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BACK BAY BOSTON
PART 1

By

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SYNOPSIS

This paper concerns the Back Bay, a former tidal estuary in Boston which was filled a century ago to create land for an expanding population. In Part I of the paper, the geology of the Back Bay and subsurface soil conditions are described. Topographic development of the area is traced and early foundation practice in the Back Bay is discussed. In Part II, the design and construction of sewers and subways are included, insofar as they provide data on soil conditions and affect ground water levels in the Back Bay. Finally, the soil mechanics and foundations aspects of building design and construction are summarized.

The author hopes that the paper will provide engineers and contractors with a useful and interesting reference for information relative to soil conditions, ground water levels, existing underground facilities and foundation practice in the area, from the earliest days of development in the Back Bay, to the deep foundations supporting the New Boston.

INTRODUCTION

The shore line of Boston today bears little resemblance to the shore line when Boston was settled in the seventeenth century. The original high water line, superimposed on a map of present day Boston in Figure 1,

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shows this relationship vividly. Over a period of two centuries, tidal areas adjacent to the land were filled by cutting down the hills and hauling materials from land outside the City.

Back Bay as defined herein extends from Boston Common to Massachusetts Avenue and from the Charles River to Washington Street, a residential and commercial area of approximately 600 acres, Figure 2. The Back Bay Fens, located west of Massachusetts Avenue, is not included in the discussion.

GEOLOGY AND SUBSURFACE SOIL CONDITIONS

GENERAL

Soil conditions in Back Bay and indeed the topography of seventeenth century Boston, owe their origin primarily to events which took place during the Pleistocene. During this period, there were successive advances and retreats of glacial ice from the region, followed by extreme variations in climate and sea level relative to the land, all of which influenced the sediments and their engineering properties.

Typical soil and rock profiles in Back Bay are shown in Figure 3. Although it is the overburden soils that are primarily of interest to the civil engineer practicing in the area, the underlying bedrock has become increasingly important with the construction of major high-rise buildings on deep foundations. Thus, we begin with a description of the rock and progress upward through the more recent sediments.

BEDROCK

The best account of the bedrock geology in the Boston area is given by LaForge (12)*. Bedrock in the Boston Basin belongs to the Boston Bay Group which includes two formations, a lower one called the Roxbury Conglomerate and an upper one named the Cambridge Slate. The Cambridge Slate underlies the Back Bay and indeed most of the Boston peninsula, Cambridge, Watertown and Somerville as well as parts of Medford, Everett, Chelsea, East Boston, North Quincy and Hingham. It is believed to be at least 2000 to 4000 ft. in thickness.

The Cambridge Slate consists dominently of fine-grained clayey rocks which are slaty in places. The slaty cleavage is frequently absent and "argillite" is a better and more common name for the rock.

The parent sediments were deposited in a period which Kaye (11) believes is probably Carboniferous in age. The formation was subjected to tec-

*Numbers in parenthesis refer to References listed at end of paper.

Figure 1 - Colonial Shoreline Superimposed on a Modern Map.

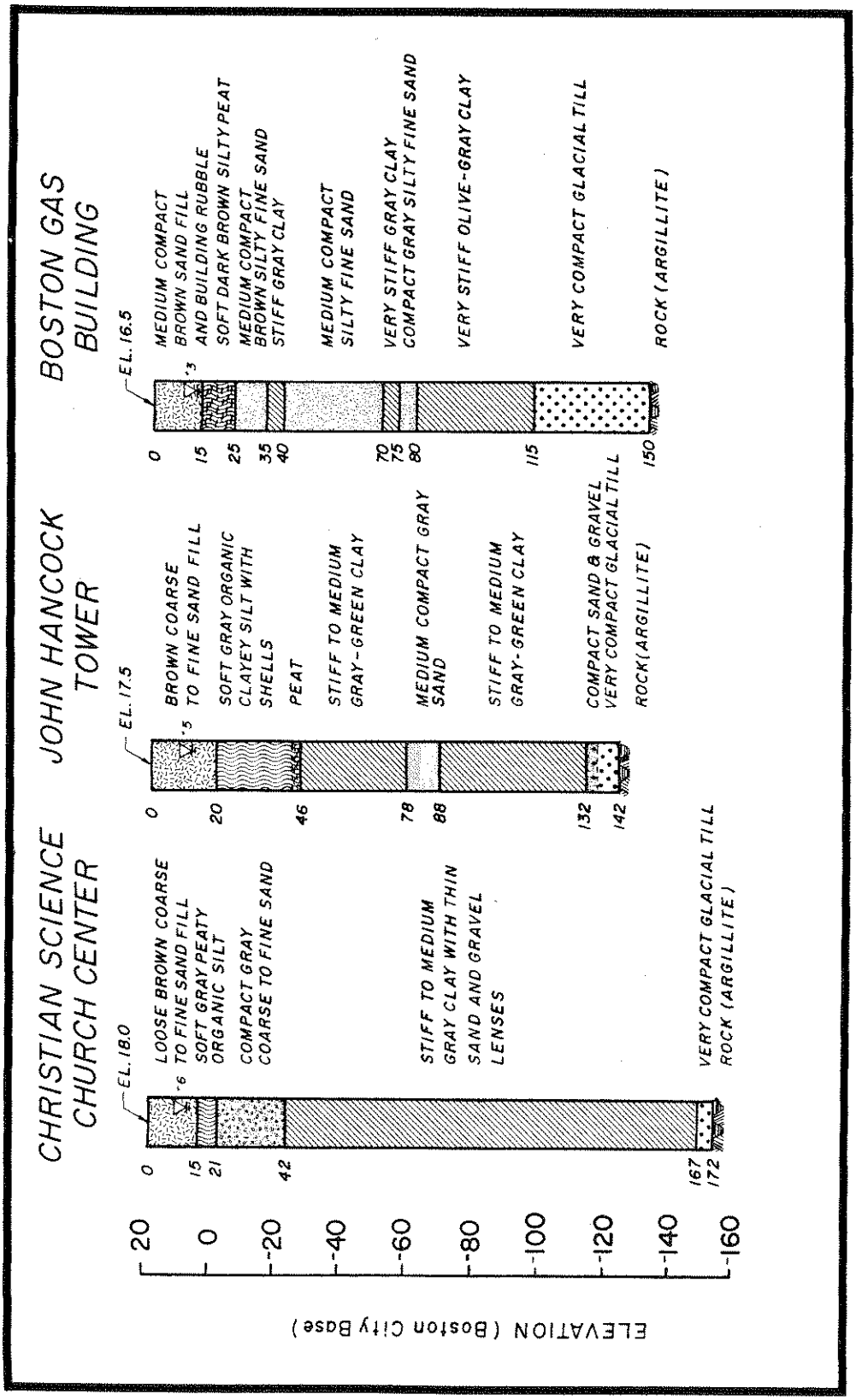

Figure 3 - Typical Soil Profiles in Back Bay.

tonic stresses which produced several broad folds and a number of lesser ones in the Boston Basin. The major fold axes are aligned roughly east-west and plunge toward the east. Faults are fairly numerous and dikes and sills cut through the formation, the most common intrusive rock being diabase. Other fine-grained igneous rocks and volcanic tuff have also been encountered in core borings.

The argillite is derived from siltstone, claystone or shale and is generally bluish-gray or brownish-gray in color. It is well-stratified with a dip commonly from 50 to 60 degrees but varying from 30 degrees to near vertical. Kaye (11) describes the rock locally as "----having a fairly well developed slaty cleavage. Typically, these rocks are thin bedded or banded, and consist of alternating light- and dark-gray strata ranging from 1 to 100* centimeters in thickness. Bedding parting is absent or poorly developed, and fissility is lacking." Descriptions of the rock encountered in tunnels driven below the greater Boston area are included in papers by others (1), (2), (13) and (14).

Deep borings in the Boston area have shown that the argillite has been altered or weathered at some locations to a soft light-gray clayey material which is predominently kaolin. Intensive alteration has occurred in some areas to depths of 300 ft. or more.

In 1914, in his report on the new Cambridge site for M.I.T., Professor W. O. Crosby (18,p.225) noted "----the slate to be extensively and deeply decomposed. In fact, the slate is, in large part, rotted to a whitish and more or less plastic clay; and close observation is necessary to determine the line between the drift and the bedrock."

Kaye (11) attributes the kaolinized zones most probably to the roots of an extensive lateritic regolith that mantled southern New England in the Tertiary, but recognizes the possibility that the alteration is hydrothermal in origin.

Within the Back Bay, altered argillite has been encountered in test borings at Beacon and Clarendon Streets, below the Boston Common Garage, at Castle Square, and for the Boston Gas building at Park Square. It was not found during drilling for the Prudential Center or for the new John Hancock building and parking garage.

To the foundation engineer, the presence of the altered argillite and the occurrence of clay seams within an otherwise relatively hard indurated rock, present an important condition to be explored for any major building project.

*Kaye now believes that 0.1 to 10 centimeters is more typical although much thicker strata do occur, for example at the Christian Science Church Center development.

Before and during the Pleistocene glaciation, the surface of the rock was eroded to form deep valleys. The Back Bay is located on the eastern edge of one such valley. As a result, rock is relatively deep, generally from 100 to 200 ft. below ground surface.

Subsequently, the valleys were filled with thick deposits of sediments of glacial origin.

OVERBURDEN SOILS

General: During the past 65 years, the Boston Society of Civil Engineers has made a significant contribution to our knowledge of the distribution of overburden soils in the Boston area by publishing the logs of test borings, and maps showing boring locations. In 1903, J. R. Worcester (17) contributed a paper to the Society which included logs of the earliest borings. He supplemented this information in a paper on "Boston Foundations" (18) published in the first volume of the Journal in 1914. Subsequently, the Subsoils of Boston Committees extended the work, collecting data and publishing boring logs. Information on the Back Bay is contained in Journal issues of September 1931 and October 1949. The most recent contribution, published in the July-October 1969 issue of the Journal, includes logs of many deep borings made during the last 15 years.

A detailed description of Back Bay sediments is given by Judson (6,p.7-48) in his contribution to "The Boylston Street Fishweir II", a fascinating series of papers of the Robert S. Peabody Foundation for Archaelogy.

Soils which overlie rock in the Back Bay include glacial till, a marine clay, sand and gravel outwash and organic soils. Finally, a century ago, sand and gravel fill was transported into the Back Bay to cover these natural deposits. Typical soil conditions at three locations within the Back Bay are shown on Figure 3. The stratigraphy around the easterly fringe is very complex.

Glacial Till: The first deposit of any significance to cover the bedrock during the Pleistocene was the glacial till or hardpan, deposited by the overriding glacier. Throughout the Boston area, the till commonly mantles the bedrock, varying in thickness from a few feet to over 100 ft. Thick deposits of glacial till form numerous islands in Boston Harbor (Deer Island) and other distinct hills on the mainland (Orient Heights) which are known as drumlins.

Originally, all of the major hills on the Boston peninsula including Copp's Hill in the North End and Fort Hill in the South End were thought to be drumlins, Crosby (4,p.345), underlain by shallow bedrock. However, recent test borings and geological investigations have suggested that the

"Trimountain," which included Mount Vernon Hill, Beacon Hill, and Pemberton (Cotton) Hill, is a far more complex geologic feature which includes deep deposits of overthrust sediments of all types which were bulldozed up and over the underlying till and outwash materials by a secondary advance of glacial ice.

Glacial till is an unsorted, generally non-stratified mixture of rock fragments and minerals of all sizes, varying from cobbles and boulders to silt and clay-size particles. The unweathered till is generally blue-gray in color, but weathering has oxidized the material in the topographic highs to a rusty buff color. The till is very compact and generally difficult to excavate. In the Back Bay, the unweathered till is relatively thin, varying from a few feet to perhaps 30 ft. in thickness.

Occurring with the till in many places in the Back Bay is a relatively pervious stratum of sand and gravel, probably an outwash deposit. The continuity of this stratum was demonstrated during extended dewatering for deep caisson foundations to support a building located on Harrison Avenue between Herald and Traveler Streets. Deep observation wells located at the Prudential Center, approximately one mile away, dropped as much as 30 ft. and piezometers installed below the clay across the Charles River at the M.I.T. Hayden Memorial Library were lowered by 1 to 2 ft.

Clay: The most famous of the local sediments is known as Boston blue clay, actually a silty clay of medium plasticity which is blue-gray to a drab olive-green in color. Silt and clay-sized particles, sorted from the till by glacial streams, settled out in a relatively quiet marine environment in bays around Boston, primarily from Boston to Lynn. Generally, the clay occupies the topographic lows between the predominently glacial till highs.

In the Back Bay, the clay is typically from 50 to 125 ft. in thickness, but clay to a depth of 180 ft. was encountered in borings for an apartment building located at the corner of Beacon and Fairfield Streets. Clay underlies all of the Back Bay. The stratum contains many lenses of fine sand, local strata and pockets of granular soils and occasional boulders.

At the time the clay was deposited, the sea stood 30 ft. or more higher than its present level. Subsequently, sea level fell relative to the land to expose the clay surface to weathering and erosion. At that time, when the sea level was perhaps 70 or 80 ft. below that at present, the surface of the clay at the higher elevations dried to form a stiff to hard weathered crust, commonly called yellow clay. Drying had less effect with increasing depth below the surface and the clay commonly becomes medium to soft in consistency toward the bottom. The stiff crust of the clay stratum plays an important part in supporting structures within the Back Bay area.

Sand and Gravel Outwash: Following a readvance of glacial ice perhaps twelve to fourteen thousand years ago, termed the Lexington Substage by Judson (6,p.23), well-stratified sand and fine gravel outwash materials were deposited over parts of the surface of the eroded and weathered Boston clay. In the Back Bay area, the sand and gravel is well-developed and generally continuous west of Copley Square. Beginning around Dartmouth and Exeter Streets, it increases in thickness westerly toward Massachusetts Avenue on the colonial peninsula in the Back Bay called, appropriately, Gravelly Point. At the Christian Science Church Center, the coarse to fine sand is approximately 20 ft. thick, Figure 3. East of Copley Square, the outwash occurs irregularly. It is absent at the John Hancock site, Figure 3.

The outwash is generally a medium compact to compact gray well-graded gravelly sand, deposited by rapidly moving streams of glacial melt waters. The outwash is very pervious and, in contrast to the glacial till, it can be excavated easily since it contains little binding silt and clay-size particles.

Organic Soils: In recent times following the glacial age, organic deposits formed throughout the Back Bay. Three distinct types of organic soil have been encountered: (1) fresh water peat, formed in areas having sluggish drainage; (2) organic silt with shells, deposited in salt water by tidal action; and (3) salt marsh peat, which accumulated along the shore line of a slowly rising sea.

An ancient fresh water swamp, in which peat formed and trees grew, occurred in the central to easterly section of the Back Bay. According to Judson (6,p.29), good surface drainage, which had undoubtedly been established by erosion when the clay stratum was exposed to drying, was probably blocked by the irregular outwash sand deposits. The peat which accumulated is relatively thin, generally less than 5 ft. in thickness.

As the sea level rose relative to the land, beginning some eight to ten thousand years ago, the fresh water peat bogs were eventually flooded, and marine silts and peats formed in the new salt water environment. The organic silt which accumulated in the sluggish tidal currents is generally gray in color and varies from a non-plastic silty fine sand to a plastic peaty clayey silt with shells.

The silt overlies the lower fresh water peat, or where the peat is absent, the silt was deposited directly on the outwash sands or the surface of the clay stratum. Around the fringes of the Back Bay in particular, the organic silt is overlain by salt marsh peat which began to accumulate to keep pace with a slowly rising sea.

Organic soils blanket the Back Bay area continuously and vary in thickness from 5 to 25 ft. Where the thickness is greatest in the central section of the Back Bay, the top surface of organic soil generally occurs near or below El. 0, Boston City Base*. Originally, the surface was much higher, but considerable compression has occurred under the weight of man-made fills. At the fringes of the Back Bay and on Gravelly Point (Massachusetts Avenue), the top surface of organic soils occurs up to El. +9, see Kaye (8).

SEA LEVEL CHANGES AND CRUSTAL RISE

Positive evidence that sea level was considerably lower relative to the land than at present, is the occurrence of a thin layer of fresh water peat overlying the clay as much as 20 to 30 ft. below present mean sea level. The well-preserved stump of a pine or cedar tree with roots was found at El. -15 Boston City Base, a depth of 30 ft. below street level, during construction of the Boylston Street Subway just west of Church Street in 1913. This discovery is reported by Manley (18,p.406). In one corner of the excavation for the Berkeley Street John Hancock building in 1946, oak and maple stumps were found at El. -20. In addition, sharpened stakes and wattles, remains of ancient Indian fishweirs, were found at El. -12 to -20 in the excavations for the New England Mutual and John Hancock buildings. A fascinating description of these discoveries is provided by Judson (6,p.7) and Barghoorn (6,p.49). At fishweir time, perhaps 4000 to 5000 years ago, water level was at least 15 ft. below the present sea level.

A sample of fresh water peat, recovered from a caisson excavated to support the I.B.M. building located at the corner of Clarendon and Boylston Streets was radiocarbon-dated to be approximately 5,600 years old, Kaye and Barghoorn (9). At this location, the peat occurred at El. -20 and was approximately 1 ft. in thickness.

Sea level change and crustal rise in the Boston area are described in detail by Kaye and Barghoorn (9). They conclude that sea level at Boston reached to within 2 ft. of its present level about 2800 years ago. Furthermore, Kaye (10) reports that while sea level was about at today's elevation 116 years ago, it was approximately 0.5 ft. lower at the turn of the century.

It is interesting to note that half a century ago, many engineers believed that settlement and perhaps displacement of the clay were responsible for the presence of peat, fishweirs and tree stumps substantially below sea

*All elevations used herein are referenced to Boston City Base where El. 0.0 is 5.65 ft. below USCGS Mean Sea Level.

level. For example, in his 1914 paper, Worcester (18,p.3) writes the following interesting account "----under a section of Cambridgeport and a part of the Back Bay the material (clay) is extremely soft, so soft, in fact, that it apparently is quite free to flow from heavily loaded areas towards places where the load is less. It is not definitely determined, so far as the writer knows, whether such a flowing takes place, or the clay is gradually being compressed. It is certain, however, that widely-spread settlements have occurred, in some instances to a very marked extent. A section of Cambridgeport covering about one-half square mile, centering roughly on Massachusetts Avenue and Albany Street, has settled to a maximum amount of about 2 ft.* In Boylston Street, between Berkeley and Clarendon Streets, the Transit Commission found the well-preserved remains of a weir or fence at about grade -18. It does not seem possible that this could have been constructed below low tide level or grade 0. Near Church Street was found a well-preserved stump of a tree with roots, at about grade -15. Another instance of subsidence is found in the depth at which peat is encountered. This material must have been formed above water, but is now found, overlaid with silt, far below grade 0. On Tremont Street, above Dover, it was found at about grade -12, and on Boylston Street it has been found at grade -19. This tendency to settle will have to be taken into consideration in locating heavy structures in the future. It is not enough to gain the necessary support in piles which may rest in a gravel crust, but the settlement of the crust may seriously injure important structures, as it is believed to have already done in the case of the Public Library and the New Old South Church."

In commenting on the tree stump found during subway construction, L. B. Manley (18,p.406) reasoned that "----its presence at this depth indicates a settlement of the surface of at least 25 ft."

In his discussion of the Worcester Paper, Charles R. Gow (18,p.191) relates the presence of peat below the organic silt to a rather rapid subsidence: "Thus, when we find peat deposits at great depths below the marsh level, we may assume that such settlements as their presence indicates may reasonably have occurred during a comparatively short period of subsidence such as the one we are now discussing. This assumption is strengthened by the known fact that the peat deposits are usually covered with a deposit of silt, proving that the vegetation was suddenly stopped by a rapid subsidence of the marsh level below the surface of the water. Had the subsidence been as gradual as that which we now assume it to be in general, there seems to be no good reason why the peat should not be continuous to the surface."

*This settlement was later attributed to compression of organic soil below recently filled land.

Henry F. Bryant (18,p.205) was not convinced, however, and had some rather astute comments on the subject: "Mr. Worcester suggests that peat at considerable depth indicates land subsidence. I accept that statement with some hesitation. In the case of fresh water peat, that is certainly not the case, as we find it to depths of forty, seventy and even one hundred feet, completely filling old glacial pot holes. I have in mind one or two instances of tidal marshes where the subsidence would of necessity be quite irregular had the bottom of the peat ever been at or near the surface. I think that the evidence is favorable for Mr. Worcester's theory, but I do not think it is by any means proven."

TOPOGRAPHIC DEVELOPMENT

GENERAL

The last remaining element in the soil formation throughout the Back Bay area is the man-made fill placed during the last 175 years. Historically, it is of some interest to recount the topographic development in the area, for the filling of this great tidal basin was to be the most drastic single alteration in the history of Boston's changing topography. A summary of the sequence of filling is shown on Figure 2 and a detailed account of the topographic development is given by Whitehill (16). Further information can be found in Bunting (3). A number of maps prepared by the Coast and Geodetic Survey and the engineering firm of Fuller and Whitney, Figures 4 through 13, provide an interesting chronology of the Back Bay filling and building development.

MILL DAM

The earliest encroachment on the Back Bay tide flats occurred in 1794 when the town granted the marshy flats at the foot of Boston Common to be filled for the building of five ropewalks (long sheds for the manufacture of rope) to replace those which burned in the fire of that year.

The first significant filling in the Back Bay took place when a mill dam was constructed from Charles Street at the foot of the Common, westerly to Sewall's Point in Brookline, near the present Kenmore Square. The Mill Dam ran along what is now Beacon Street, at that time called Western Avenue.

To complete the tidal power project, a cross dam was built from Gravelly Point in Roxbury to intersect the main dam along a line just east of the present Massachusetts Avenue. At high tide, water was admitted into the "full basin" located in the Fens west of the cross dam. It powered machinery in mills located along the cross dam on Gravelly Point, discharging

into the easterly "receiving basin". At low tide, water was sluiced back into the Charles River through the main dam near the present Exeter Street.

Uriah Cotting began construction of the Mill Dam for the Boston and Roxbury Mill Corporation, chartered in 1814. Mr. Cotting died in 1819 and the work was finished under Colonel Laommi Baldwin. The dam, which carried a toll road, was opened for travel on July 2, 1821. In 1880, Mr. E. W. Howe (7,p.87) described the design and construction of the Mill Dam as follows:

> As an example of an engineering structure of sixty years ago, perhaps a description of this sea-wall may be of some interest. The "Mill Dam" as it is called, was built for the purpose of utilizing the rise and fall of the tide as a source of power, but has been chiefly used as a public highway. Its construction was begun about the year 1818, and completed in 1821. It is about a mile and one half in length, and consists of two parallel walls about 50 feet apart between their outer faces. In excavating through them for the construction of the new sluices at the outlet of the lake in the Back Bay Park, the construction of the old dam was found to be as follows: For the northerly wall starting from a grade of 1.75 feet below low water, there was first laid a course of 12″ × 12″ timbers, four in number, running lengthwise of the wall, the four occupying a width of 6 feet; on these was laid a course of 9″ × 9″ timber crossways of the wall and about 9 inches apart; next there was another course of five 12″ × 12″ timbers laid lengthwise. The timber was white pine, and the courses were treenailed together with oak treenails 1¾″ square; one treenail in every other bearing. The southerly wall has only two courses of timber, the lower course of 12″ × 12″ laid lengthwise, and the upper of 9″ × 9″ laid crosswise. Otherwise the two walls are alike. The walls are of rubble masonry, 6 feet wide at the bottom and 3 feet wide at the top of Roxbury pudding-stone, laid dry and very loosely. The wall is ballasted with small stones from the bottom to the top of the masonry; the ballast having a width of 8 feet at the bottom and nothing at the top. The back-filling is of mud to a height of 8.5 feet above the timber work, then 5 feet of sand, and then from 1.5 to 2 feet of road material. The whole height of the masonry is 15 feet. The wall has evidently settled somewhat and is somewhat out of a straight line, but not so much so as to cause any fear of its destruction. The wall is all afloat, so to speak, on the mud; there being from six to eight feet of mud underneath it,

with no piling or other foundation other than the timber work before described; while the average thickness of the wall is but three tenths of the height.

With low water maintained in the Back Bay receiving basin, the tide flats dried up and clouds of fine dust blew in every direction. For a time, then, before sluice-ways were built to keep the flats covered with water, the organic silts and peat at higher levels were subject to dessication.

PUBLIC GARDEN

In 1819, the ropewalks at the foot of the Common burned in their turn, and subsequently in 1824 the City of Boston bought back the land for about $50,000 and voted that it be "forever after kept open and free of buildings of any kind for the use of the citizens," (16,p.98). During the period 1824 to 1836, most of the remainder of what is now the Public Garden was filled.

There were many attempts following acquisition of the land by the City to develop the area for commercial purposes, especially during the period 1840 to 1850. They were always defeated, and finally in 1859 the land was officially voted the Public Garden by an act of the Legislature.

RAILROADS

In 1831, both the Boston & Worcester and the Boston & Providence Railroads were chartered. Embankment construction across the Back Bay was immediately begun to bring the rail lines into Boston.

The Boston & Worcester line was opened for travel as far as Needham in 1834. The tracks crossed the Back Bay on an embankment at the location of the present Boston & Albany tracks. The following year the Boston & Providence line was opened. It crossed the Back Bay in a southwest-northeast alignment from Roxbury to a station at Park Square. The two lines intersected near the present Back Bay Station, at the site for the new John Hancock Garage under construction in air rights over the Massachusetts Turnpike.

The railroads influenced the growth of the Back Bay in two important ways. First, they greatly interferred with the flow of water, hence reducing the usefulness of the area as a power project, increasing its undesirable aspects and hastening the day of its filling. Second, they influenced materially the ultimate layout of streets in the Back Bay, which factor had a tremendous impact on its physical and sociological development.

MISCELLANEOUS EARLY FILLING

In addition to the railroad embankments, a certain amount of piece-

meal filling took place during the 35 years following the construction of the Mill Dam. By 1836, the shoreline ran south from Beacon Street roughly along Arlington Street to Tremont, thence southwest along Tremont to approximately Dover Street, then west to about where Massachusetts Avenue and Columbus Avenue now join, Figure 2. A little filling also took place during this period north of Beacon Street and west of Charles Street up to Cambridge Street, and west on Beacon Street to Embankment Road.

The principal change occurring in the Back Bay during these years was that the erstwhile tidal basin had become an offensive open sewer and Boston residents demanded that it all be filled.

MAJOR BACK BAY FILLING

In 1856, after several years of wrangling, a tripartite indenture was completed among owners of the Back Bay land and water; the Commonwealth, the City and various private parties. The Boston and Roxbury Mill Corporation was given the tide flats north of their Beacon Street Dam (later called the "water side of Beacon"). The Commonwealth was given the area bounded roughly by Beacon, Arlington, Boylston and an irregular line between Exeter and Fairchild Streets. The Boston Water-Power Company was given the remainder of the Back Bay. The City, "uncooperative throughout, and rapacious in its demands", (16,p.151), was left out. It did, however, build Arlington Street jointly with the State.

The indenture was confirmed in 1857 and the Commissioners were authorized to fill and sell the Commonwealth's land. The Commonwealth let a contract in 1858 to Norman Munson and George Goss, partners in a contracting office at 22 Congress Street. A year later, a separate contract between Munson and Goss and the Boston Water-Power Company was signed to fill the Power Company's land north of Beacon Street.

Sand and gravel fill was brought by rail from a farm in Needham belonging to the Charles River Railroad Company. This farm was located near the present day Route 128 at Needham Avenue. The operation involved 145 cars, 80 men and two of the earliest steam shovels. Three 35-car trains were continually on the road, one arriving at the Back Bay every 45 minutes. When the trains arrived at the borrow pit, they were divided in half and each half was fed by one 25-horsepower steam shovel. Two shovelfulls filled one car and the 35-car train could be loaded in ten minutes. Some of the sand hills leveled were 50 ft. high and in the first year about twelve acres were leveled, fourteen having been created. The rate of filling was approximately 2500 cu.yd. per day. Generally, fill was placed to about El. 12 but streets were built up to approximately El. 18. As fill was placed

north of Beacon Street, a granite sea wall was constructed on the north side of the new Back Street.

The rate of filling can be traced by a series of maps prepared at ten year intervals by Fuller & Whitney, Figures 7 through 13. The extent of filling shown on these maps is summarized on Figure 2. By 1861 the shoreline was just west of Clarendon Street, in 1871 it was an irregular line between Exeter and Hereford Streets, and by 1882 filling had been completed to approximately Massachusetts Avenue. In the following ten years, all of the Back Bay Fens was filled, ending up with the layout of the Fenway and adjacent areas.

RECENT FILLING

Subsequent events in the topographic development of the Back Bay area include the first Esplanade filling, a 100 ft. promenade along the south shore of the Charles River adjacent to Back Street and the Beacon Street houses. In 1910, the tidal dam was constructed, controlling water in the Charles River Basin to El. 8. In 1929-31, the Storrow embankment and ponds were constructed and in 1951, Storrow Drive was built.

BUILDING FOUNDATION PRACTICE BEFORE WORLD WAR I

GENERAL

Construction of buildings followed closely behind the Back Bay filling. One of the first major buildings was the Arlington Street Church, constructed at the corner of Arlington and Boylston Streets in 1859. Shortly thereafter, the Museum of Natural History (now Bonwit Teller's) and the M.I.T. Rogers Building, both designed by W. T. Preston, were constructed. Within 50 years, private homes, hotels, churches, schools, a public library and many other buildings were to occupy the former tidal basin.

Members of the Boston Society of Civil Engineers contributed significantly to the evolution of foundation design and construction in the area. The 1914 J. R. Worcester paper (18) provoked voluminous discussion which reflects the practice of the times. From this work and other records and publications, we can reconstruct the important features of this early foundation practice.

SOIL BEARING PRESSURES

In 1903, Worcester (17) had recommended safe bearing pressures for soils found in Boston which varied from 2.5 tons per sq. ft. for soft clay to 4.5 tons for hard compact materials. By 1914 (18,p.19), he had found the

upper limit to be conservative. Based on his experience and results of load tests on one ft. square plates, he suggested the following tentative safe soil bearing pressures:

Soil Type	Safe Bearing Pressure (tons per sq. ft.)
Dry, hard, yellow clay, "Bowlder clay", dry sand or gravel	6.0
Compact, damp sand, hard sandy clay, hard blue clay	5.0
Medium blue clay, whether or not mixed with fine sand	3.5
Soft clay, running sand (confined)	2.5

By comparison, our present code defines eight materials and expands the range from 1 to 10 tons per sq. ft., using 1 ton for soft clay. Worcester's recommended safe bearing pressure for soft clay was later found to be too high, especially for large loaded areas.

The importance of footing size and the overlapping effects of stresses from adjacent footings had been discussed earlier and Worcester acknowledged the danger in extrapolating from load tests run on small plates. However, he reasoned (18,p.10), somewhat incorrectly, that "There is also present in every test a condition having exactly the opposite tendency, which renders them unreliable. This is, that when a limited area is loaded, the soil has a chance to flow out in every direction and, as the area of the load increases, the opportunity for flow is relatively decreased. The first error which would be liable to give too high capacities, is important in the case of a harder ground over a softer. The second, which may give too low results, is more likely to be found in the case of a soft plastic material, like clay, immediately under the loaded point." The importance of long term settlement from consolidation had not yet been recognized, although significant settlement of major structures, many founded on closely spaced friction piles, had already been observed.

Charles R. Gow (18,p.181) believed that the soil pressures suggested by Worcester were conservative, except for soft clays, and he offered that "----he has at times adopted values as high as eight tons for the cemented clays and gravels with no unsatisfactory results." In addition, Henry F. Bryant (18,p.208) frequently used eight tons for the "bowlder clay in the Boston drumlins." Others, including Charles T. Main (18,p.216) felt that the soil bearing pressures were too high, in particular that for the soft clay. Main stated that "Because of the effect of vibration and the observance of

what happened in a weaving mill in the earlier part of my experience, I have been very conservative regarding the loads on soils, and many years ago decided on the following:

Soft clay	1 ton per sq. ft.
Compact sand and gravel	1 to 2 tons per sq. ft.
Hardpan	2 to 3 tons per sq. ft. (under favorable conditions,4)"

In his later experience, he increased loads on all but the soft clay by about 50 percent. His assessment of the soft clay proved to be correct, although others were using from 1.5 to 2.5 tons per sq. ft.

Engineers of the time generally agreed that all parts of the structure should be supported on a stratum of soil below the organic silt and peat. They further concurred in the importance of taking borings to determine subsurface soil conditions.

WOOD PILES AND PILE CUTOFF

In the Back Bay area, buildings were commonly supported by wood piles driven through fill and organic soils. As Professor W. O. Crosby (18,p.226) of M.I.T. put it: "This formation (blue clay), reinforced by piles, has been the main reliance for deep foundations, or the foundations of important structures, throughout a large part of the lowland areas of the Metropolitan District."

A safe load of ten tons was commonly used on spruce piles having a tip diameter of approximately 6 inches. In the Back Bay, piles were driven to bear in the sand and gravel outwash or the hard clay crust where these materials offered point resistance. Elsewhere, piles were driven into the medium to soft clay to act as friction piles. Drop hammers were used, having weights commonly from 1800 to 2300 lb. which were dropped from 10 to 25 ft.

Most specifications required that piles be driven in accordance with the Engineering News formula: ($P = \frac{2WH}{p + 1}$) and the applicability of this formula was widely discussed. Following an evaluation of several pile load tests, Worcester (18,p.19) concluded that the Engineering News formula could be modified to allow a 50 percent higher load, i.e., by allowing 3WH, although he recognized that the Engineering News formula "----does not appear always to have a factor of safety of 6, as it is supposed to have." Most other engineers were more conservative and thought the Engineering News formula should be used. Harry E. Sawtell (18,p.246), a structural engineer

with Charles T. Main, cited five good reasons why he would regret to see Worcester's modification made: "First, that it would result in greater settlements under working loads; second, from long observation it is believed that a large part of the piles driven are, unlike test piles, seldom given the penetration required which now results in doing what Mr. Worcester would do by changing the formula; third, that an unknown percentage of spruce piles driven under the present conditions are unreliable, due to brooming and breakage; fourth, that as this construction is out of sight, a greater factor of safety should be obtained than for construction in sight which can be inspected; fifth, that the factor of safety obtained by the Engineering News formula is now relatively low when based on a reasonable settlement of the pile itself."

Although inspection procedures have improved and over-driving is less common, these arguments are still sound.

From some fourteen load tests performed on friction piles, Worcester (18,p.18) found that the average skin friction over the embedded length of the pile was 628 lb. per sq. ft. for a deflection of ¼ in. For design, he suggested using 300 lb. per sq. ft. to give a factor of safety equivalent to the Engineering News formula. With great wisdom he noted, however, that "--- it is not always safe to take into account the portion of the pile which is embedded in an inferior material, and the objection to the use of this method is the uncertainty as to how much length to consider."

Henry Bryant (18,p.208) replied emphatically that embedment in inferior material should never be considered. "In fact, I think that with a layer of soft material underlying a considerable depth of hard filling, the latter should be considered as negative since it is likely to seize the pile and, in settling, to push it down. This has occurred several times in my observation." For 20 years, Bryant had designed for a skin friction equal to 1,000 lb. per sq. ft. for the area of pile embedded in the supporting soil. For an average pile diameter of 8 inches, this is approximately 1 ton per ft. of length. This was considered to be 50 percent of the actual skin friction. "From this I would deduct a similar amount (1 ton per ft.) for penetration in filling underlaid by any considerable depth of peat or silt." Again, for comparison, our present building code allows a skin friction in inorganic clay equal to 500 lb. per sq. ft. and requires that effects of downward friction forces from subsiding fill be considered.

On the matter of design skin friction, H. S. Adams (18,p.211) used a skin friction equal to one-third of the safe bearing pressure. "For example, if the clay is good for 3 tons per sq. ft. for foundation, it is good for about 1

ton per sq. ft. in grip upon the pile." For wood piles driven in the medium to soft Boston clay, the one-third rule can be accepted today, although we recognize that the allowable bearing capacity is less than 3 tons per sq. ft.

In addition, both negative skin friction from subsiding fill and false driving resistance were also recognized and discussed in 1914. In his discussion of pile driving and testing for the new M.I.T. buildings in Cambridge, Charles T. Main (18,p.217) stated "These piles generally pass through a fairly hard fill of blue-black silty mud and shells before reaching the harder sand stratum in which they get most of their support. This fill gives considerable resistance to driving, and soon after the pile reaches the sand, it would generally appear, by the small penetrations under the hammer, that a theoretically satisfactory bearing power had been reached. This is not practically acceptable, however, as the fill is unreliable and subject to large future settlement owing to decomposition, etc., and should not be depended upon for permanent support, even if it appears to give temporary support, therefore the piles are driven into the hard sand stratum to a depth that will give a satisfactory support to them from that material alone."

Wood piles were commonly spaced 2.5 ft. on centers but a spacing of 2 ft. was not uncommon where heavy loads were to be supported. While his explanation was a little strange, Henry S. Adams (18,p.211) recognized the danger in driving piles too close together in clay. "If they are driven closer than that (3 ft.) in clumps, the material between the piles is so compressed that it looses its grip, and does not hold the interior piles to the extent that it should." There was ample evidence to support his concern. Below the Trinity Church tower at Copley Square, there are over 2,000 friction piles in an area 90 ft. square, an average spacing of about 2 ft. The Church had settled nearly a foot. Closely spaced wood friction piles also support the Old South Church on Boylston Street. The average load under the base of the tower is 3.18 tons per sq. ft. By 1914, the tower leaned 2.5 ft. toward Boylston Street as a result of differential settlement. (It was later dismantled and reassembled on a level foundation.

It was common practice in Boston to cut off wood piles at the average tide level, El. 5 Boston City Base, with entire safety. After the Back Bay was filled and through the remainder of the nineteenth century, the ground water level in the Back Bay was approximately El. 8 and as a result many buildings were constructed on piling cut off *above* El. 5.

Although there was ample evidence by 1914 that sewers and drains in the Back Bay were affecting the ground water table, Worcester (18,p.6) felt that El. 5 was too low and suggested a cutoff as high as El. 8. Wisely, most engineers at the time disagreed with him, believing that El. 5 or 6 should be

maintained. Frederick P. Stearns (18,p.201) reasoned that with the presence of an increasing number of floor drains and decreased infiltration of surface water as the land was built upon, ". . . piles to support important structures should be cut off below rather than above grade 5." Charles T. Main (18,p.397) indicated that piles for the M.I.T. building would be cut off no higher than grade 13, Cambridge base (El. 8 Boston City Base).

In final discussions, Worcester (18,p.415) challenged his fellow engineers to cite a case where rotted piles had been found below El. 8. Although no examples were forthcoming, he changed his recommendation to El. 6.

In 1931, following the discovery of rotted wood piles below the Boston Public Library, the BSCE Committee on Boston Subsoils (14,p.244) was of the opinion that untreated wood piles should be cut off not higher than El. 3 in the Back Bay.

A further discussion of ground water levels throughout the Back Bay is presented in Part II of this paper.

PILE CAPS AND CONCRETE

Piles were commonly topped with a granite capping stone or a series of stones upon which the stone and brick foundation walls were constructed. After the turn of the century, concrete almost completely took the place of stone for foundations and also drove out the use of steel beams and girders in grillages and cantilevers. Prior to the time concrete was used to cap foundations, it was placed around the heads of piles to prevent the lateral motion of the piles, and to some extent connect them together. At Trinity Church, for example, two feet of dry concrete were placed around the wood pile heads in four layers, each 6-inch layer being thoroughly compacted. The upper surface of concrete was kept 1 inch below the heads of the piles so that every granite stone could be firmly rested on the piles.

OTHER PILES AND GOW CAISSONS

Toward the latter part of the century, concrete was being used in foundation construction. The Simplex pile, the Raymond standard taper pile and Gow caissons were introduced just after the turn of the century. Composite piles had been used since the turn of the century to overcome the cost of cutting off wood piles at a low grade. For the concrete extensions, headless barrels were used for forms, stacking one above the other. A history of the use of concrete piling is given by Gow (5).

HYDROSTATIC PRESSURE

It was a further requirement of the Boston Building Department that basement floors be placed at or above El. 12. However, with "waterproofed" construction, some basements were placed below this grade. For

determination of uplift pressure on floors, Worcester (18,p.19) initially assumed El. 12 as the highest water level on the basin side of the City, but later changed his recommendation to El. 11 (18,p.415). It is interesting to note his design assumption relative to uplift pressure (18,p.8). When a structural floor supported by piles was used, he assumed full water pressure acting over the entire area of the floor because the earth was likely to settle away. On the other hand, when the floor rested directly on the ground, he reasoned that ". . . obviously less than the whole area is exposed to water, for part must bear on the soil. Experiments reported by J. C. Meem would indicate that with a sandy soil not over 50 percent is so exposed. The writer has been in the habit of making this assumption in Boston." In subsequent discussions of his paper, no one questioned his assumption. Perhaps no uplift failure occurred because El. 12 was a conservative assumption for water level.

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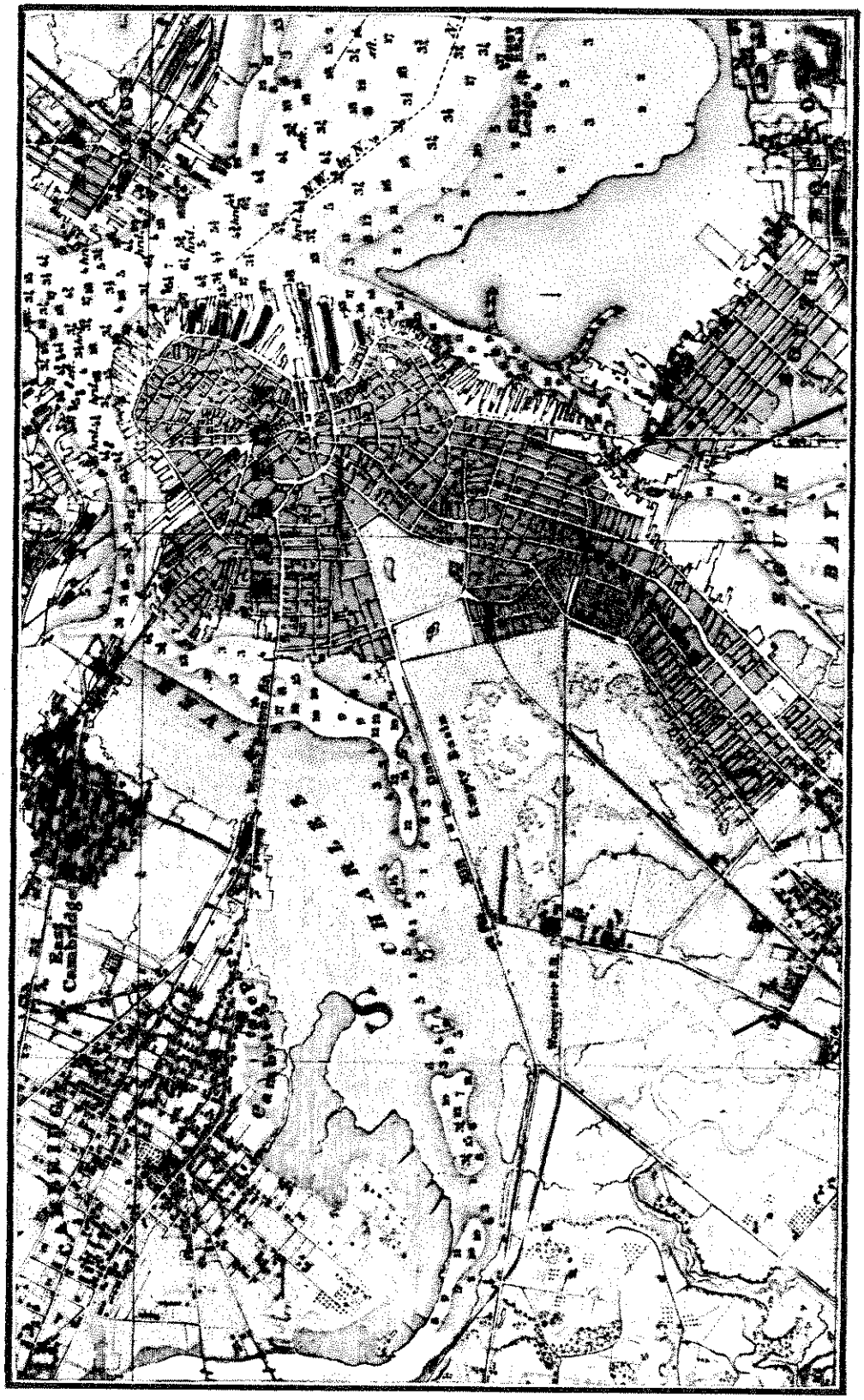

Figure 4 - Boston, About 1848, from a Coast and Geodetic Survey Map Dated 1857.

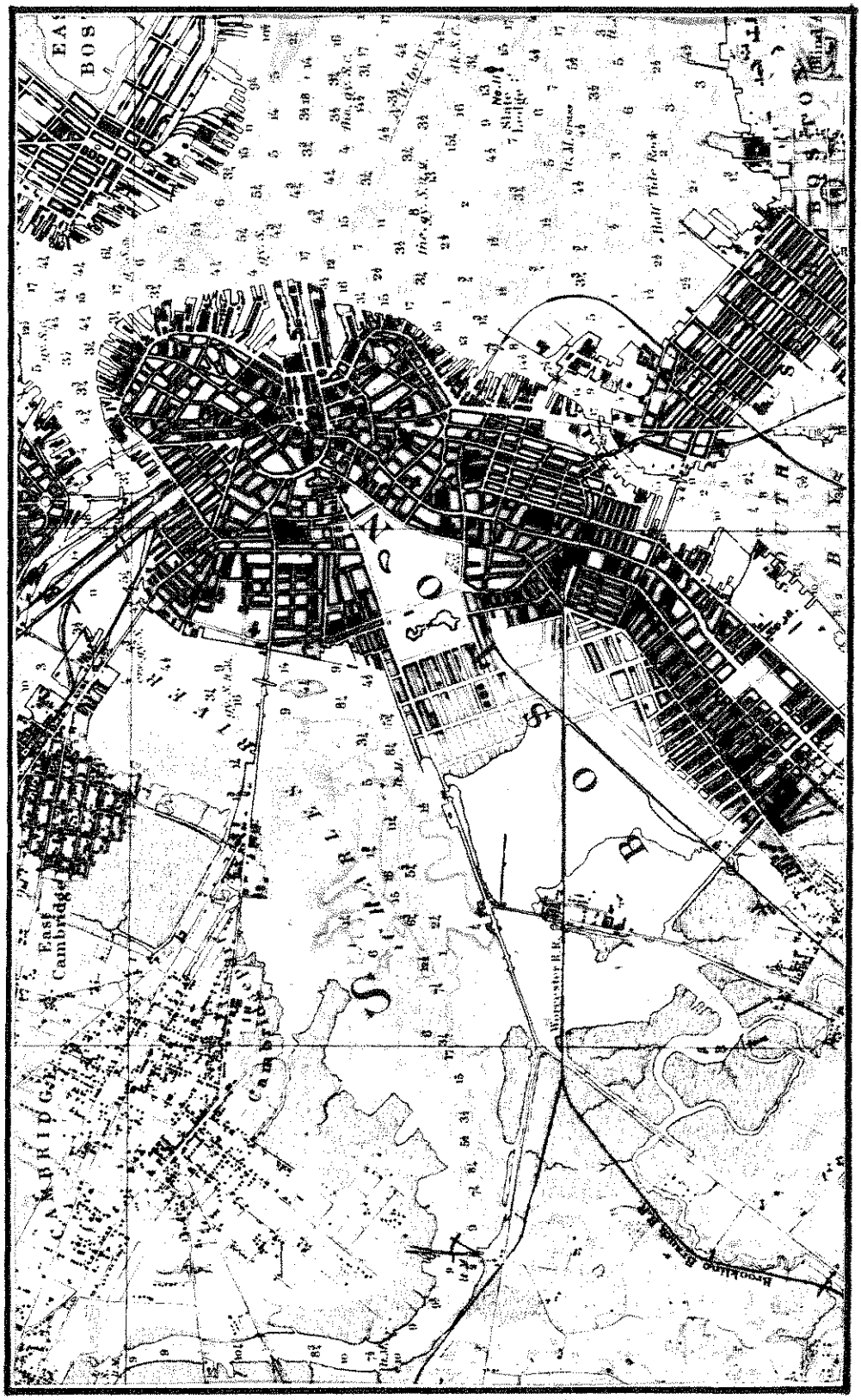

Figure 5 - Boston, About 1863, from a Coast and Geodetic Survey Map Dated 1872.

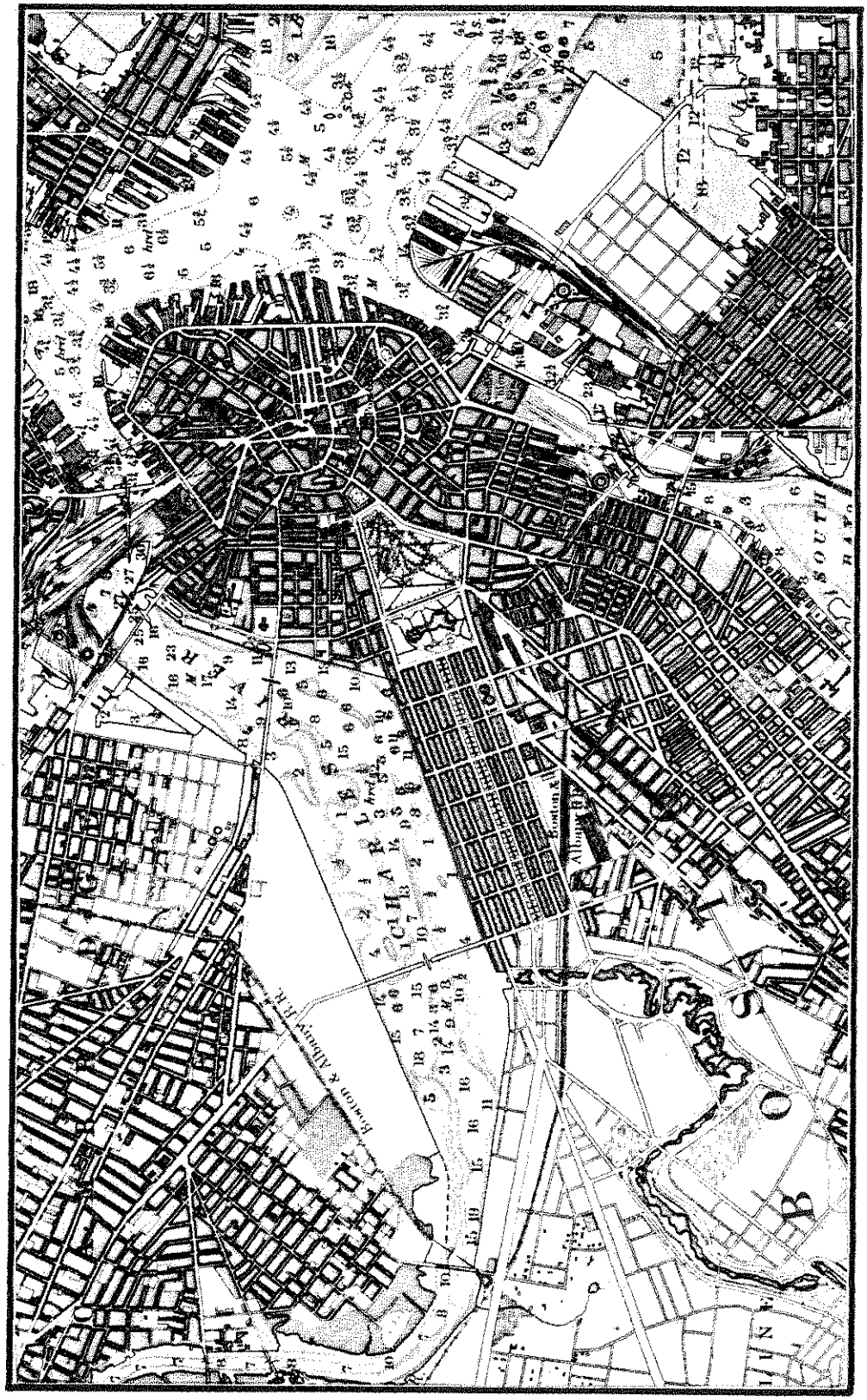

Figure 6 - Boston, About 1895, from a Coast and Geodetic Survey Map Dated 1901.

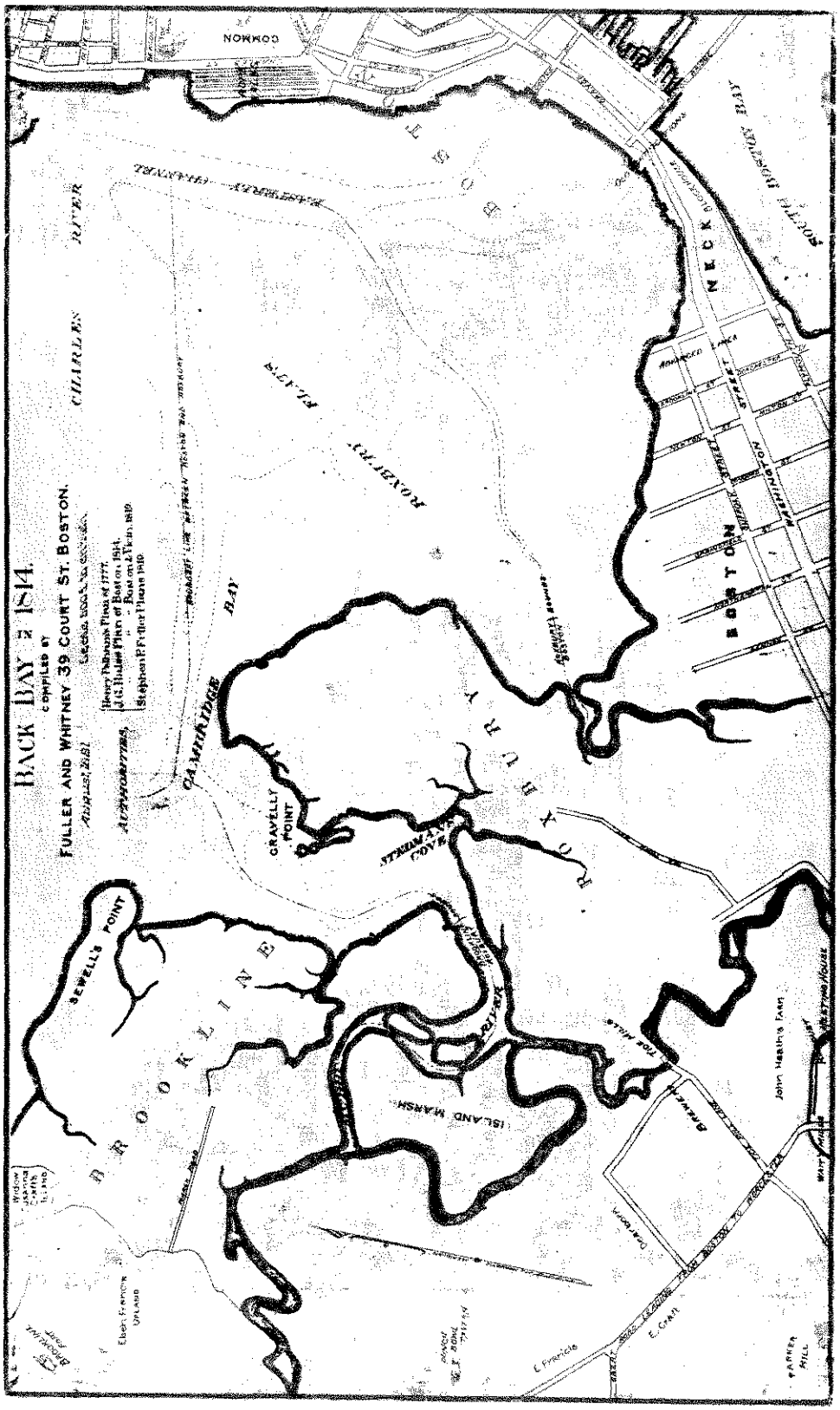

Figure 7 - Back Bay in 1814.

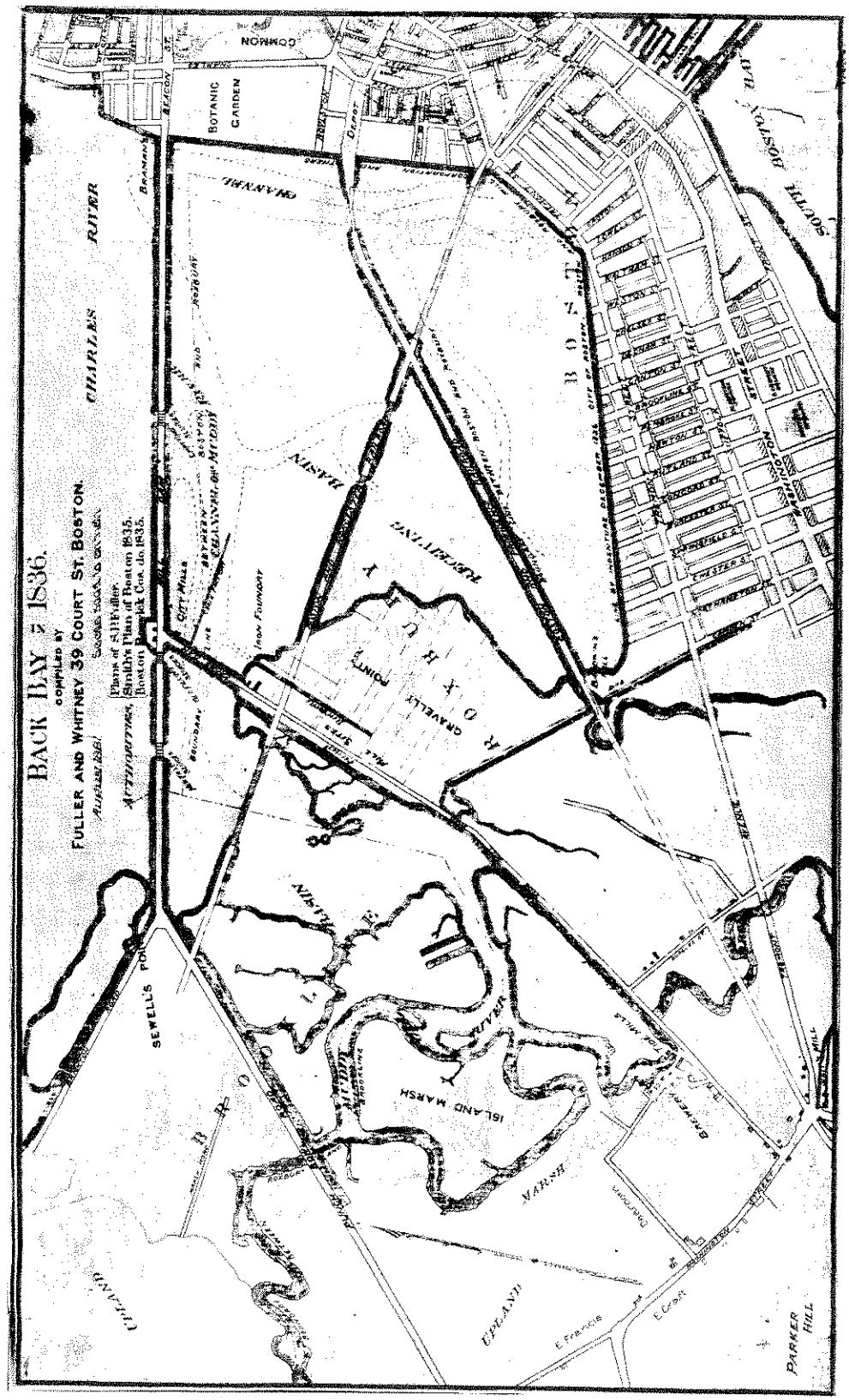

Figure 8 - Back Bay in 1836.

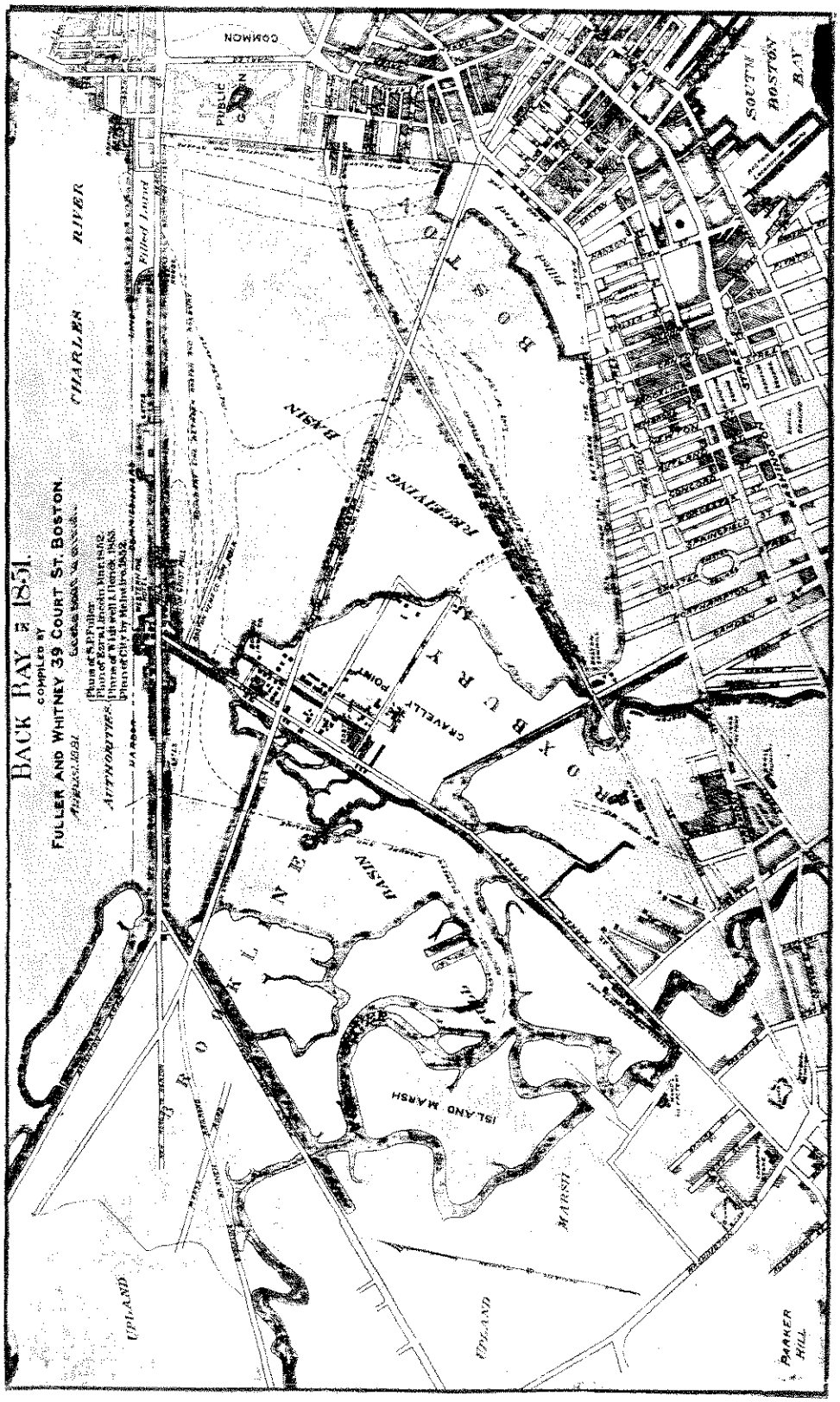

Figure 9 - Back Bay in 1851.

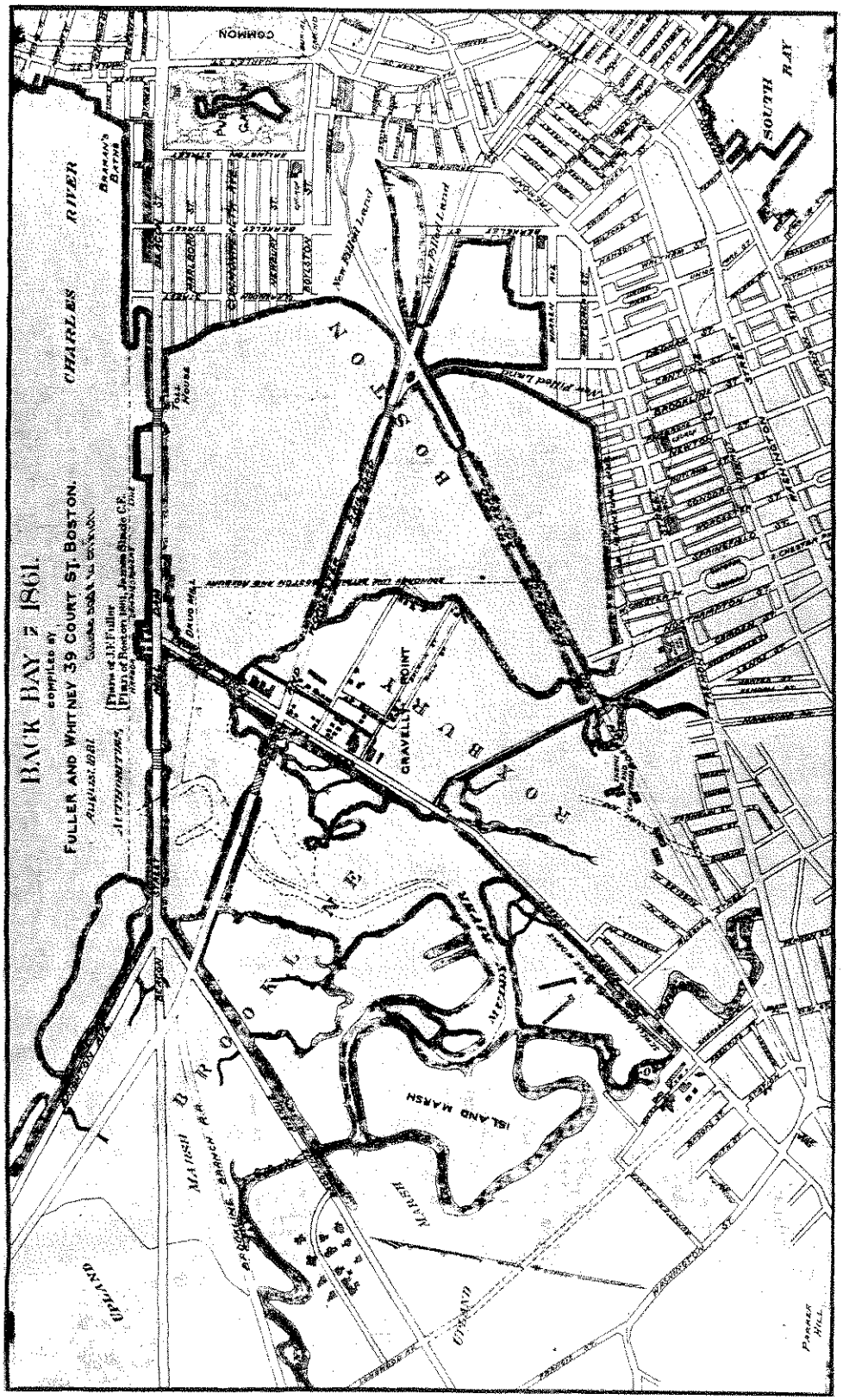

Figure 10 - Back Bay in 1861.

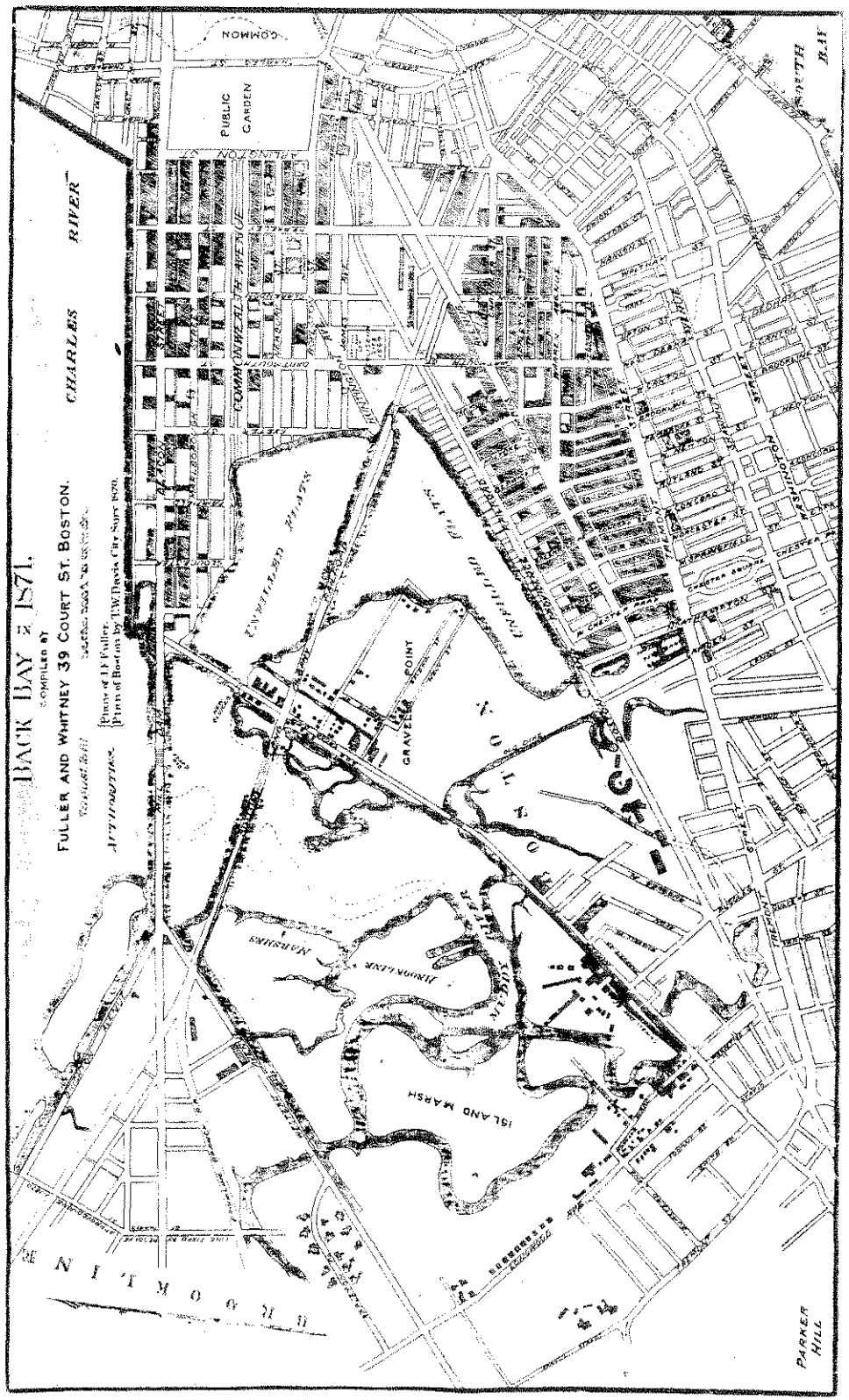

Figure 11 - Back Bay in 1871.

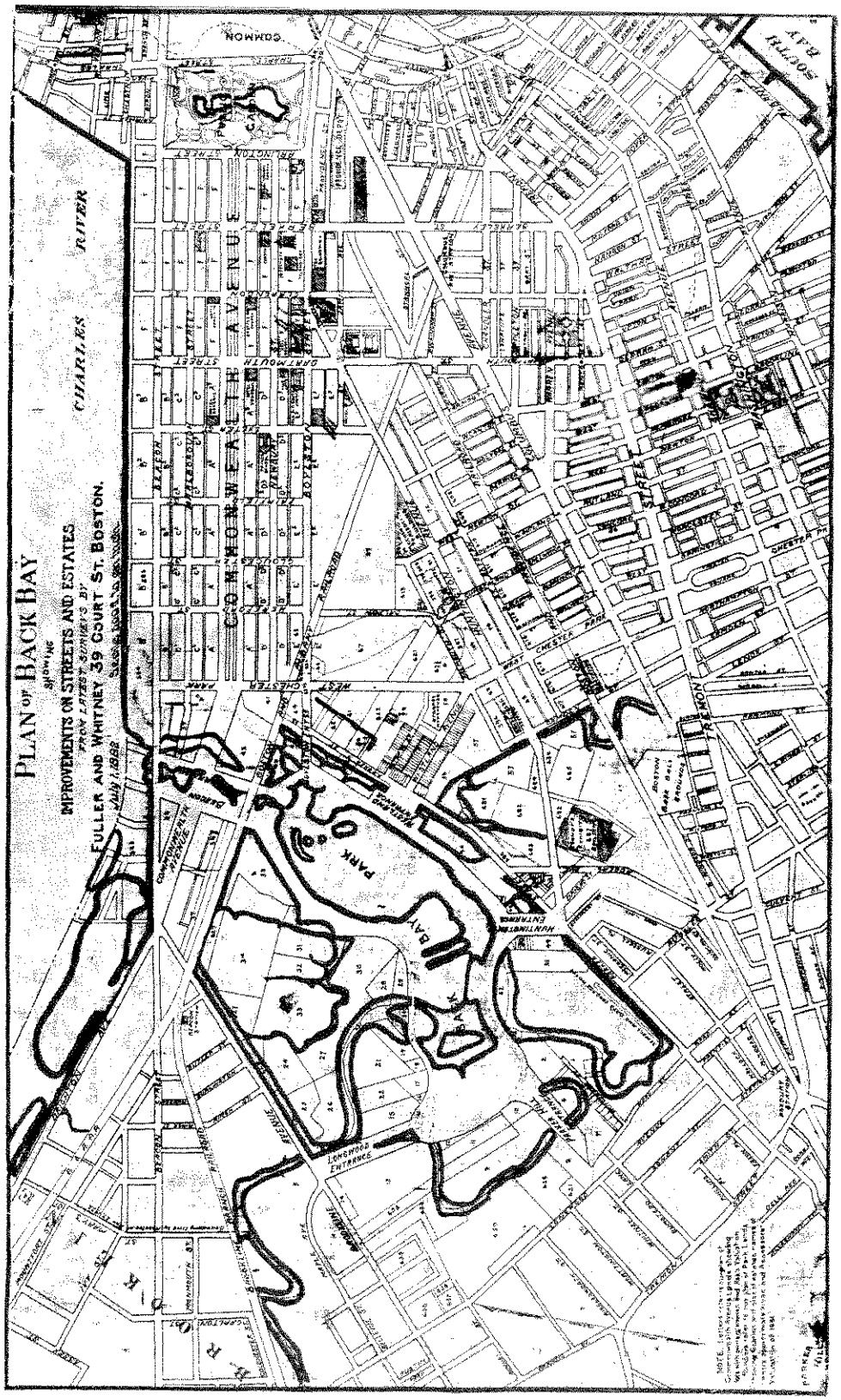

Figure 12 - Back Bay in 1882.

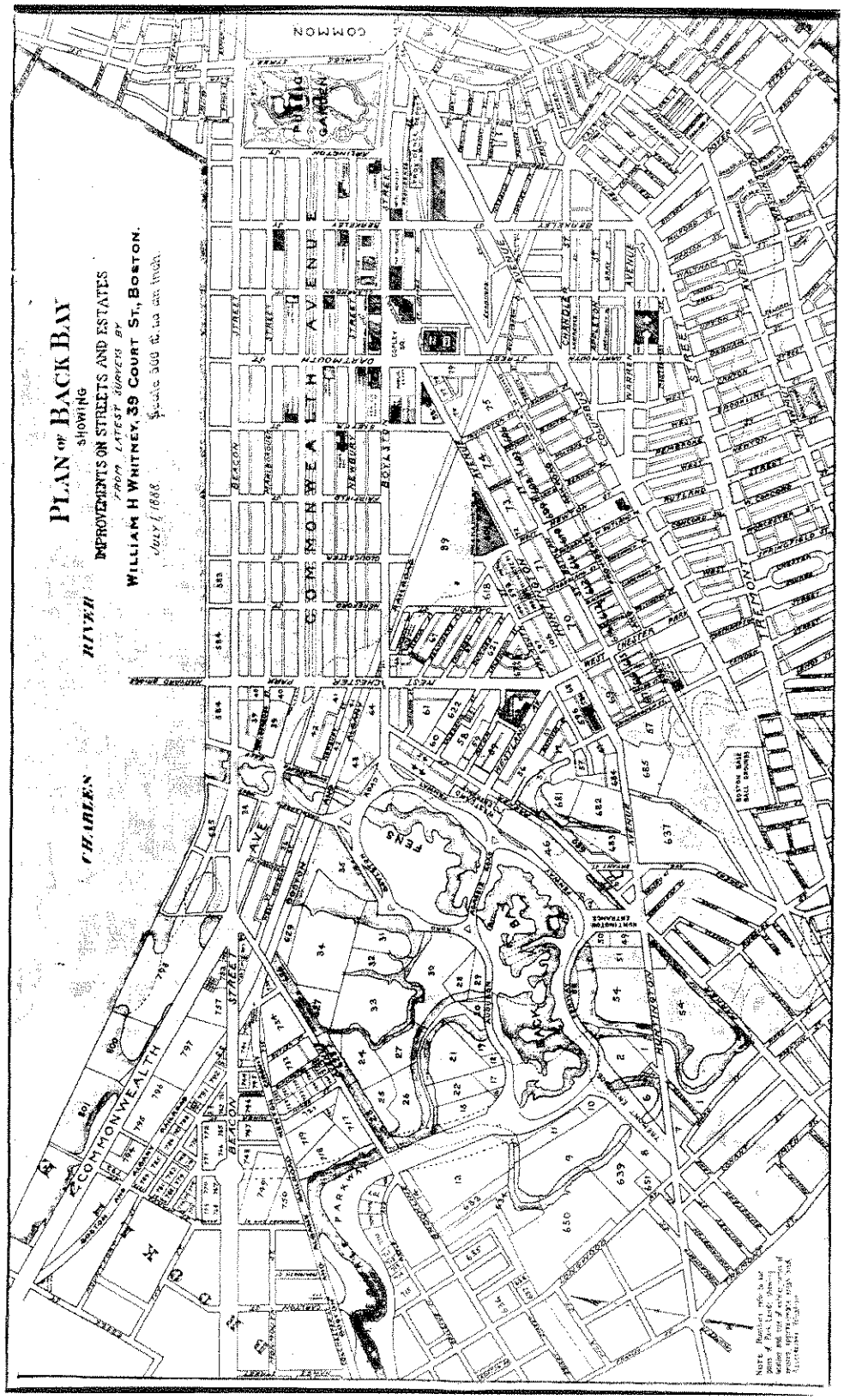

Figure 13 - Back Bay in 1888.