1905 ELSE 3000

Error 53 : File not found.

This error routine is initiated as a check to see if the output data file already exists. If file does not exist then the following steps are performed. The main difference between this procedure and that for existing files being that the title is written to the data file.

1905 CLOSE
1910 OPEN FILE$ FOR OUTPUT AS #1
1920 PRINT: PRINT " NEW FILE"
1930 PRINT #1, TITLE$
1940 RESUME 1530

If none of the error traps listed above succeed, then write message and end the program.

3000 PRINT " UNKNOWN ERROR NUMBER ";ERR : PRINT
3010 END
START

Interactive input of:
1) Data Title
2) Min and Max. axis coordinates
TITLE$, XMIN, YMIN, XMAX, YMAX

Are title and axis coordinates correct?

NO
440

YES
660

Open communications with the
Hippod Digitizer

760

Initialize main borehole array counter I = 1

710

Interactive input from Hippod Digitizer
1) Coordinate string; XY$
2) Borehole reference; BH(I)

725

Convert XY$ into X and Y Components

750

Has Key F1 been pressed?

NO
860

YES
850

Increment main borehole array counter I = I + 1

870

Do you want to continue processing data?

NO
950

YES

END

FIG. A 2.1(b)
From Fig. A.2.1(a)

980
Calculate rotation of coordinate axis away from the Hipad axis

1060
Calculate X and Y coordinates for each borehole relative to coordinate axis

1115
Do you want to print the data?

YES
1180
Send formatted data to the printer

NO
1360
Do you want to store the data?

NO
END

YES
1430
Interactive input of file name

FILE$

1435
Open file for input

Error 53
1600
Error trapping subroutine

Close file

Open file for output

Open file for appending

Write title in file

1570
Write borehole reference and coordinates in file for each borehole

END
<table>
<thead>
<tr>
<th>Number</th>
<th>X Coordinate</th>
<th>Y Coordinate</th>
</tr>
</thead>
<tbody>
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<td>880</td>
<td>3.06719</td>
<td>8.261331</td>
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<td>3.600577</td>
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<td>90</td>
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APPENDIX III
PROGRAM BHOFFSET

INTRODUCTION

This section describes the program BHOFFSET.PAS. The program is written in Borland Int.'s TURBO PASCAL Ver. 2.0. TURBO PASCAL is a compiler, this means the program is converted into machine instructions before it is run. Unlike the BASIC program which must be run while the interpreter runs, this program may be run like a DOS external command (i.e. it has a file extension COM). The end result of this is that the program is fast.

The Pascal language allows for program development as a series of blocks. Each block, called a Procedure, may be developed and tested independently of the rest of the program. Not only is this very convenient for programming, it also makes the program easy to read. BHOFFSET contains a main portion and a series of procedures. The procedures are run simply by calling their name and passing them the appropriate parameters. All the procedures are called from the main part of the program.

The program BHOFFSET first reads a text data file generated by BHDIGIT.BAS. This data file contains the borehole reference number and the X and Y coordinates. The program prompts the user for the coordinates at the start and end of the alignment and the maximum perpendicular offset from this alignment. This latter information is used to define a criteria zone as depicted in figure 3.2. The program looks at all the boreholes in the data file and selects the boreholes
which are located within this zone.

The selection process is performed in the Procedure CALCULATIONS. The angle, $\phi$, subtended by the alignment and a line from the start of the section to the borehole must first be calculated. (Refer to figure A3.1 for definitions of the variables used in procedure CALCULATIONS). If $\phi$ is greater than 90 the borehole is located West of the section and is skipped (see figure A3.1). If the borehole is not eliminated by the above test, the perpendicular offset is calculated. If the offset is greater than the maximum specified offset then the borehole is skipped. If the borehole is still not eliminated, then the distance along the alignment is calculated. If this distance is greater than the length of the section then the borehole is skipped. All the boreholes which pass the above three tests are written to the results file. This file includes the borehole reference number, distance along the section, offset and $X, Y$ coordinates. This selection process is discussed in greater detail in the section of this appendix which presents the procedure CALCULATIONS.

To aid in general program development a set of commonly used procedures which enhance those already included in TURBO PASCAL has been used. These procedures perform simple tasks such as prompting the user to push any key before continuing with the next operation, inserting blank lines on the monitor or performing interactive input for Boolean value (yes or no) based decisions. Another procedure has been used which checks for errors when opening data files. These procedures are not presented in this report. The interested Pascal programmer can easily develop an equivalent set of procedures. These procedures are contained in files called ROUTINE.INC and IOCHECK.INC which are added to the program BHOFFSET when it is compiled.
The following is an example of the display and prompts that are viewed on the screen during program execution. The tables of data are presented in the same format as the files from which they are read or written (i.e. the input and output files). To avoid scrolling the screen, the screen is cleared numerous times during program execution. The following is how the display would appear if the screen were not cleared. The user responses are shown in bold lettering.
***** PROGRAM BHOFFSET *****

(last revision 11-10-86 M.Hawkes)

This program reads a data file containing the borehole reference number and X and Y coordinates. The program then prompts the user for the start and end coordinates and a maximum offset for a profile alignment. The program selects all the boreholes from the data file which are located on the alignment and calculates the distance and offsets for these boreholes. The latter information is written in a file of the users choice.

***** TO CONTINUE, PLEASE STRIKE ANY KEY *****
Enter the name of the data file: **CAME84.DAT**

Number of Boreholes in this record: 779

WOULD YOU LIKE TO VIEW THE DATA ? (Y/N) **Y**

Title 1984

Number of data: 779

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Xcoord</th>
<th>Ycoord</th>
</tr>
</thead>
<tbody>
<tr>
<td>577</td>
<td>13.11</td>
<td>4.52</td>
</tr>
<tr>
<td>578</td>
<td>13.25</td>
<td>4.61</td>
</tr>
<tr>
<td>579</td>
<td>13.33</td>
<td>4.65</td>
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<tr>
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<td>4.72</td>
</tr>
<tr>
<td>576</td>
<td>13.33</td>
<td>4.78</td>
</tr>
<tr>
<td>575</td>
<td>13.2</td>
<td>4.68</td>
</tr>
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<td>574</td>
<td>13.09</td>
<td>4.63</td>
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<tr>
<td>551</td>
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<td>6.21</td>
</tr>
<tr>
<td>573</td>
<td>13.22</td>
<td>6.16</td>
</tr>
<tr>
<td>550</td>
<td>13.21</td>
<td>6.11</td>
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<tr>
<td>549</td>
<td>13.24</td>
<td>6.08</td>
</tr>
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<td>570</td>
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<td>6.05</td>
</tr>
<tr>
<td>548</td>
<td>13.24</td>
<td>6.01</td>
</tr>
<tr>
<td>547</td>
<td>13.2</td>
<td>5.99</td>
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<tr>
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<td>13.26</td>
<td>5.97</td>
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<td>571</td>
<td>13.3</td>
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<td>13.37</td>
<td>5.99</td>
</tr>
<tr>
<td>559</td>
<td>13.29</td>
<td>5.88</td>
</tr>
</tbody>
</table>

***** TO CONTINUE, PLEASE STRIKE ANY KEY *****

XCoord at start of Section ? **18.24**

Ycoord at start of Section ? **3.42**

Xcoord at end of Section ? **18.47**

Ycoord at end of Section ? **7.00**

Start Coordinates: (18.24, 3.42 )

End Coordinates : (18.47, 7.00 )

Any Changes ? (Y/N) **N**
WITHIN WHAT RANGE OF OFFSET DO YOU REQUIRE (ft) ? 150

***** CALCULATING *****

15

WOULD YOU LIKE TO VIEW THE RESULTS ? (Y/N) Y

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Distance</th>
<th>Offset</th>
<th>(Xcoord,Ycoord)</th>
</tr>
</thead>
<tbody>
<tr>
<td>853</td>
<td>0.54</td>
<td>11.50</td>
<td>(18.26, 3.96)</td>
</tr>
<tr>
<td>844</td>
<td>0.74</td>
<td>9.00</td>
<td>(18.28, 4.16)</td>
</tr>
<tr>
<td>845</td>
<td>0.97</td>
<td>-5.27</td>
<td>(18.31, 4.39)</td>
</tr>
<tr>
<td>846</td>
<td>1.27</td>
<td>-11.26</td>
<td>(18.33, 4.69)</td>
</tr>
<tr>
<td>847</td>
<td>1.54</td>
<td>-23.51</td>
<td>(18.36, 4.96)</td>
</tr>
<tr>
<td>835</td>
<td>1.73</td>
<td>-16.68</td>
<td>(18.37, 5.15)</td>
</tr>
<tr>
<td>841</td>
<td>2.06</td>
<td>148.10</td>
<td>(18.22, 5.48)</td>
</tr>
<tr>
<td>842</td>
<td>2.06</td>
<td>71.24</td>
<td>(18.3, 5.48)</td>
</tr>
<tr>
<td>836</td>
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<td>-7.11</td>
<td>(18.39, 5.62)</td>
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<tr>
<td>829</td>
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<td>-21.11</td>
<td>(18.43, 6.01)</td>
</tr>
<tr>
<td>828</td>
<td>2.61</td>
<td>52.12</td>
<td>(18.36, 6.03)</td>
</tr>
<tr>
<td>830</td>
<td>2.62</td>
<td>-125.93</td>
<td>(18.53, 6.03)</td>
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<tr>
<td>825</td>
<td>2.69</td>
<td>56.78</td>
<td>(18.36, 6.11)</td>
</tr>
<tr>
<td>827</td>
<td>2.69</td>
<td>-116.76</td>
<td>(18.53, 6.10)</td>
</tr>
<tr>
<td>826</td>
<td>2.7</td>
<td>-29.71</td>
<td>(18.44, 6.11)</td>
</tr>
</tbody>
</table>

WOULD YOU LIKE TO RECALCULATE WITH A NEW RANGE ? (Y/N) N

Enter the name of the Output file (eg. TREMONT) : PEARL84

Would you like another run ? (Y/N) N
The program is presented in sections, first the main program then the individual procedures. A complete listing of the program is presented at the back of this appendix. Additional explanatory notes are added in the listings, these are written in *italics*. Each section is accompanied by a flow chart which gives a simplified overview of the program operations.

**PROGRAM BHOFFSET (Main Portion)**

The operations performed by the program BHOFFSET are presented in the flow chart in figure A3.2(a) and (b). Like many programs the major part of the instructions involve the handling of input and output. Most of the action takes place in the Procedures, and the real work is performed in the Procedure CALCULATIONS. The procedures are called one after another as dictated by the main program. The procedures are all self contained operations on the parameters that are transferred from the main portion of the program. When the procedure statement is encountered during program execution, control is transferred to the procedure. When the procedure finishes, program execution continues from the statement following the procedure statement. The procedures called from the main body of the program are presented in the following sections. At the end of this section the screen display from a typical BHOFFSET session is presented.

A general description of the program operation has already been presented in the introduction. More details are given in the procedure descriptions. The complete listing of the main portion of program BHOFFSET is presented at the back of this appendix, with additional explanatory notes added in *italics*. The remainder of this appendix describes the procedures of the program BHOFFSET one at a time.
PROGRAM BHOFFSET(INPUT,OUTPUT);
{Written by Martin Hawkes, last revision 8/5/86}

{$l Routine.INC}
{$l IOCheck.INC}

Include compiler directive: Routine.INC includes commonly used procedures WaitForAnyKey, YesOrNo, Lines and Beep among others. IOCheck contains commonly used procedure IOCheck.

{$l-}

Compiler directive disables I/O error handling.

CONST Space = ' ';

TYPE
Title = STRING[255];
Name = STRING[20];
BH_Id = RECORD
    BH_Num : INTEGER;
    Xcoord,Ycoord : REAL;
END;
BH_OK = RECORD
    BH_Num : INTEGER;
    Offset,Distance : REAL;
    Xcoord,Ycoord : REAL;
END;
BH_Ref = ARRAY[1..1000] OF BH_Id;
BH_Okay = ARRAY[1..100] OF BH_OK;

VAR
FileVar                   : TEXT;
I,Num_Data,Num_Result : INTEGER;
X1,Y1,Xend,Yend,Range : REAL;
FileName                  : Name;
Heading                   : Title;
BH_data                   : BH_Ref;
BH_result                 : BH_Okay;
Flag,OKay,OK              : BOOLEAN;

FileVar; File var variable identifies the file generated by BHDIGIT containing the digitized data.
I; Working variable.
Num_Data; Number of Boreholes in the file identified by FileVar.
Num_Result; Number of Boreholes which are within the offset of the section.
X1,Y1; Coordinates at the start of the section.
Xend,Yend; Coordinates at the end of the section.
Range; Maximum permissible offset from the section.
Filename: Name of the output file containing all the boreholes within the offset of the section.

Heading: Title given to the boring data in program BHDIGIT.BAS.

BH_Data: Borehole numbers and coordinates in Filevar as generated by program BHDIGIT.BAS.

BH_Result: Borehole numbers, Distance and Offsets for all the boreholes within the maximum permissible offset of the section.

Flag, OK, OK; Working variables.

LABEL 20, 30, 40;

BEGIN
  Lines(3);
  WRITELN (Space:20,'***** PROGRAM BHOFFSET *****');
  Lines(3);
  WRITELN (Space:10,'Disk containing Borehole locations must be in the A: Disk Drive');
  WRITELN;
  WRITELN (Space:10,'Disk containing the Output Borehole Distances and Offsets must be');
  WRITELN (Space:15,'in the B: Disk Drive.');
  WaitForAnyKey;

Preliminary information for user so the input and output disks are not confused

30: CLRSCR; Lines(3);
    File_Name(FileName);

Procedure Filename interactively asks user for filename containing data and initializes file. See listing and explanation.

Read_Data(Heading, Num_Data, BH_Data);

Procedure Read_Data reads the data from data file. See listing and explanation.

Writeln; Writeln;
IF YesOrNo ('WOULD YOU LIKE TO VIEW THE DATA ?') THEN
  Write_Data (Heading, Num_Data, BH_Data);

Allows user the option to view the data in the file generated by BHDIGIT. Procedure Write_data writes the data on the monitor for viewing. See listing and explanation.

40: CLRSCR; Lines(3);
  WRITE (Space:10,'Xcoord at start of Section ?');
  READLN(X1);
  WRITELN; WRITE (Space:10,'Ycoord at start of Section ?');
  READLN(Y1);
WRITELN; WRITE (Space:10,'Xcoord at end of Section ?');
READLN(Xend);
WRITELN; WRITE (Space:10,'Ycoord at end of Section ?');
READLN(Yend);
CLRSCR; Lines (5);
WRITELN (Space:5,'Start Coordinates: ,X1:5:2,,
' ,Y1:5:2,''));
WRITELN;WRITELN (Space:5,'End Coordinates :
',Xend:5:2,',,Yend:5:2,''));
Lines(3);
IF YesOrNO ('Any Changes ?') THEN GOTO 40;
20: WRITELN;
WRITE ('WITHIN WHAT RANGE OF OFFEST DO YOU REQUIRE (ft) ?');
READLN(Range);

Interactive input of the start and end coordinates of the Section and maximum permissible offset. Allows for mistakes by looping to line 40.

Calculations(Num_Data,Num_Result,BH_Data,BH_Result,X1,Y1,
Xend,Yend,Range);
Beep;

Procedure Calculations, calculates the distance and offset of the boreholes using the coordinates of the boreholes and the end coordinates of the section. Boreholes within the Maximum offset are written into array BH_Result. See listing and explanation.

Shell_Sort(Num_Result,BH_Result);
Beep;

Procedure Shell_Sort sorts the Boreholes, Distances and Offsets in array BH_Result into order of ascending distance from the start of the section. See listing and explanation.

WRITELN;
IF YesOrNo ('WOULD YOU LIKE TO VIEW THE RESULTS ?') THEN
Write_Results(Num_Result,BH_Result);

Allows user option of viewing the boreholes within the maximum permissible offset. Procedure Write_Results writes the results on the monitor. See listing and explanation.

WRITELN;
Flag := FALSE;
IF YesOrNo ('WOULD YOU LIKE TO RECALCULATE WITH A NEW RANGE ?') THEN
BEGIN
 WRITELN;WRITELN ('RANGE MUST BE LESS THAN ',Range:5:0);
 Flag := TRUE
END;
IF flag THEN
BEGIN
FOR I := 1 TO Num_Result DO
BEGIN
    BH_Data[I].BH_Num := BH_Result[I].BH_Num;
    BH_Data[I].Xcoord := BH_Result[I].Xcoord;
    BH_Data[I].Ycoord := BH_Result[I].Ycoord;
    Num_Data := Num_Result
END
END;
IF flag THEN GOTO 20;

 Allows user option of recalculating with a new offset. If a new
 Offset is chosen (ie. Flag is TRUE) then the BH_Data array is
 replaced with the BH_Result array and the program loops back to
 line 20.

REPEAT
    Writeln;Write(’Enter the name of the Output file (eg. TREMONT):’);
    Readln(FileName);
    IF Length(FileName) > 8 THEN
        BEGIN
            Beep;
            Writeln;
            Writeln (’NAME TOO LONG ! TRY AGAIN’)
        END
    UNTIL Length(FileName) <= 8;
    FileName := FileName + ’.PRN’;
    Assign(FileVar,FileName);
    Rewrite(FileVar);

 Interactively asks user for output file name and checks to make
 sure it is acceptable. File Extension PRN is added so file can be
 read directly into a LOTUS 123 spread sheet. Initializes the file
 for data output.

FOR I := 1 to Num_Result DO
BEGIN
    WITH BH_Result[I] DO
    Writeln(FileVar,BH_Num,Distance,Offset);
END;
Close(FileVar);

Write Borehole number, distance and offset to the output file for
all the boreholes which are within the permissable offset.

CLRSCR; Lines(3);
IF YesOrNo (’Would you like another run ?’) THEN GOTO 30
END.

Interactively asks the user if he/she wishes another run.
PROCEDURE FILE_NAME

The procedure described in this section interactively asks the user to specify the name of the data file to use. The Borehole reference numbers and coordinates contained in this file will be used throughout the main program. If the file is found, then the program opens the file. If the file is not found, then an error is reported. The Procedure IOCheck (contained in the include file Routine.INC) interprets the error and prints a message. The procedure File_Name is repeated until a file is successfully opened.

The operations performed by Procedure File_Name are presented as a flow chart in figure A3.3. The procedure is listed as follows, with additional comments added in Italics.

```
PROCEDURE File_Name(VAR FileName:Name);
BEGIN
  REPEAT
    WRITE(Space:10,'Enter the Name of the data file: ');
    READLN(FileName);
    ASSIGN(FileName,FileName);
    RESET(FileName);
    IOCheck(OK);
    Procedure IOCheck traps errors due to incorrect filename. If Filename and initiation are okay then OK is TRUE.
    IF NOT OK THEN WRITELN ('Cannot Find File ',FileName);
    UNTIL OK;
  END;
Procedure will repeat until the file is successfully initiated.
```
PROCEDURE READ_DATA

The procedure presented in this section reads the data contained in the data file specified in the Procedure File_Name. This file is referred to by the program as FileVar (short for the File Variable). The procedure counts the number of borehole records as it reads them. This information is referenced Num_Data. The operations performed are schematically presented in the flow chart in figure A3.4.

The first row of the data file contains the heading for the data to follow. This information is read into the computer memory (RAM) and referenced by the variable Heading. Next, the Borehole number and the X and Y co-ordinates are read from a single line of the data file, this information is referenced by the program as the variables BH_Num, Xcoord and YCoord, respectively. This information is also referenced collectively as BH_Data. This latter feature, known as a "data record", is one of the appealing features of computer languages such as Pascal and C. Entire data records may be swapped or deleted without having to deal with their component parts. The variable BH_Data is a subscripted variable known as an array. The first borehole record in the file is subscript 1, the second subscript 2 etc..

The location of the record in the array, the subscript, is controlled by the array counter Num_Data. The counter is increased for each borehole data record read from the data file (ie. each line). When all the borehole records have been read the variable Num_Data will contain the total number of borehole data in the array.

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The program reads each line of the data file storing the information in the computer memory (RAM) until the end of the file is encountered. At this point the data read loop is exited and the procedure displays the number of data records read from the data file.

A complete listing of the Procedure Read_Data is listed as follows with additional comments added in italics;

```
PROCEDURE Read_Data(VAR Heading:Title;VAR Num_Data:Integer; VAR BH_Data:BH_Ref);
BEGIN
  READLN(FileVar,Heading);

  The title of the borehole data is read from the file and assigned to the variable Heading.

  Num_Data := 0;
  WHILE NOT EOF(FileVar) DO
    BEGIN
      Num_Data := Num_Data + 1;
      WITH BH_Data[Num_Data] DO
        READLN(FileVar,BH_Num,Xcoord,Ycoord);
    END;
  Lines(3);  Writeln(Space:10,'Number of Boreholes in this record:
',Num_Data);

  The Borehole number and coordinates are read into the array BH_Data for each borehole until the end of the file is encountered. The loop counter Num_Data counts the number of boreholes read from the file.

  CLOSE(FileVar)
END;
```
PROCEDURE WRITE_DATA

The Procedure Write_Data displays on the monitor the information read from the data file by the procedure Read_Data. The information is contained in the array BH_Data and consists of the Borehole reference number and the X and Y coordinates. A screen full of data is displayed with table headings. The user is prompted to press any key before the procedure continues. When a key is depressed the screen is cleared and the next screen full of data is displayed. This process is repeated until all the data in the array has been displayed.

A flow chart depicting the procedure operations is presented in figure A3.5. A complete listing is presented on the following page, with additional comments added in italics.
PROCEDURE Write_Data (Heading: Title; Num_Data: Integer; BH_Data:BH_Ref);

Procedure to write the reference numbers and coordinates of the boreholes contained in the array BH-Data under the appropriate column headings.

BEGIN
  CLRSCR; Lines (2);
  WRITELN ('TITLE: ', Heading);
  WRITELN ('Number of data:', Num_Data);

Write the data information at the top of the screen.

  WRITELN;
  WRITELN ('BoreHole Xcoord Ycoord');

Write the column headings.

FOR I:= 1 TO Num_Data DO
  BEGIN
    WITH BH_Data[I] DO
      WRITELN (BH_Num:5,Xcoord:15:2,Ycoord:10:2);
      IF FRAC (I/20) = 0 THEN
        BEGIN
          WRITELN; WaitForAnyKey; CLRSCR;
        END;
      END;
  END;

Check to see if the screen is full, 20 boreholes to the screen. If the number of boreholes written, I, is exactly a multiple of 20 then screen is full. Procedure WaitForAnyKey is contained in include file Routine.Inc and prompts the user to press any key before continuing.

WaitForAnyKey
END;
PROCEDURE CALCULATIONS

The procedure presented in this section is where most of the action in the program BHOFFSET takes place. This procedure selects all the boreholes which are located along the alignment. The alignment is defined by start and end coordinates and an offset, which in effect defines a rectangular area as depicted in figure 3.2. This information is specified by the user in the main program and is passed to this procedure for use in the calculations. A flow chart for the operations performed in the procedure Calculations is presented in figure A3.6 and a complete listing with additional comments is presented at the end of this section. A schematic of the parameters used in the procedure is shown in figure A3.1.

The variable 'Lenth' which contains the length of the alignment is purposely misspelled, this is because the word Length is reserved for a predefined procedure in the Pascal language. This realization came about after many frustrating hours of debugging what appeared to be a perfectly good program, and shows that the smallest (almost trivial) overlooked details can be the most difficult to deal with. A detailed description of the operations presented in figure A3.6 follows.

The first step is to perform the calculations which can be applied to every borehole record. These are the calculations which pertain to the alignment and which do not need to be done repeatedly for each borehole record. The length of the section, Lenth, is determined by Pythagoras theorem.
The rotation of the alignment away from the x-axis, $\Theta$, see figure A3.1 is next calculated. For the special case when the alignment is in the X direction the difference in Y coordinates is 0, and $\Theta$ will be 0. Otherwise, $\Theta$ is calculated from the trigonometric relation listed in the program.

Before starting the primary data calculation loop the array counters must be initiated. Variable 'I' is used to subscript the records in the BH_Data array and the variable Num_Result will be used to subscript the records in the BH_Result array. The BH_Result record will contain the borehole reference number, the X and Y coordinates, the distances and the offset. This information will be referenced, BH_Num, Xcoord, Ycoord, Distance and Offset, respectively.

The primary data loop may now be started. As seen from figure A3.6 some portion of this loop is performed for every borehole in the array BH_Data. The variables for the borehole data records are calculated one step at a time and records are eliminated at three points along the way. The design of the loop is such that the calculations are performed in an order permitting borehole records to be eliminated at as many stages as possible while no extra calculations are performed other than those necessary for the calculations of the Distance and Offset. The operations contained in the diamonds in figure A3.6 perform the eliminations and only the Records that make it through all the steps in the loop are written to the BH_Result array. The calculations and eliminations proceed as follows.

The angle, $\alpha$, (see figure A3.1) between a line from the borehole to the start of the alignment and the X axis is calculated in a similar manner to $\Theta$. The difference between $\alpha$ and $\Theta$ will give the angle between a line from the
borehole to the start of the alignment and the alignment, \( \emptyset \) (see figure A3.1). This angle is corrected to a full circle angle by comparing the borehole coordinates to those at the start of the alignment. If the absolute value of \( \emptyset \) is greater than \( \pi/2 \) radians then the borehole is located west of the section. If the borehole is located west of the section the procedure skips to the end of the primary data calculation loop, checks to see if there are any more data records left and enters the beginning of the loop with the next record or ends the procedure. For this elimination to work it is essential that the west end of the alignment always be specified as the start of the alignment, if this is not done then boreholes which may satisfy the criteria will be eliminated by the above check.

If the borehole is not located west of the section then it is necessary to increase the BH_Result array subscript, Num_Result. This is because the following calculations will be stored straight into the file as performed. The entire record may be eliminated or over written if necessary. The distance between the borehole and the start of the alignment, Dist (see figure A3.1) is calculated in a similar manner as Lenth. The Offset is then calculated using a trigonometric relationship. The Offset will be positive if the borehole is located north of the alignment (m is positive) and negative if vice versa. The absolute value of the Offset is compared to the maximum offset (Range) specified by the user in the main portion of the program. If the Offset is less than the Range then the Distance (see figure A3.1) is calculated using a trigonometric relationship. The Distance and Offset are stored in variables in the data record as they are calculated.
If the Offset is greater than the Range then Num_Result (BH_Data record subscript) is decreased. When the Distance and Offset are calculated for the next borehole the data already contained in the record will be overwritten by the new information. The procedure then skips to the end of the primary data calculation loop, checks to see if there are any more data records left and enters the beginning of the loop with the next record or ends the procedure. In the actual program execution and as depicted in the listing, the loop is not as gracefully exited as described above or as shown in the flowchart. A boolean variable 'Flag1' is made true and the following calculations are not performed if Flag1 is true. This minor complication is a result of the limitations in translating a computer program from English to machine language. In the Pascal language the loop simply cannot be exited at this point and flags must be set to skip the rest of the loop. The effect however, is identical to that depicted in the flowchart.

Finally, if the Distance is greater than the Length then the borehole is located east of the section and the procedure again skips to the end of the loop. If the Distance is less than the Length, then the borehole reference number and coordinates are added to the BH_Result record.

In the next step the loop ends for all the boreholes. The BH_Data array subscript is incremented, and a check is made to see if there are anymore records in the BH_Data array that have not been used. If all records have been used then the procedure ends. If there are more records then the primary data calculation loops is entered at the beginning for the next boreHole record.

The complete procedure listing is presented on the following pages with
additional comments in italics;
PROCEDURE Calculations (VAR Num_Data, Num_Result : INTEGER; 
BH_Data : BH_Ref; 
VAR BH_Result : BH_Okay; 
X1, Y1, Xend, Yend, Range : REAL);

Procedure to calculate the perpendicular offset and distance of all the boreholes along the section. All the borehole records for which the offset is less than the maximum permissible offset are written to a separate array for modifying or storing on disk.

VAR
Theta, Beta, Phi, Xdiff, Ydiff, Lenth, Dist : REAL; 
Flag : BOOLEAN; 
I : INTEGER;

Theta; Angle between section and Y-axis. 
Beta; Angle formed between line from start of section to the borehole and the Y-axis. 
Phi; Angle formed between line from the start of section to the borehole and the section. 
XDiff, YDiff; Numerical difference in coordinates between the borehole and the start of the section. 
Lenth; Length of the section. 
Dist; Distance between the borehole and the start of the section. 
Flag, I Working variables.

Refer to fig. A3.1 for a description of all the variables in this procedure.

LABEL 10;

BEGIN
CLRSCR;
GOTOXY(29, 12);
WRITE (** ** ** CALCULATING ** ** ** ** ** ** ** ** ** ** ** **

Display message to user.

Xdiff := Xend - X1; Ydiff := Yend - Y1;
Lenth := Sqrt(Sqr(Xdiff) + Sqr(Ydiff));

Calculate length of the section.

IF Ydiff = 0 THEN theta := 0 ELSE 
Theta := Arctan(Ydiff / Xdiff);

Calculate rotation of alignment with respect to X-axis.

I := 1; 
Num_Result := 0;
Initialize counters.

WHILE I < Num_Data+1 DO
BEGIN {LOOP FOR ALL BOREHOLES}
  GOTOXY(40,14);
  WRITE(Num_Result);
  Flag := FALSE;

Display user message initiate variables for while loop.

  Xdiff := BH_Data[I].Xcoord-X1;
  Ydiff := BH_Data[I].Ycoord-Y1;
  IF Xdiff = 0 THEN Beta := PI/2 ELSE
    Beta := Arctan(Ydiff/Xdiff);
  Phi := Beta-theta;

Calculate the angle between line from the start of section to borehole and the section, , (see Fig ).

  IF (Xdiff < 0) AND (Ydiff > 0) THEN Phi := PI+Phi;
  IF (Xdiff < 0) AND (Ydiff < 0) THEN Phi := PI-Phi;

Correction to Phi for different quadrants.

  IF ABS(Phi) > PI/2 THEN GOTO 10;

If the borehole is located before the start of the section then skip to end of loop.

  Num_Result := Num_Result+1;

Increase the position counter for the BH_Result array.

  Dist := Sqrt(Xdiff*Xdiff+Ydiff*Ydiff);

Calculate the distance of the borehole from the start of the section.

  WITH BH_RESULT[Num_Result] DO
  BEGIN
    Offset := Dist*Sin(Phi)*1000;
    IF (Abs(Offset)) < Range THEN Distance := Dist*Cos(Phi)
  
Calculate the perpendicular offset of the borehole from the section. If the magnitude of the Offset is less than the maximum permissible offset then calculate the distance of the borehole along the section.

  ELSE
  BEGIN
    Num_Result := Num_Result-1;
    Flag := TRUE
END;

If magnitude of offset is not smaller than the maximum permissible offset then decrease the array counter and set flag. Decreasing the Num_Result counter will cause the BH_Result record of this loop to be overwritten by the record of the next loop.

IF Distance > Lenth AND NOT Flag
     THEN Num_Result := Num_Result-1

If the borehole is located beyond the end of the section and the borehole has not already been ruled out (ie. flag is not set), then decrease the array counter.

ELSE
     BEGIN
     BH_Num := BH_Data[i].BH_Num;
     Xcoord := BH_Data[i].Xcoord;
     Ycoord := BH_Data[i].Ycoord
     END

If the borehole has passed all the above tests then write the additional borehole information into the BH_Result array. If Distance < Lenth, and the Offset > Range then the record will be written to the BH_Result array but will be over written by the record of the next loop.

END; {with BH_Result}
10: I:=I+1

Increase the loop counter.

END; {LOOP FOR ALL BOREHOLES}
END;
PROCEDURE SHELL_SORT

Of all the procedures presented in this report this one is the most difficult to describe. The procedure Shell_Sort sorts the data array Data_Result into order of increasing distance from the start of the alignment. This procedure is a modified version of a sort procedure presented by D.S. Stivison in his book Turbo Pascal Library (Sybex, 1986). It uses the Shell-Metzner sorting algorithm. The method is depicted in the flow chart of figure A3.7. The method consists of a series of passes over the data array. Each pass compares all the records separated by the number of positions given by the variable Gap. To best understand the procedure consider an array containing the numbers 1 through 10 scrambled up as depicted in figure A3.8(a). The goal of the procedure Shell_Sort is to unscramble the numbers and place them in the same array using a fast algorithm. The procedure is described in the following paragraphs.

The number of data, Num_Result will be 10. The variable gap is set midway through the array, at 5. All the elements separated by 5 positions are compared and if they are out of order are swapped. The comparisons are depicted in figure A3.8(b) and the resulting array is shown in figure A3.8(c).

The variable Gap is halved. For this example consider the gap now equal to 3. The comparison procedure is repeated. This time when a swap is made above the third (Gap) location the comparisons must be stepped back by Gap positions to see if the record is to be relocated further in the array. Figure A3.8(d) shows the comparisons up to the sixth location where the first swap is to be made above the third location. Figure A3.8(e) shows the data array at this point and figure A3.8(f) shows the comparisons to be made after stepping back. Note how
the number 3 will have been relocated from the eighth to the second location during this pass. The comparison between the seventh and tenth element will also result in a swap and the comparisons will then be stepped back to the fourth element. The comparisons are continued until all the elements separated by 3 locations are compared. At this stage the array will be shown in Fig A3.8(g).

Again the Gap is halved and all the elements in adjacent locations (Gap = 1) are compared. This pass will result in a fully sorted array. When the next loop halves the Gap, the Gap will become zero and the Procedure is terminated.

The advantage of this algorithm is that elements in widely different locations may be swapped in one operation. This will save a considerable amount of time in comparison to a bubble sort, which only moves out of place elements one position at a time.

In the Procedure Shell_Sort the elements are the BH_Result data records and the comparisons are made between the Distance variables within this record. The swaps are performed by the Procedure FlipFlop which is contained within the Procedure Shell_Sort. A complete listing is presented on the following pages with additional comments added in Italics.
PROCEDURE Shell_Sort (Num_Result:INTEGER; VAR F_Result: BH_Okay);

VAR
  Gap,J,I: INTEGER;
  Temp : BH_OK;

Procedure to sort the borehole records into order of increasing distance from the start of the alignment. The procedure uses the Shell-Metzner sorting method to compare and swap the borehole records.

PROCEDURE FlipFlop;

Procedure to swap two Borehole locations within the array BH_Result. Temp acts as temporary data record to hold information from the first location during the swap.

BEGIN
  Temp := BH_Result[J];
  BH_Result[J] := BH_Result[J+Gap];
  BH_Result[J+Gap] := Temp;
END;

BEGIN {Procedure Shell_Sort}
  Gap := Num_Result DIV 2;

Set the variable Gap to half the number of data.

WHILE Gap > 0 DO
BEGIN
  FOR I := (Gap+1) TO Num_Result DO
  BEGIN
    J := I-Gap;
    WHILE J > 0 DO
      IF BH_Result[J].Distance > BH_Result[J+Gap].Distance THEN

  Compare all the boreholes in the array that are separated by Gap number of positions.

  BEGIN
    FlipFlop;
    J := J-Gap;
  END

  If the elements are out of order, they are swapped.

    ELSE J := 0
  END;            {for I := ...}
  Gap := Gap DIV 2;
Once all the boreholes separated by Gap number of positions compared, GAP is halved and the routine is repeated.

END;  {while Gap > 0}

Gap is continually halved until the routine compares adjacent boreholes.

END;
PROCEDURE WRITE_RESULTS

The procedure presented in this section displays on the screen the information contained in the array BH_Result. This information consists of the borehole reference number, the Distance and Offset and the coordinates. A screen full of data is displayed with table headings. The user is then prompted to press any key before the screen is cleared and the next screen full of data is displayed. This process is repeated until all the data in the array have been displayed.

The flow chart for this procedure is identical to the one presented for Procedure Write_Data (figure A3.5) except for the table headings and data which now include the Distance and Offset. A complete listing is presented on the following page, with additional comments in Italic.
PROCEDURE WRITE_RESULTS(Num_Result:INTEGER;BH_Result:BH_Okay);

BEGIN
  CLRSCR; Lines(3);
  WRITELN (' Borehole Distance Offset (Xcoord,Ycoord)');

Write column headings at top of the screen.

FOR I:= 1 TO Num_Result DO
BEGIN
    WITH BH_Result[I] DO
      WRITELN (BH_Num:10,Distance:10:2,Offset:9:2, ' (',Xcoord:5:2, ',',Ycoord:5:2, ')');
    IF FRAC (I/20) = 0 THEN
      BEGIN
        WRITELN; WaitForAnyKey; CLRSCR;
        END;
    END; {with BH_Result}

Write the borehole number, distance, offset and coordinates of
the boreholes contained in the array BH_Result under the column
heading. Check to see if the screen is full, 20 boreholes to the
screen. If the number of boreholes written /I/, is exactly a
multiple of 20 then screen is full.

WaitForAnyKey;
END;
FLOWCHART FOR PROGRAM BHOFFSET PAS (MAIN)

BEGIN

PROCEDURE File_Name

Interactive input of filename for BHOFFSET data. Check file and check for errors File Name.

PROCEDURE Read_Data

Input the Borehole reference number and X,Y coordinates of all the bores in file File Name. BH.Num, Xcoord, Ycoord

Would you like to view the data?

NO

PROCEDURE Write_Data

Display table headings for Borehole reference number and X,Y coordinates. Fill screen with data. Prompt user to press any key. Then display next screen full of data until all data has been displayed.

Interactive input of start and end coordinates for profile alignment X1, Y1, Xend, Yend.

Display start and end coordinates of profile alignment

Are there any changes to be made to coordinates?

YES

NO

To Fig. A3.2(b)
**Fig A3.2(b) FLOWCHART FOR PROGRAM BOFFSET.PAS (MAIN)**

**From Fig. A3.2(a)**

- Interactive input of maximum borehole offset from alignment.
  - Range

**PROCEDURE Calculations**

- Go through all the boreholes in the data file, skip the boreholes which are located west of the alignment, calculate the distance of the borehole along the alignment, and calculate the offsets. Skip boreholes whose offset is greater than the range. Write all boreholes which pass above criteria to array BH_Result.

**PROCEDURE Shell-Sort**

- Sort the borehole reference number, distance, and offset in array BH_Result into order of ascending distance from the start of the section.

**Replace Data Array with Results Array**

- Would you like to view the result?
  - NO
  - YES: **PROCEDURE Write Results**
    - Display table headings for borehole reference, distance, offset, and X, Y coordinates. Fill screen with results. Prompt user to press any key, then display next screen until all results have been displayed.
    - Would you like to recompute with a new range?
      - NO
      - YES

**Interactive input of file name in which to store the results.**

- Filename

- Check to make sure filename is valid. If it is, add filename extension .PRN so Lotus 1-2-3 can find the file. Write all the results to the file.

- Would you like another run?
  - NO
  - YES

**END**
Fig A3.3  FLOWCHART FOR PROCEDURE FILE_NAME

BEGIN

Interactive input of data file name.
FILENAME

Display error message restore program at beginning of procedure.

Prepare data file for processing

Is there an input/output error?

YES

NO

END
Fig A3.4 FLOWCHART FOR PROCEDURE READ_DATA

BEGIN

Read the title of the borehole data from the data file. Heading

Initialize the borehole counter
NumData := 0

Increment borehole counter
NumData = NumData + 1

Read BH reference number and coordinates for this borehole
BH_Num, Xcoord, Ycoord

Is this the end of the profile?

NO

YES

Display the number of borehole records in the file.

END
BEGIN

Display BHole Data title and number of boreholes in the record
  Heading, Num Data.
  (for procedure write Data only)

Display table headings for data

Display each BHole reference number, coordinates, distance and offset for write results
  Proc write Data: BH Num, Xcoord, Ycoord
  Proc write Results: BH Num, Distance, Offset, Xcoord, Ycoord

Is the screen full of data (20 lines)?

NO

Prompt the user to press any key, wait until key is pressed before continuing

clear the screen.

NO

Is this the last borehole in the data file?

YES

END
FLOWCHART FOR PROCEDURE CALCULATIONS

Calculate the distance of the borehole along the alignment
Distance

Is the borehole east of the alignment?
Distance > length?

YES

Decrease Results Counter
Num-Results -= 3

NO

Write borehole reference number and coordinates into 'BhtResult file' (distance and offset are in the file when they are calculated)
BHNum, xCoord, yCoord

Is this the last borehole in the data file?

YES

NO

Increment the data counter
I = I+1

END
Fig. A3.7 FLOWCHART FOR PROCEDURE SHELLSORT

BEGIN

Set variable GAP as half the number of borehole results records

WITH the first borehole record in the file

J = 1

Is the distance for this borehole greater than that for the borehole located at J + GAP in the file?

NO

YES

Swap the locations of the two boreholes
Procedure Flip-Flop

do back GAP boreholes in the file
J = J - GAP

NO

Does the in record before the first record in the file exist?

YES

WITH the next borehole in the file
(Don’t go back GAP boreholes if borehole doesn’t exist)

NO

Is there a borehole located at J + GAP in the results file?

NO

Divide the GAP by 2

YES

GAP > 0

NO

END
Fig. A3.8  EXAMPLE OF THE SHELL-METZNER SORTING ALGORITHM.

Location: 1 2 3 4 5 6 7 8 9 10

(a) Original scrambled array:
8 7 2 6 5 1 10 3 9 4

(b) Gap = 5, Comparisons (lines indicate comparisons, arrows indicate swaps):

(c) End of Gap = 5 pass:
1 7 2 5 4 8 10 3 9 5

(d) Gap = 3, Comparisons before the first stepback:

(e) Array at the first stepback, Gap = 3:
1 4 2 5 3 8 10 7 9 5

(f) Comparisons after the first stepback, Gap = 3:

(g) Array at end of Gap = 3 pass:
1 3 2 5 4 8 6 7 9 10
APPENDIX IV
LOTUS 1-2-3 WORKSHEETS

INTRODUCTION

The BSCE boring data is stored in digitized form in a data base using the software package Lotus 1-2-3 Version 2.0. 1-2-3 is an integrated software package containing a combination of a spreadsheet program, a data base management system, and graphics. 1-2-3 offers an easy to learn and very flexible environment. The flexibility of the system has proven ideal for the entry of borehole records, calculation of the elevations, selection of borehole data meeting certain criteria and the graphical presentation of the results.

This appendix is not intended to be a lesson in worksheet development. The worksheets presented contain many macro keystroke commands which allow for a high degree of automation. In its simplest form a macro is a collection of keystrokes which are stored within the worksheet. These keystrokes can be collectively executed (typed) simply by pressing a couple of keys. This rudimentary programming language is unique to Lotus products. Macros may contain programming commands to ask questions, make decisions and perform tasks that extend the capabilities of 1-2-3. For those readers unfamiliar with the basic 1-2-3 operation, the macros presented in this appendix may appear very foreign. During operation of the worksheet the macros remain out of view. The macros replace the normal 1-2-3 menus with customized menus that are specifically geared for the input and manipulation of the boring data. No knowledge of how the macros operate or even of basic 1-2-3 commands is required.

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The macros which are contained within the worksheets discussed in this appendix are presented one at a time. To help in understanding the macro listings it is important to note that each macro uses only two columns. The left column does not contain any macro keystrokes but contains range labels which refer to the value or expression in the right column. The labels preceded by a \n are macro names (naming the keystrokes in the column to the right). The remaining labels refer to the locations of variables which are used in the macros or locations for branching. For further information on the 1-2-3 command language the interested reader is referred to Simpson's 1-2-3 Macro Library, A. Simpson, Sybex, 1986.

Two worksheets have been created to manipulate the data which is contained in separate files. These worksheets have been named DATAEDIT and PROFILE and will be described separately, as the functions that they perform are largely unrelated.
LOTUS 1-2-3 WORKSHEET DATAEDIT

The purpose of worksheet DATAEDIT is to create an environment in which the BSCE boring data can be easily entered. The Borehole Reference number, coordinates, strata descriptions, depths, elevations and SPT n-values are to be entered in a format that can act as a database for future manipulation. The requirement for the database is that all the data be contained in columns forming a table. A table heading must be provided which contains the name of the data in each column. Each row of the table must contain as complete a set of entries as possible which correspond to the table heading. The table heading for the borehole database is presented in figure A4.1. The database operations will only recognize a single row as the table heading. For the purpose of database operations the row of the table heading beginning with 'Bore' in figure A4.1 is used, the remaining rows are included for clarity.

The worksheet DATAEDIT contains the formatting and macro keystrokes necessary for entering and editing the data. The worksheet must be loaded into 1-2-3 using the 'Retrieve' command from the 1-2-3 menu. When this is done a macro in the worksheet is automatically initiated which displays the menu presented on the following page;
This menu contains all the macro keystroke commands that are available in the worksheet. It also provides a quick reference for the keystrokes necessary to initiate any macro. Holding the ALT key while depressing the M key will display the macro menu at any time. Pressing ENTER causes the screen to display the table headings presented in figure A4.1.

The table heading will remain at the top of the screen at all times. Furthermore the "Borehole #" column will be a row heading and will remain as the extreme left column of the worksheet at all times. These 'frozen' columns and rows will act as a permanent reference so the user will not get lost in the database.
The macro which displays the menu and then displays the table and sets the heading ([ALT] M, menu macro), is presented below. Comments are preceded by asterisks.

\[M \backslash \text{WTC} \quad \text{*--- Clears screen headings.} \\
\text{\{GOTO\}Menu~\{}\text{?}\text{\}}} \\
\text{\{GOTO\}A70~} \\
\text{\{DOWN 7\}\{RIGHT\}} \\
\text{\backslash WTB} \quad \text{*--- Place row and column headings.} \]

At this stage the data table will be empty. The output file from program BHDIGIT containing a complete list of borehole numbers and X, Y coordinates must be combined with the worksheet. The file is combined using the [ALT] I (Import) macro. This macro moves the cursor to the appropriate location for combining the data file and allows the user to select the file to combine. The file is then imported and is displayed on the screen as it arrives. The table heading will now appear as shown in figure A4.2. As can be seen from this figure, only the Borehole # and the X, Y coordinate columns are filled, it remains the objective of this worksheet to add the remaining information. The current drive and directory is used to find the data files. If the user needs to change these attributes this should be done using the 1-2-3 main menu commands. The import macro is presented below.

\[\backslash \text{I \{GOTO\}A77~} \\
\text{\backslash FIN} \quad \text{*--- Import file of numbers.} \]
If some additional boring data has already been entered and stored (as will be discussed later) then this file may be retrieved for further additions by using the the [ALT] R (Retrieve) macro. The Retrieve macro is very similar to the import macro. The macro is presented below;

```
\R \{GOTO\}A70~
/FCCE    *--- combine entire file.
```

As with the import macro the data file will be automatically combined in the correct location within the worksheet.

The database may contain several thousand borehole records spanning the entire 8,192 available rows of the worksheet. To aid in locating a specific borehole record the [ALT] F (Find) macro may be used. This macro when initiated will ask for the borehole being sought. The macro then searches for the borehole and displays the row number for the first entry containing this borehole number. The user must enter this number on the go to prompt, then the cursor will move to the location in the database containing the borehole being sought. The Find macro is as follows;

```
#       *--- Heading for criterion Range
Criterion 101 *--- Range containing Borehole
/F        \{GETNUMBER "ENTER THE BOREHOLE TO SEARCH FOR ",Criterion\}
/DQF
\{LET Cell,\@CELLPOINTER("Row")
~Q *--- To exit the query menu.
\{GOTO\}Cell    *--- Cell contains the row number
\{GOTO\}D
```

Now that the cursor can be moved to the borehole record selected for entering,
the entry process can be started. The borehole number and coordinates are already in place from the Retrieve or Import macros (see figure A4.2). Rows must now be inserted to make room for the descriptions. [ALT] S initiates the Data input macro. To use the S macro the cursor must first be positioned in the strata description column of the borehole record to be entered (see figure A4.2). The macro asks for the number of strata in the borehole description and then inserts the correct number of rows. To meet the requirements of the database the coordinates and borehole numbers must be written on each row. This information will not be included for the blank lines just inserted, so the S macro copies this information down the appropriate number of rows. The macro then moves the cursor back to the strata description column. The first description will always be "Surface" and this is automatically entered. Figure A4.3 shows how the database will appear after the [ALT] S macro has been invoked. The remainder of the descriptions must be typed in manually from the keyboard. The macro [ALT] S is presented on the following page.
Strata 5 *--- Range containing the
\S Surface~ number of strata
{Down}
{GETNUMBER "ENTER THE NUMBER OF STRATA.\:",Strata}~
{IF Strata=1}{1strata}
{IF Strata=2}{2strata}
{IF Strata=3}{3strata}
{IF Strata=4}{4strata}
{IF Strata=5}{5strata} *--- Branching for
{IF Strata=6}{6strata} different number
{IF Strata=7}{7strata} of strata.
{IF Strata=8}{8strata}
{IF Strata=9}{9strata}
{IF Strata=10}{10strata}

Enter {Right}{Down} ENTER 1st STRATA~
{QUIT}

1Strata /WIR{Down}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN}~{Enter}

2Strata /WIR{DOWN 2}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 2}~{Enter}

3Strata /WIR{DOWN 3}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 3}~{Enter}

4Strata /WIR{DOWN 4}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 4}~{Enter}

5Strata /WIR{DOWN 5}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 5}~{Enter}

6Strata /WIR{DOWN 6}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 6}~{Enter}

7Strata /WIR{DOWN 7}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 7}~{Enter}

8Strata /WIR{DOWN 8}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 8}~{Enter}

9Strata /WIR{DOWN 9}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 9}~{Enter}

10Strata /WIR{DOWN 10}~
{UP}{LEFT}/C{LEFT 2}~.{LEFT 2}{DOWN 10}~{Enter}
The macro as presented can only cater for up to 10 strata descriptions per borehole. If the number of strata exceed 10 the line insertions and other operations must be performed using the 1-2-3 menu commands.

Two small macros are included in the worksheet which simply type the repetitive descriptions of "Blue Clay" and "Gravel". More of these type of macros may be added if the user wishes the format is as follows;

\texttt{\textbackslash G \text{Gravel} \\
\textbackslash B \text{Blue Clay}}

These descriptions are only typed by the macro so further descriptions may be added or they may be entered by pressing ENTER.

The IBM PC on which most of the data has been entered, can use either the numbers on the numeric keyboard, or the arrows (cursor movement), but not both simultaneously. The macro [ALT] D (Depth) allows entry of the depths for each strata using the numeric keyboard. The macro will move the cursor so the arrows are not needed and the user can enter the depths (or elevations) using the numeric keyboard. Furthermore, this macro knows how many rows to enter the data for and will automatically position the cursor in the cell for surface elevation entry when all the depths have been entered. Once the surface elevation is entered the macro "calls up" another macro, [ALT] C (Calculate) which calculates and enters the elevations for all the strata. Figure A4.5 shows how the borehole database will appear after the Depth and Calculate macros have been used.

To use the Depth macro, first position the cursor in the Depth column, and
Surface row for the borehole record (see figure A4.4). Press the [ALT] key and type D, the surface depth ,"0", will be entered and the cursor will automatically move down to the next row. The [Num Lock] key must be depressed so that the numbers rather than the arrows work on the keyboard. Type the depth followed by [ENTER], the cursor will automatically move down to the next rows. This is repeated until all the depths for the borehole record have been entered the cursor will the move to the first row for elevation entries (see figure A4.4) and prompt for Surface elevation. After entering the surface elevation the macro goes on to calculate all the strata elevations for the surface elevation and depth information before moving to the location for the next data record.

The Depth macro is presented below:

```
Counter 3 *--- Range containing loop
\D 0~{DOWN} Counter.
{LET Counter,0}
{FOR Counter,1,Strata,DoThis}
{UP Strata+1}{Right} *--- Reference made to Surf.Elev.~{?}~ range containing the
{DOWN} number of strata.
{C} *--- Branch to [ALT] C macro

DoThis {?}~{DOWN}
```

The Calculate macro follows. As stated above this macro is automatically initiated when the Depth macro is used. The macro can also be initiated by itself when only the elevation calculations are required.
The S and Depth macros described above are repeatedly invoked to enter data for as many borehole records as required. The SPT n-values must be entered manually using the keyboard and cursor arrows. A portion of the completed database is presented in figure A4.5.

For some borehole records presented in the BSCE borehole compilations the elevations of the strata interfaces are given without the depths. For these boreholes the [ALT] A macro is used to calculate and enter the depths. To use this macro the cursor must first be located in the first row of the depth column.
(see figure A4.4). The only difference between this and the Calculate macro is the form of the equation to calculate the values. The A macro enters the surface depth "0", then writes the equation for the next row. The macro then skips to the portion of the Calculate macro labeled 'Same', this portion copies the equation down the correct number of rows. The A macro is presented below;

```
\A 0{DOWN}
+{RIGHT}{UP}{ABS}-{RIGHT}~
{Same}
```

The database can be saved using the [ALT] X (Xtract) macro. This macro only saves the part of the worksheet that contains the table of borehole descriptions (the database). Before invoking the Xtract macro, the last row of the database must be determined. If the last borehole number is known this can be done using the Find macro. The Xtract macro moves the cursor to the start of the range to save and calls the 1-2-3 commands for extracting a portion of a worksheet. The macro will prompt for the last row of the database and the file name in which to save the data. The macro is presented below;

```
\X {GOTO}A70~
/FXFG
```

The last macro in the worksheet DATAEDIT allows the entire database to be erased, leaving the worksheet empty of data. This may prove useful when working with more than one borehole database. The macro checks with a Prompt before erasing any data, to make sure that you really want to erase all the data. It takes a long time to erase a large data file so this procedure is not
recommended. It may be quicker to retrieve the empty DATAEDIT worksheet (as described at the beginning of this appendix). The macro requires the user to input the last row of the data to erase. The Erase macro is presented on the following page:

```
ERASE? 0
\E {GETNUMBER "ERASE THIS DATA ?(1-NO,0-YES)",Erase?}
  {IF Erase?=1}{QUIT}
  /RE{BACKSPACE}
  A77.G
```

Once all the boreholes records have been entered and saved the worksheet may be exited using the 1-2-3 Quit command. If more records become available and the data base needs to be updated, the worksheet DATAEDIT is reloaded into 1-2-3 as described at the start of his section. The old database file is combined with the worksheet using the Retrieve macro, and the new records are added in the appropriate location using the macros that have been described in this section. Finally the updated version of the database is saved using the Xtract macro.
LOTUS 1-2-3 WORKSHEET PROFILE

Once the database has been created using the worksheet DATAEDIT the data may be used for generating & plotting soil profiles. The Lotus 1-2-3 worksheet PROFILE has been developed to generate the soil profile using the DATAEDIT database and the BHOFFSET output file. The macros in this worksheet use the database management operations available in the 1-2-3 software to create a subset of the database containing only the boreholes selected by the program BHOFFSET. The 1-2-3 menu command which allows this to be easily done is called "Extract". The extract operation requires locations within the worksheet data to be identified which have certain attributes. These locations are referred to by Lotus as 'ranges'. The purpose of the ranges will become clearer as the worksheet PROFILE is explained. The worksheet contains all the range names and attributes that are required, explicit knowledge of them is not required to use the worksheet.

Like the worksheet DATAEDIT all the operations are performed automatically by a series of macros. The worksheet must be loaded into 1-2-3 using the 'Retrieve' command from the 1-2-3 menu. When this is done a macro in the worksheet is automatically initiated which displays the following menu;
Like the worksheet DATAEDIT, the menu contains all the macro keystroke commands that are available in the worksheet. It also provides a quick reference for all the keystrokes necessary to initiate any macro. Holding the [ALT] key while depressing the M key will display the macro menu. The macro which displays the menu is identical to the M macro presented for worksheet DATAEDIT. Pressing ENTER causes the screen to display the heading presented in figure A4.1. This is the heading for a range called "Data".

The Data range contains the input data for the 1-2-3 extract operation. To fill the data range with data the R (Retrieve) macro is used. The data is contained in a file which was created by the worksheet DATAEDIT. The portion of the macro which imports the data file is identical to the Retrieve macro presented
for the worksheet DATAEDIT. The macro moves the cursor to the appropriate location for combining the database file and allows the user to select the file for combining. The database is then automatically imported into the Data range in the worksheet. The data range will appear as illustrated in figure A4.5. The database files that are combined with PROFILE will not all be the same size, hence the Retrieve macro defines the size of the database that it just imported. This is done by using the END key (defined on the IBM PC keyboard) to find the last row. The location is assigned the name "Data" by the macro. The retrieve macro is presented below, comments are preceded by asterisks.

\R {Goto}A50~
/FCCE(?)~   *--- Combine entire file.
{GOTO}A51~
/RNCData~{BS}.   *--- Create the range "Data".
{END}D{DOWN}{END}{DOWN}{END}{D{RIGHT}6}~

Next, the file created by the program BHOFFSET containing the borehole numbers, distances and offsets for the boreholes to be shown on the profile must be combined with the worksheet. The I (Import) macro combines this information. The macro moves the cursor to the appropriate location asks the user for the file name and combines the file at the location.

The BHOFFSET file was sorted by the program BHOFFSET into increasing distance from the start of the section, it is now required that the information be sorted by increasing borehole number. The database is sorted by increasing borehole number so the extracted range will be sorted by increasing borehole number. To keep track of the corresponding boreholes in the BHOFFSET file and the extracted range, the BHOFFSET file must be resorted into order of increasing borehole

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number. After the Import macro has combined the file it then sorts the file by increasing borehole number. Finally the macro defines the size of the BHOFFSET file in the same manner as was done for the R macro and assigns it the range name "Criterion". The Import macro is presented below;

```
\l
{GOTO}!10~
/FIN(?)~
/DSD(BS){END}{DOWN}{RIGHT 2}~
P(BS){END}{DOWN}~A~ "--- Define range & sort keys
G
{GOTO}!6~
/RNCCriterion~(BS){END}{DOWN}~
```

The last range that must be defined for the 1-2-3 extract database operation is the 'Output' range where the extracted information will be placed. This range must have a table heading corresponding to the data range (figure A4.1). The output range is already defined in the worksheet PROFILE no further modifications for the new database are required as long as the table heading is not changed. The locations of the Data, Criterion, and Output ranges in the worksheet are shown schematically in figure A4.6.

The database extraction operation is now performed by invoking the E (Extract) macro. All rows in the Data range which have a borehole number equal to any of the borehole numbers listed in the Criterion range are copied into the Output range. The result of this operation is to create a mini database containing only the boreholes to be depicted on the chosen profile. The output range is formatted exactly like the data range, the only difference between the two is the borehole data they contain.
After the boreholes to be depicted on the profile have been extracted into a mini database, the next step is to 'dress up' the Output range so that the profile may be generated. The final profile plot is generated by the operations built into the 1-2-3 software. The format for the plot is contained in the worksheet PROFILE. The plot is an X-Y plot of the distance along the section versus the elevation of the strata change (see figure 3.4). The strata interfaces are plotted as +’s and are connected by lines. In order that the last strata of a borehole is not connected to the first strata of the next borehole, the boreholes must be separated by a empty row. This is because when 1-2-3 encounters an empty row in the X-Y plotting operation the plot line is ended and restarted. Furthermore, because all the distances for each strata of any one borehole are the same the lines will plot as vertical lines with horizontal tick marks for the strata interfaces (see figure 3.4).

The X and Y coordinates of each borehole in the Output range need to be replaced by the distance and offset. The latter information is contained in the Criterion range. The distance and offset must be copied onto each line of the borehole because as stated above a plot of distance versus strata interface elevation is to be generated.

The Extract macro first inserts the empty rows between different boreholes in the Output range. The size of the Output range must first defined. This is done in a similar manner as for the Data and Criterion ranges. The Output range is then assigned the name 'FurRange'. The macro counts the boreholes by counting the number of empty rows that are inserted, this information is contained in a location named #Holes. The current borehole number is stored in a location named
Borehole. The macro steps through every other row of the 'Fulrange' and compares the borehole number of the row to the borehole number in the location Borehole. A schematic of the macro operation is presented in figure A4.7. If the row borehole is greater then the macro steps up to the row it skipped over and compares its borehole number. If this is greater then a empty row is inserted above this row and the row borehole number is copied into the location Borehole and the process is continued. If the row borehole is not greater then the macro steps back down and inserts an empty row above this row. The row borehole number is copied into the location Borehole and the process is continued. The method of comparing every other borehole then stepping back is used because it takes approximately half as much as it would if every row were compared.

If a borehole is encountered which does not have a description (just a row in the Output range, then 'NO DESCRIPTION' is entered in the strata description column and the borehole number and coordinates are copied onto a second row. The latter operation is to ensure that the macro which copies the distances and offsets into place can handle the no description case.

The Extract macro is presented on the following page, the distance and offsets are copied into place by another macro (C, Copy macro) invoked automatically by this macro.
Row 63  *--- Location containing
  Row number.

#Holes 4  *--- Location containing the
total number of boreholes.

Counter 18  *--- Location containing the
loop counter.

Borehole 159  *--- Location containing the
previous borehole number.

\E  {GOTO}150~
/DQE  *--- Extract the Criterion range
Q~  for the Data range.
/RNCFulRange~{BACKSPACE},
{END}{DOWN}{RIGHT 6}~ *--- Define 'Fulrange'.
{LET Borehole,0}{LET #Holes,0}{LET Row,0}
{FOR COUNTER,0,@ROWS(FulRange)-1,2,Check}
{\C}  *--- Initiate the C macro

Check  {IF @CELLPOINTER("Contents">Borehole){Newhole}
  {DOWN 2}  *--- Compare borehole numbers.

Newhole  {UP}  *--- Step up compare boreholes.
  {IF@CELLPOINTER("Contents">Borehole){NuHole}{RETURN}
  {DOWN}
  {LET Borehole,@CELLPOINTER("Contents")}~
  /WIR~{LET #Holes,#Holes+1}  *--- Insert empty row
  {DOWN}  increment counter.
  {RETURN}

NuHole  {IF @CELLPOINTER-2=Row}{NoDes}{RETURN}
  {LET Borehole,@CELLPOINTER("Contents")}~
  /WIR~{LET #Holes,#Holes+1}
  {DOWN 2}
  {RETURN}

NoDes  {LET Borehole,@CELLPOINTER("Contents")}~
  /WIR(DOWN)~{LET #Holes,#Holes+1}{UP}
  {RIGHT 3}NO DESCRIPTION{LEFT 3}
  /C(RIGHT 2)~ {DOWN}~
  {DOWN 2}{RETURN}
The C (Copy) macro is automatically invoked by the Extract macro but was
developed as a separate macro. The schematic for this macro is also presented in
figure A4.7. The Copy macro copies the offsets and distances from the Criterion
range into the 'Fulrange'. Because the boreholes are in the same order, the
first offset and distance are copied to the first borehole, the second to the
second etc.. The start and end of each borehole record are located using the END
key. After all the distances and offsets have been copied the table headings are
changed from "X" and "Y coordinates" to "Distance" and "Offset". The 'Fulrange'
will now appear as illustrated in figure 3.3 The Copy macro is presented below.

```
X 3

#Holes 18 *--- Location containing the total
        # of Boreholes form A macro.

\C
{GOTO}J9~
{FOR COUNTER,0,#Holes-1,1,DoThis}
{GOTO}J51~Distance{DOWN}^1(1000 ft.)~ *---Write new
{GOTO}K51~Offset{DOWN}^1(ft.)~ headings.

DoThis {DOWN}
\C{RIGHT}~ *--- copy for each row.
{END}{DOWN}{END}{DOWN}{DOWN}{END}{DOWN}{DOWN}
{FOR X,0,Counter,1,Do}
{RIGHT}{END}{DOWN}~

Do {END}{DOWN}{END}{DOWN}
{IF X=#Holes-1}{END}{UP} *---For the last borehole.
```

To generate the plot all that is required is to depress the F10 key. This will
invoke the preset graphics settings in the worksheet PROFILE. The screen will
display a plot of the distance column versus the elevation column (x, y type
graph see figure 3.4). The graphics setting for titles and scales may be changed
from those contained in the PROFILE worksheet to give the plot a customized
appearance. This is done by using the 1-2-3 graph menu commands. The user is referred to the 1-2-3 users manual for a full description of these commands. In order to print (or plot) the graph the Lotus 1-2-3 software PRINTGRAPH must be used. For instructions on how to use this software the users is again referred to the Lotus 1-2-3 users manual. The process is simple but the 1-2-3 environment must be exited and the Printgraph software executed. To transfer the plot image to the Printgraph software it is necessary to save the image in a file. This is done using the 1-2-3 graph menu command.

The table of borehole records presented on the plot may be printed using the P (Print) macro. The data will be printed in a formatted fashion skipping over page breaks with page numbering and margins. The table heading is written at the top of the first page, and a title line is prompted for and written on the top of every page. See figure 3.3 for an example of the printed output range. The P macro is presented below;

\P /PPRFulrange~
OH(ESC)[{~F(ESC)}#~
S(ESC)\015~
QAG

The table of borehole records presented on the plot may be saved in a file for printing or plotting at a later time or for further processing. The S (save) macro prompts for a file name to save the table in, and then saves the data. The Save macro is presented below;

\S /FXV(?){~FulRange~
### Fig. A4.1  BOREHOLE DATABASE TABLE HEADING IN WORKSHEET DATAEDIT (AND WORKSHEET PROFILE).

<table>
<thead>
<tr>
<th>Hole Coordinate</th>
<th>Strata Description</th>
<th>East Elevation EFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>X:123 Y:456</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fig. A4.2  BOREHOLE DATABASE AFTER USING THE [ALT] 1 MACRO TO IMPORT THE BUDDIGIT DATA FILE.

<table>
<thead>
<tr>
<th>Bore X Y</th>
<th>Strata Description</th>
<th>East Elevation EFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole Coordinate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X:123 Y:456</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bore X Y</th>
<th>Strata Description</th>
<th>East Elevation EFT</th>
</tr>
</thead>
<tbody>
<tr>
<td>154 2.30 5.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>155 2.37 4.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>156 2.66 4.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>157 2.61 4.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>158 2.59 4.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>159 2.65 4.65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 2.69 4.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>161 2.76 4.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162 2.78 4.78</td>
<td></td>
<td></td>
</tr>
<tr>
<td>163 2.75 4.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164 2.69 4.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>165 2.76 4.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>166 2.66 4.66</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Fig. A4.3** BOREHOLE DATABASE AFTER USING THE (ALT) S MACRO TO INSERT EMPTY ROWS AND COPY THE EXISTING INFORMATION DOWN THE ROWS.

<table>
<thead>
<tr>
<th>HOLE</th>
<th>X Coordinate</th>
<th>Y Coordinate</th>
<th>Strata Description</th>
<th>Depth Bottom of Strata</th>
<th>Elevation Bottom of Strata</th>
<th>SPT n-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>15A</td>
<td>2.30</td>
<td>5.30</td>
<td>Surface</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15B</td>
<td>2.90</td>
<td>5.20</td>
<td>ENTER 1st STRATA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15C</td>
<td>2.70</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15D</td>
<td>2.50</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15E</td>
<td>2.30</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15F</td>
<td>2.10</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15G</td>
<td>2.80</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15H</td>
<td>2.60</td>
<td>5.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15I</td>
<td>5.57</td>
<td>4.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15J</td>
<td>5.60</td>
<td>4.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15K</td>
<td>5.60</td>
<td>4.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15L</td>
<td>5.58</td>
<td>4.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15M</td>
<td>5.59</td>
<td>4.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15N</td>
<td>5.59</td>
<td>4.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15O</td>
<td>5.60</td>
<td>4.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15P</td>
<td>5.60</td>
<td>4.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15Q</td>
<td>5.69</td>
<td>4.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15R</td>
<td>5.70</td>
<td>4.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15S</td>
<td>5.98</td>
<td>4.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. A4.4  BOREHOLE DATABASE AFTER USING THE [ALT] D MACRO TO ENTER THE STRATA DEPTHS AND ELEVATIONS.

<table>
<thead>
<tr>
<th>Hole</th>
<th>Coordinate</th>
<th>Strata Description</th>
<th>Depth</th>
<th>Elevation</th>
<th>PPT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>5.30</td>
<td>Surface</td>
<td>12.5</td>
<td>-</td>
</tr>
<tr>
<td>155</td>
<td>1.10</td>
<td>5.10</td>
<td>Fly Ash</td>
<td>1.5</td>
<td>-</td>
</tr>
<tr>
<td>156</td>
<td>1.10</td>
<td>5.10</td>
<td>Fly Ash with Silt</td>
<td>2.2</td>
<td>-</td>
</tr>
<tr>
<td>157</td>
<td>1.10</td>
<td>5.10</td>
<td>Yellow Clay</td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>158</td>
<td>1.10</td>
<td>5.10</td>
<td>Blue Clay &amp; Fine Sand</td>
<td>4.3</td>
<td>-1.3</td>
</tr>
<tr>
<td>159</td>
<td>1.10</td>
<td>5.10</td>
<td>Clay, Sand &amp; Gravel</td>
<td>7.1</td>
<td>-16</td>
</tr>
</tbody>
</table>

[Cursor Location to start D and E macro.]

[Cursor Location to start C macro.]
Fig. A4.5  EXCERPT FROM THE BOREHOLE DATABASE AFTER ENTERING ALL THE INFORMATION USING THE WORKSHEET DATA EDIT

<table>
<thead>
<tr>
<th>Hole</th>
<th>Coordinate</th>
<th>Strata Description</th>
<th>Depth</th>
<th>Elevation</th>
<th>SP</th>
</tr>
</thead>
<tbody>
<tr>
<td>154</td>
<td>2.30</td>
<td>Surface</td>
<td>0</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Fill</td>
<td>12.5</td>
<td>3.5</td>
<td>10</td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Peat</td>
<td>15</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Soft Fill with Shells</td>
<td>23</td>
<td>-7</td>
<td>2</td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Yellow Clay</td>
<td>2.1</td>
<td>-15</td>
<td>25</td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Blue Clay, W/Fine Sand</td>
<td>66.5</td>
<td>-50.5</td>
<td>10</td>
</tr>
<tr>
<td>154</td>
<td>2.30</td>
<td>Clay, Sand &amp; Gravel</td>
<td>71</td>
<td>-65</td>
<td>47</td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Surface</td>
<td>0</td>
<td>20.7</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Fill</td>
<td>32.5</td>
<td>-11.9</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>W Sand &amp; Gravel Fill</td>
<td>33.5</td>
<td>-12.8</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Silt &amp; 1/Fine Sand</td>
<td>44</td>
<td>-23.3</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Fine Sand &amp; 1/F Gravel</td>
<td>45</td>
<td>-24.3</td>
<td>14</td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Blue Clay</td>
<td>51</td>
<td>-50.3</td>
<td>16</td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Fine Blue Clay</td>
<td>52</td>
<td>-51.3</td>
<td>4</td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Blue Clay, 1/F Sand</td>
<td>56</td>
<td>-35.3</td>
<td>6</td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>F Sand &amp; 1/Clay</td>
<td>60</td>
<td>-39.3</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Blue Clay, 1/F Sand</td>
<td>73</td>
<td>-53.3</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.57</td>
<td>Fine Sand 1/Clay</td>
<td>74</td>
<td>-53.3</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.67</td>
<td>Soft Blue Clay</td>
<td>111</td>
<td>-90.3</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.67</td>
<td>Hard Sand</td>
<td>121</td>
<td>-100.3</td>
<td>22</td>
</tr>
<tr>
<td>155</td>
<td>5.67</td>
<td>Sand &amp; Gravel, 1/Clay</td>
<td>125.5</td>
<td>-104.5</td>
<td>27</td>
</tr>
<tr>
<td>155</td>
<td>5.67</td>
<td>Fine Sand</td>
<td>128.3</td>
<td>-107.6</td>
<td></td>
</tr>
<tr>
<td>155</td>
<td>5.67</td>
<td>E Clay, 1/Sand 1/F Gravel</td>
<td>134.9</td>
<td>-114</td>
<td>27</td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Surface</td>
<td>0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Fill</td>
<td>22</td>
<td>-11</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Silt, Fine Sand &amp; Gravel</td>
<td>37</td>
<td>-16</td>
<td></td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Yellow Clay</td>
<td>41.5</td>
<td>-13.5</td>
<td>24</td>
</tr>
<tr>
<td>156</td>
<td>6.68</td>
<td>Blue Clay &amp; fine Sand</td>
<td>47</td>
<td>-26</td>
<td>8</td>
</tr>
<tr>
<td>156</td>
<td>6.65</td>
<td>Blue Clay &amp; Sand</td>
<td>51</td>
<td>-42</td>
<td>6</td>
</tr>
<tr>
<td>156</td>
<td>6.65</td>
<td>Blue Clay &amp; Sand</td>
<td>51</td>
<td>-52</td>
<td>4</td>
</tr>
<tr>
<td>156</td>
<td>6.65</td>
<td>Sand, Gravel &amp; hard Pan, Blers.</td>
<td>112</td>
<td>-55</td>
<td>100</td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Refusal</td>
<td>115</td>
<td>-59</td>
<td>100</td>
</tr>
<tr>
<td>156</td>
<td>6.66</td>
<td>Fine Sharp, Dirty Sand</td>
<td>255</td>
<td>-370</td>
<td>2</td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Surface</td>
<td>0</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Fill</td>
<td>33</td>
<td>-13</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Silt, Sand &amp; Shells</td>
<td>42</td>
<td>-22</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Fine Sand</td>
<td>43.5</td>
<td>-19.5</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Har Yellow Clay</td>
<td>47</td>
<td>-27</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Medium Blue Clay</td>
<td>45</td>
<td>-29</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Fine Sand</td>
<td>52</td>
<td>-32</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Coarse dirty Sand</td>
<td>53</td>
<td>-35</td>
<td></td>
</tr>
<tr>
<td>157</td>
<td>6.60</td>
<td>Dirty Sand &amp; Gravel</td>
<td>54</td>
<td>-34</td>
<td></td>
</tr>
</tbody>
</table>
Fig A4.6  SCHEMATIC LAYOUT OF THE WORKSHEET
PROFILE

MACROS

CRITERION RANGE

MACRO MENU

Data Range

Output Range

8192
**SCHEMATIC OF EXTRACT MACRO IN WORKSHEET PROFILE**

1. **Invoke Extract Macro** ([ALT]+E)
   - Extract borehole records from Data Range and place in output Range
     - Name portion of output Range filled with data, FRange
     - Initialize Counters Borehole, number of Holes and Row
     - Copy BH. Ref number of first record in FRange into Location Borehole

**CHECK**

- **Is this the last row of FRange?**
  - **NO**
    - Move cursor down two rows
    - **Is borehole reference number on the current row > Borehole location**
      - **NO**
        - Move cursor down over blank row
        - Increment number rows
        - Insert blank row
      - **YES**
        - **NEWHOLE**
          - **Is borehole reference number of this row > Borehole location**
            - **NO**
              - Move cursor back down one row
            - **YES**
              - Move cursor up one row
Fig A4.7(b) **SCHEMATIC OF EXTRACT MACRO IN WORKSHEET PROFILE**

**NUHOLE**

Is there only one row for this borehole record?

- **YES**
  - Copy borehole reference number into location borehole
  - Insert two blank rows
  - Increment number of rows
  - Enter "No Description" in strata description column
  - Copy borehole number and coordinates down one row
  - Move cursor down two rows

- **NO**
  - Copy borehole reference number into location borehole
  - Insert blank row
  - Increment number of rows
  - Copy borehole reference number into location borehole
  - Move cursor down two rows
APPENDIX V

RELATION OF DATUM PLANES IN MASSACHUSETTS

The following presents a comprehensive list of the datum planes used for elevation reference in Massachusetts. They are ordered from the highest to the lowest datum. All elevations are in feet and are given relative to the USCAGS Mean Sea Level Datum of 1929. The mean high water, low water and mean tide levels at the Comm. Pier No. 5 are also presented.

Town of Orange ----------------- +435.52
Town of North Attleboro -------- +171.25
New England Power Assn. ------- +105.68
Turner Falls Power Co. -------- + 69.26
City of Lowell ----------------- + 55.20
Locks and Canals Corp., Lowell -- + 5.20
City of Lawrence ---------------- + 5.08
Town of Framingham -------------- + 4.06
City of New Bedford -------------- + 2.55
City of Attleboro --------------- + 2.26
City of Worcester --------------- + 0.77

Comm. of Mass. 0.00 USCAGS Mean Sea Level Datum of 1929
Dept. of Public Works

Town of Natick ----------------- - 0.04
City of Chicopee ---------------- - 0.36
City of Springfield -------------- - 0.46
Town of Greenfield --------------- - 0.83
City of Haverhill --------------- - 1.43
City of Brockton --------------- - 1.57
Holyoke Water Power Co. -------- - 2.53
City of Holyoke --------------- - 2.60
City of Salem --------------- - 4.36
Town of Manchester --------------- - 4.47
City of Peabody --------------- - 4.82
Boston Low Dasta Datum -------- - 4.87
Logan Airport Datum (Waterways) -- - 5.28
City of Lynn ----------------- - 5.29
<table>
<thead>
<tr>
<th>Location</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logan Airport Datum (Highways)</td>
<td>5.35</td>
</tr>
<tr>
<td>City of Somerville</td>
<td>5.39</td>
</tr>
<tr>
<td>Town of Wellesley</td>
<td>5.50</td>
</tr>
<tr>
<td>City of Beverly</td>
<td>5.53</td>
</tr>
<tr>
<td>Town of Dedham</td>
<td>5.64</td>
</tr>
<tr>
<td><strong>Boston City Base</strong></td>
<td><strong>5.65</strong></td>
</tr>
<tr>
<td>City of Newton</td>
<td>5.72</td>
</tr>
<tr>
<td>Town of Brookline</td>
<td>5.78</td>
</tr>
<tr>
<td>City of Quincy</td>
<td>5.82</td>
</tr>
<tr>
<td>City of Revere</td>
<td>5.84</td>
</tr>
<tr>
<td>City of Everett</td>
<td>5.90</td>
</tr>
<tr>
<td>City of Chelsea</td>
<td>6.00</td>
</tr>
<tr>
<td>Town of Norwood</td>
<td>6.03</td>
</tr>
<tr>
<td>Met. Water Supply Commission</td>
<td>6.049</td>
</tr>
<tr>
<td>Mean Low Water (Waterways)</td>
<td>6.23</td>
</tr>
<tr>
<td><strong>City of Cambridge</strong></td>
<td><strong>10.84</strong></td>
</tr>
<tr>
<td>Town of Walpole</td>
<td>23.28</td>
</tr>
<tr>
<td>U.S. Army Engineers</td>
<td>-100.35</td>
</tr>
<tr>
<td>Boston Navy Yard (Basic Bench)</td>
<td>-105.08</td>
</tr>
<tr>
<td>Met. District Commission (Sewers)</td>
<td>-105.62</td>
</tr>
<tr>
<td>Boston Transit Commission</td>
<td>-105.62</td>
</tr>
<tr>
<td>Town of Needham</td>
<td>-105.62</td>
</tr>
</tbody>
</table>
APPENDIX VI
BOSTON BASIN SOIL PROFILES.

The following pages contain the soil profiles created using the methods described in chapter three of this report. The plans showing the locations of the profiles are contained at the back of this appendix (figures A6.1 to A6.6). The profiles are presented in 5000 and 2500 foot sections with a vertical scale exaggeration of 20 times. On each section is indicated the adjoining and intersecting sections. Other relevant information may also be contained on the profiles.

The profiles have been edited by hand using the profile plot created by the worksheet SUMMARY. The soil interface symbols which are shown on the plots, are plotted by the graph settings in the worksheet SUMMARY and serve as a guide for drawing the soil interfaces. The key for these symbols is shown on figure 3.7, some the symbols may represent different interfaces than those shown in this key depending on the stratigraphy at the location of the profile. Soil descriptions have been added to the profiles for clarity. The profiles are based only on the boreholes from the last two compilations of the BSCE boring data (1931-1984) which are plotted on the profile, no other data has been considered.

Figure A6.7 is the key which applies to all the profiles. The profiles are then presented in alphabetical order of the street name with which the profile is most closely associated (see plan map at end of chapter three). The soil interfaces depicted in the profiles are based upon interpolation between boreholes and may not represent the actual subsurface conditions.
Fig. A6.1 LEGEND FOR THE BOSTON BASIN
SUBSURFACE SOIL PROFILES.
BOSTON PENINSULA PROFILES

Albany Street
Arlington Street
Atlantic Avenue
Back Street
Beacon Street
Boylston Street
Cambridge Street
Causeway Street
Commercial Street
Dartmouth Street
Deham Street
Embankment
Federal Street
South of Government Center
Haverhill Street
Herald Street
Herford Street
Interstate 93 South
Leverett Circle
MA. Pike
Purchase Street
Shawmut Avenue
State Street
Summer Street
Stuart Street
Government Center to Sumner Tunnel
Washington Street
Worchester Street
Soil Profile Along ALBANY STREET
MA. Ave to Randolp St. (BSCE Data)

* 1949 & 1969 BSCE Data indicate different locations of the interface between soil types in these regions. The 1969 interface is the lower of the two shown.
Approximately 70% of the profile the top of the hill is encountered at +15 to -5' BCB.

* 1949 & 1969 BSCE Data indicate different locations of the interface between the Silt and Clay in this region. The 1969 interface is the lower of the two shown.
Soil Profile Along BEACON Street

Arlington to Devonshire St. (BSCE Data)

Elevation BCB (ft.)

Distance from Arlington St. (1000 ft.)

State Street Profile
Soil Profile SOUTH OF GOVERNMENT CTR.

Milk St. to Gov. Ctr. (BSCE Data)

- Fine Sand
- Silt, Clay
- Gravel
- Clayey Silt, Sand
- Blue Clay
- Very Silty Sand, Gravel
- Low Clay, Fine Sand

Elevation BCB (ft.)

Distance from Milk St. St. (1000 ft.)

Washington Street Profile

Levett Circle Profile

Marked Dec. 1986

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Soil Profile Along HEREFORD Street

Huntington Ave to Charles R.(BSCE Data)

Distance from Huntington Ave.(1000 ft.)
Soil Profile Along I 93 SOUTH
Randolph to Essex St. (BSCE Data)

Distance from Randolph St. (1000 ft.)

Albany Street Profile

Purchase Street Profile

Elevation BCB (ft.)

1949 & 1969 BSCE Data indicate different locations of the interface between soil types in these regions; the 1969 interface is the lower of the two shown.
Soil Profile through LEVERRETT CIRCLE
Gov.Ctr to Charles River Dam (BSCE Data)

Elevation BCB (ft.)

Distance from Gov. Ctr. (1000 ft.)

SOUTH OF GOV. CTR. PROFILE.
Soil Profile near MA. PIKE

MA. Ave to Arlington St. (BSCE Data)

Distance from MA. Ave (1000 ft.)
Soil Profile near PURCHASE STREET

Lincoln & Essex to Atlantic (BSCE Data)

BSCE borings data indicate an approximate 35° slope on the East side of Fort Hill Drumlin.
Soil Profile Along SHAWMUT AVE.
Mass. Ave to East Berkeley (BSCE Data)
Soil Profile GOV .CTR. to SUMNER TUNNEL

(BSCE Data)

Distance from Cambridge Shore (1000 ft.)
SOUTH BOSTON PROFILES

Damrell Street
Dorchester Avenue
E Street
West of E Street
Fort Point Channel
North South Boston
Soil Profile Along DAMRELL Street

Expressway to Harbor (BSCE Data)

Elevation BCB (ft.)

Distance from Expressway (1000 ft.)

M. Howes Jan '87
Soil Profile Along DORCHESTER AVENUE

Broadway St. to Expressway (HSCE Data)

Elevation (ft.)

Distance from Broadway St. (1000 ft.)

SILT & CLAY, some fine SAND
precluded to depth of 200 ft. without encountering Bedrock.
Soil Profile near E STREET
Harbor to Cypher St. (BSCE Data)

Elevation BCB (ft.)

-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40

Distance from Cypher St. (1000 ft.)

-5.0
-3.0
-1.0

West of E Street Profile
Soil Profile across NORTH SOUTH BOSTON
Dorchester St. to Naval Res. (BSCE Data)

Distance from Dorchester St. (1000 ft.)
Soil Profile across NORTH SOUTH BOSTON
Dorchester St. to Naval Res. (BSCE Data)

Distance from Dorchester St. (1000 ft.)

North South Boston
Profile Contoured

Boston Harbor
EAST BOSTON PROFILES

Addison Street
Bennington Street
Border Street
Condor Street
Orleans & Lovell Street
Porter Street
Soil Profile near BENNINGTON STREET
Addison to Antrim St. (BSCE Data)

Elevation BCB (ft.)

Dist. from Addison & Saratoga St (1000 ft)
Soil Profile near CONDOR STREET

Border to E. end Condor St. (BSCE Data)

Distance from Border St. (1000 ft.)

Bedrock encountered at approximately 130 ft. BCB

Elevation BCB (ft.)
CHARLESTOWN PROFILES

Alford Street
Front Street
Rutherford Avenue
Soil Profile near ALFORD STREET

North of Sullivan Square (BSCE Data)

Dist. from Sullivan Square (1000 ft.)
Soil Profile near RUTHEFORD AVENUE

South of Sullivan Square (BSCE Data)

Elevation BCB (ft.)

Dist. from Sullivan Square (1000 ft.)
CAMBRIDGE PROFILES

Mount Auburn Street
Boston University Bridge
Eighth Street
North of Fresh Pond
Harvard University
High Street
Huron Avenue
Main Street
Magazine Beach
Massachusetts Avenue
Memorial Drive
Morse School
MIT Campus
Pearl Street
Soil Profile North of FRESH POND

Blanchard to Raymond Street (BSCE Data)

Elevation BCB (ft.)

Dist. from Hubbard & Raymond St (1000 ft)
Soil Profile North of FRESH POND

Blanchard to Raymond Street (ESCE Data)
Soil Profile near HARVARD UNIVERSITY
Ash to Athens St. (BSCE Data)

Dist. from Ash & Mt. Auburn St. (1000 ft.)
Soil Profile near HURON AVENUE
Golf Course to Brattle St. (BSCE Data)

Dist. from Brattle & Auburn St (1000 ft.)
Soil Profile near MA. AVENUE.
Harvard Sq to Lafayette Sq. (BSCE Data)
Soil Profile near MA. AVENUE.

Harvard Sq to Lafayette Sq. (ESCE Data)

Distance from Harvard Square (1000 ft.)
Soil Profile near MEMORIAL DRIVE
Grant & Atens to Magazine St (BSCE Data)

Dist. from Grant & Atens St. (1000 ft.)
Soil Profile near MIT CAMPUS

Vassar to Amos St. (ESCE Data)

Dist. from Vassar & Mem. Drive (1000 ft.)

M. Hopkins, Jan. 97

Eighth Street Profile

MIT Campus Profile Continued
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