Settlement, Topography & Geologic Studies of Boston

A review of the important studies from the last two centuries is key in understanding Boston's complex geology.

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In 1630, John Winthrop and his fellow Puritans set sail from their native England to "found a city upon a hill" — a city that cannot be hid. This effort was unhindered by Native Americans because roughly ninety percent of them had died from disease just before founding this city. As Winthrop unfeelingly put it, by this misfortune "God hath thereby cleared our title to the place." What Winthrop termed "the Lord's Waste" was quickly transformed into a second England. The endeavor was aided by a fortuitous sequence of geologic events that produced a safe harbor, bountiful spring water and good natural sites for fortifications for the new settlers and Winthrop's dream was fulfilled (see Figure 1-1). However, the early settlers gave scant thought to the extremely complex and unusual geology of the region other than curse, under their breath, the stones that grew in the fields each spring. Anyone trying to explain that one of the greatest structural zones of North America passes just west of Boston and that the city now rests on a fragment torn from ancient Africa would have been expelled from the colony, if not hung as a heretic (see Figure 1-2).

The ancient North American and African plates — referred to as Laurentia and Gondwana, respectively — collided in a zone just west of Boston about 650 to 620 million years ago (see Figure 1-3). The geologic character of this margin and the structure to the east of this belt are not seen elsewhere on the Atlantic coast of the United States. When the much later rifting of about 225 million years ago began to form the present North Atlantic Basin, the split left a piece of northwest Africa clinging to North America. This fragment became the foundation upon which Boston was built. The city and its harbor lie in their own much smaller rift basin formed during a pause in the collision at the very end of the Proterozoic (pre-Cambrian) about 600 million years ago. An array of volcanic debris, gravel, sand and mud gradually filled and overflowed the rift. As the collision ended in the late Ordovician about 440 million years ago,

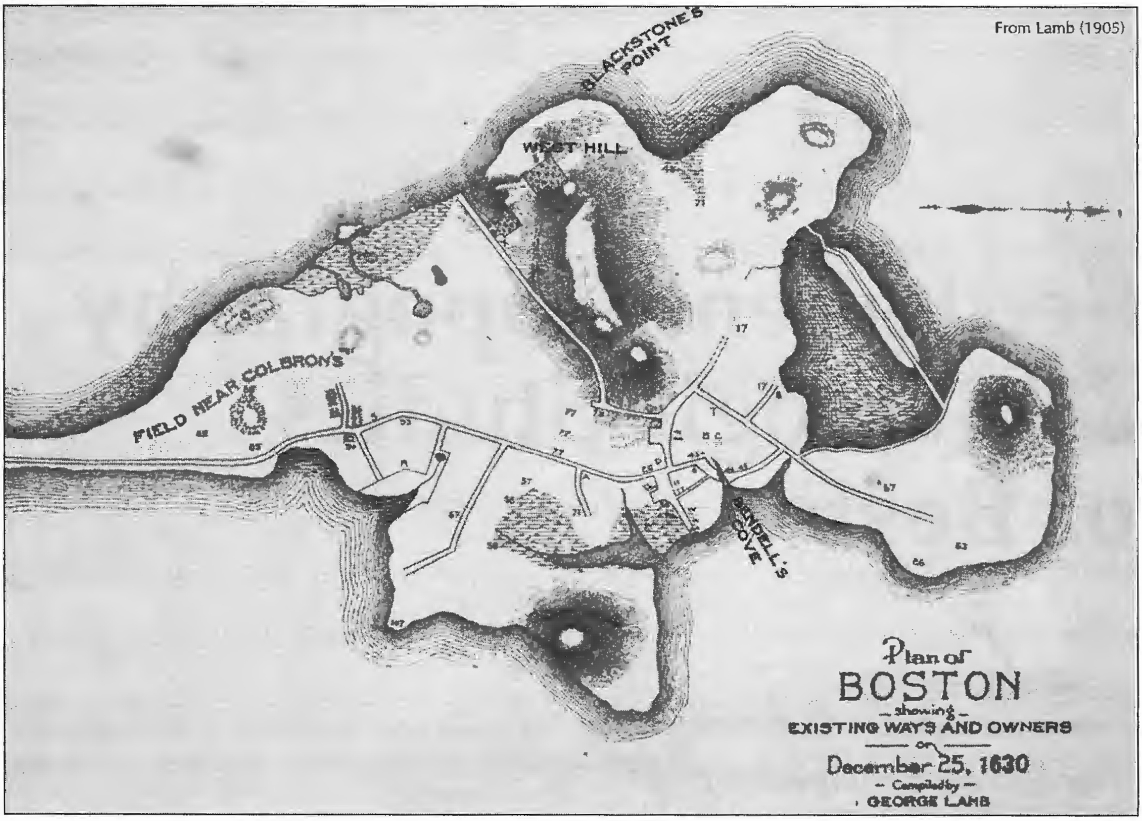


FIGURE 1-1. Plan of Boston from 1630 showing the existing ways on the Shawmut Peninsula.

volcanic upheavals formed masses of granite on both sides of the rift to give added character. These and subsequent events produced numerous kinds of structures and rock representing almost all later geologic periods. The region remains active, with earthquake activity and other indications of crustal movement, and is not at all passive. Repeated glaciations during the Pleistocene stripped off the overburden from the bedrock and then haphazardly re-covered it with a wide variety of deposits that were locally deformed by glacial readvances. The wide fluctuations in sea level as the ice advanced and retreated along the coast left behind a confusing array of terrestrial and marine debris. The last retreat of the ice left high drumlins and hollows that have filled with water, soft sediment and peat as the sea level rose from the melting ice to create coastal marshes and beaches. The land also suffered a tilt to the south when it rebounded from the ice removal, which, combined with tectonic subsidence and a vast leveling and infilling by man, created a varied, interesting and complex coastal environment. All of these features make the Boston area one of the most challenging anywhere since nearly every site is different. The challenge in overcoming the attendant problems resulted in achieving a remarkable number of engineering firsts.

Boston's Firsts

Both the city of Boston and the state of Massachusetts contributed much to the development of the study of the area's geology and its application to the extensive underground work on water, sewer and subway tunnels, and especially the recently completed Central Artery/Tunnel Project. This endeavor had many forbearers, including: Mother Brook, the first American canal built by Europeans in 1639; the tall 1716 Boston Light that was the first American lighthouse; and the bridge to Charlestown in 1785, which was considered at that time to be the greatest engineering enterprise ever undertaken in America. The bridge

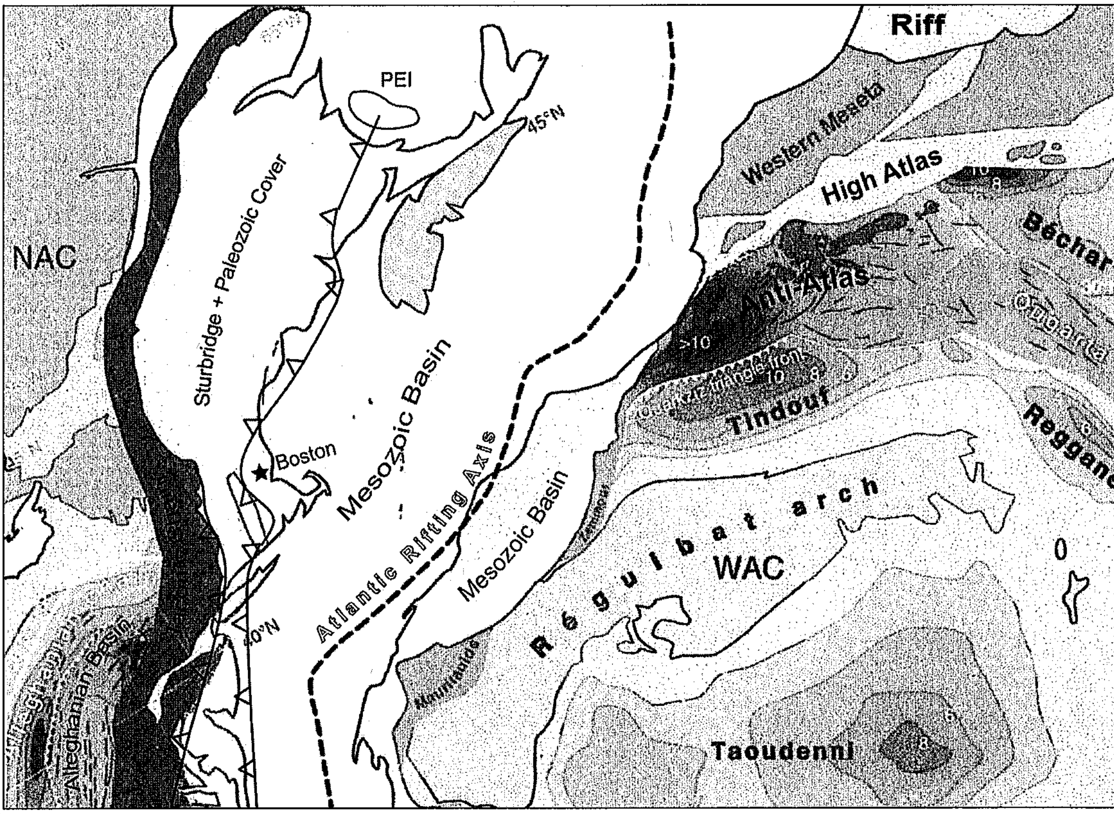


FIGURE 1-2. Map showing the New England/Morocco connection prior to the opening of the North Atlantic Basin.

was soon to be followed by the second greatest work, the Middlesex Canal, which was started in 1795, completed in 1803 and served as the prototype for the Erie Canal and the boom in canal construction. These achievements were joined by the first sewer system built from 1787 to 1834, the first gravity railway near Boston Common in 1805, the first chartered railway in 1826 and the longest bridge in North America in 1835 — the Canton Viaduct — for the Boston-Providence railway (still in use by Amtrak). The first subway was built in 1897, followed by the first extensive city water system of dams, aqueducts and tunnels; and farther west, the Hoosac Tunnel, the first great railway tunnel, introduced many new advances in tunneling. Boston also has the greatest filled area for residences in the world. Keeping with this tradition, the cofferdams built for the Ted Williams Tunnel, which opened in 1995, were the largest in scope in North America. The early engineering projects, which led to the formation of the first engineering society in the nation in 1848, the Boston Society of Civil Engineers, required an ever-expanding need to understand the area's geology, perhaps explaining why Boston was the first city to have a geologic map in 1818 and Massachusetts the first state to have a geological survey in 1833. What surely would have astonished John Winthrop was the first modern description of an earthquake in 1755, "shorn of God's vengeance," by his direct descendant and namesake John Winthrop of Harvard College. This earthquake started Winthrop's student John Adams on his career of writing.

Early Settlement

Native Americans reached southwest Pennsylvania some 16,000 years ago, south of the retreating glacial ice front, but were not recorded in Boston until much later when they built extensive fish weirs in the Back Bay (now near

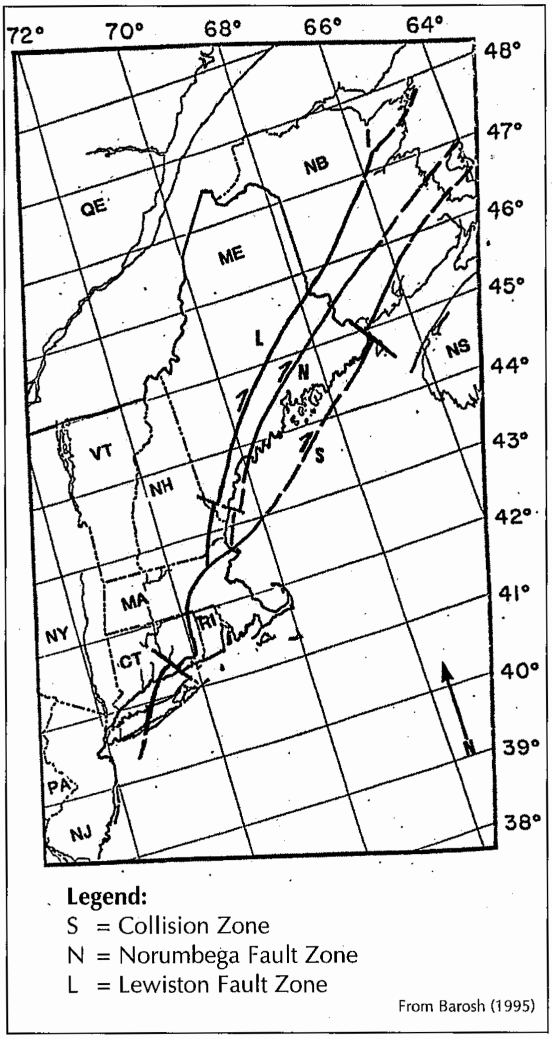


FIGURE 1-3. Map of New England and adjacent Canada showing the collision zone between ancient North America (Laurentia) on the northwest and ancient Africa (Gondwana) on the southeast, along with regional faults.

Boylston Street) between 5,300 and 3,700 years ago. These remains were uncovered in various subway and deep foundation excavations (Decima & Dincauze, 1998). More important are the Indian hornfels quarries in the Blue Hills that were being worked about 7,000 years ago for arrowhead material, which was very scarce in the region. This arrowhead hill, or Massachusetts in Algonquin, gave name to both the area and the tribe that lived there (Bowman & Zeoli, 1977). Norsemen were believed by some (without evidence) to have explored the Boston area between 900 and 1000 A.D. This belief was held by some to a sufficient degree that a statue commemorating Leif Erikson was erected on Commonwealth Avenue at Charlesgate East in 1887. Many early European fisherman, traders and explorers followed from the end of the fifteenth century. At least fourteen explorations of the northeast coast of North America were made in the sixteenth century and twenty-seven known ones made in the first twenty years of the seventeenth century (Dexter, 1984). The quest for cod brought sixteenth-century English, Basque and Portuguese vessels that would have visited the waters around the Shawmut Peninsula — Shawmut being a Native American name meaning "living waters." By 1625, these vessels numbered three to four hundred or more annually, some ninety years after the first failed settlement of Quebec and nearly a hundred years after the first ten fishing boats were spotted. In 1602, Native Americans in Basque boats wearing European clothes sailed by a temporary settlement on Cuttyhunk Island in southeastern Massachusetts set up by Bartholomew Gosnold, who later founded Jamestown in sunnier Virginia. Soon a flurry of mostly short-lived outposts and settlements dotted the coast in the region. Samuel Champlain mapped the Massachusetts shoreline in 1605 as did Captain John Smith who made a foray up the coast from Virginia in 1614. Smith decided New England was a suitable name for the region and Prince Charles bestowed his name to the Massachusetts River washing the western side of Shawmut Peninsula (see Figure 1-4).

Sites north and south of Boston were settled by Europeans first, saving the best for last. Boston might easily have been the home of the Pilgrims had they not balked at hiring Smith as their guide in 1620. When Captain Miles Standish, with a small group of Pilgrims and Native American guides, came along the shore from Plymouth in a small open sailboat and entered Boston Harbor on September 19, 1621, they realized that this site was ideal, but decided they had already invested too much at Plymouth to move. David Thompson founded a trading post in the bay on the

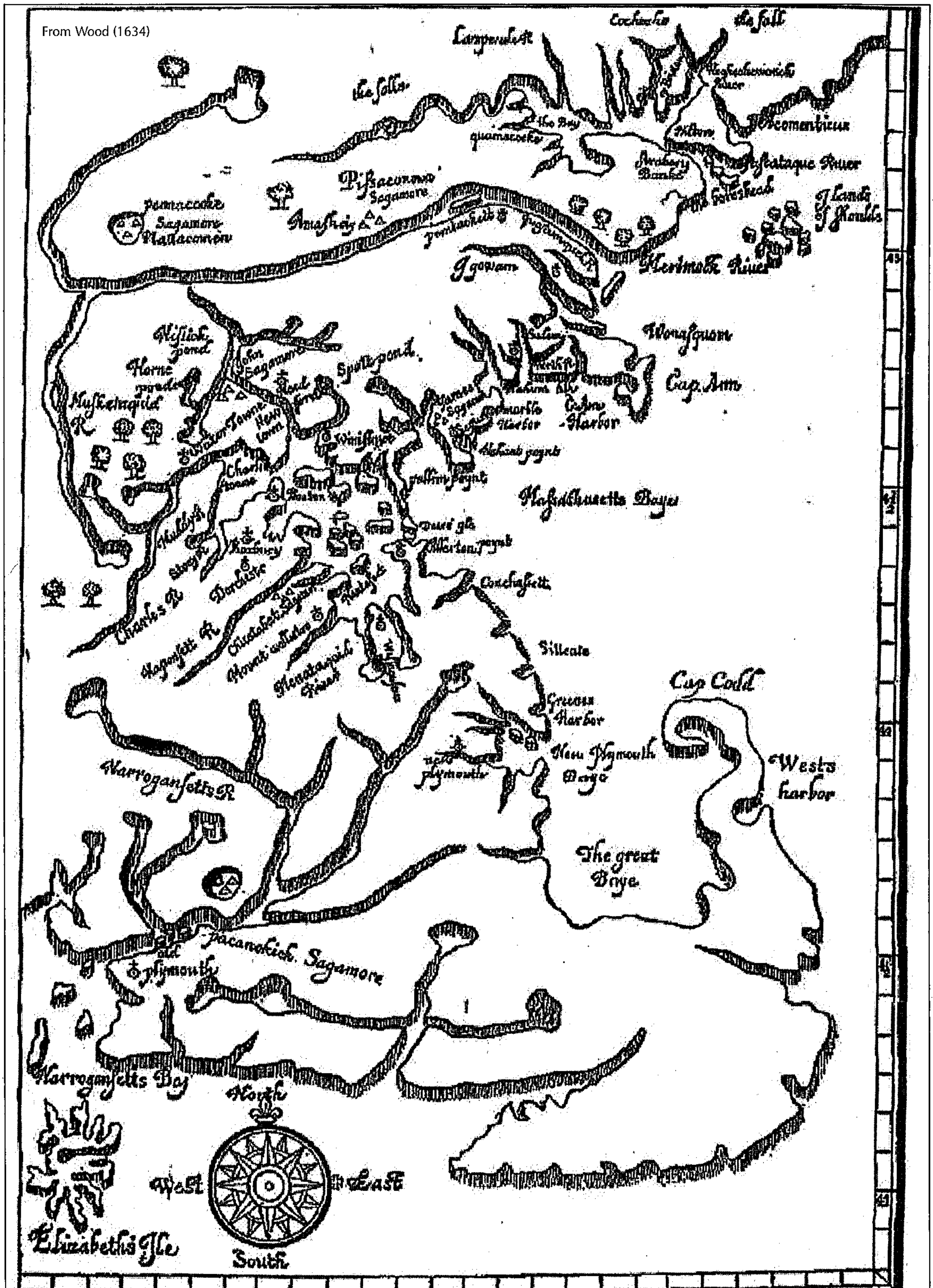


FIGURE 1-4. First map of southeastern New England showing Boston and other towns.

FIGURE 1-5. A plan of the town of Boston in 1775.

appropriately named Thompson Island and the retired Episcopal minister William Blaxton (Blackstone) arrived on Shawmut Peninsula in 1625. There were perhaps fifty people in several settlements close to Shawmut to greet the Pilgrims.

Shawmut Peninsula

The Shawmut Peninsula, which was later christened as Boston, was shaped by all the geologic events described above. For much of its history, from its founding in 1630 to the filling of the tidal flats along the coastline and the Charles River in the eighteenth and nineteenth centuries, Boston had the smallest land mass of any major city (see Figure 1-5). It was quite small at the beginning, only about 487 acres, and was dominated by the three prominent joined hills called the Trimountain — or, in the looser spelling of the day, either Tramount, Tremount, Tramountaine or Trimountain. Nowadays it is spelled Tremont. If Boston Neck to the south is included, the city was 717 acres (Seasholes, 2003). At low tide it formed the peninsula, but at high tide it was an island complex connected to the south by a narrow neck that was awash at times and deep enough to drown unwary travelers (see Figure 1-6). It was one of over fifty islands counted in 1621 in the large Massachusetts Bay that stretches out to the east and indents the New England coast (see Figures 1-4 & 1-7). The number is now down to thirty-eight, since islands such as Nix's Mate (now just a shoal) and Calf Island (now a small rock remnant) have disappeared, but they still act as a buttress to the Atlantic storms and shelter Boston. An incredible mixture of drumlins, moraine, marine clay and thrusted sediments (which include outwash sand, clay and till) was packed into this small city that now is dominated by Beacon Hill. The peninsula juts northward and was flanked by broad tidal flats on the west along the Charles River, but a snug harbor on the east that sent ships around the world was the pride of Boston. The ancient rift basin forming the depression in which the city and the bay lie is mostly filled with relatively soft argillite bedrock, a sedimentary rock formed mostly from mud. The western and southern edges rise into hilly areas underlain by more resistant conglomerate and volcanic rock — a step below the higher surrounding granite cored terrain that juts seaward north and south of the bay. The city's one shortcoming is the lack of a major navigable river connecting it to the interior, such as the Merrimack to the north, but this deficiency helped turn its attention outward into the broader world.

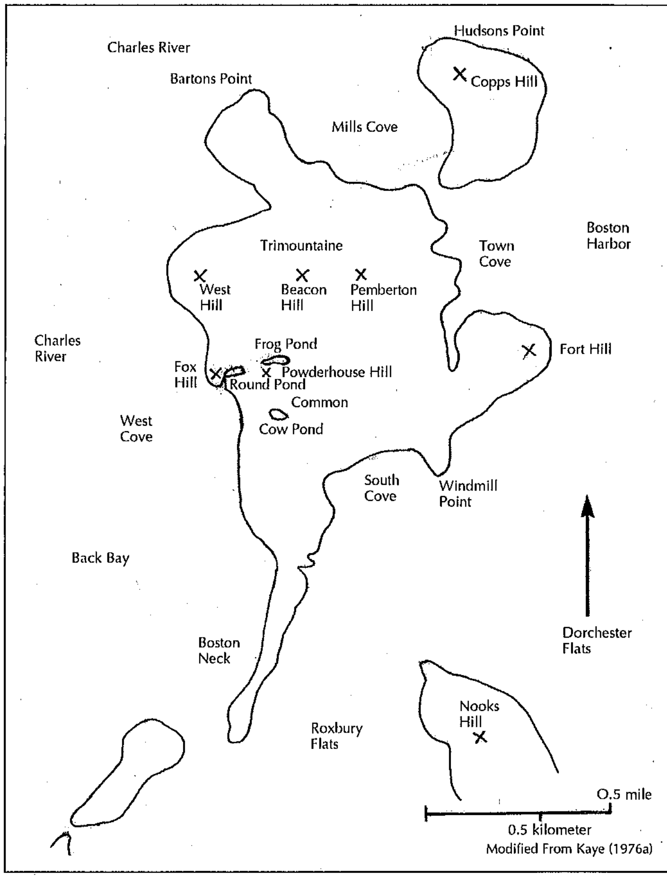


FIGURE 1-6. Shawmut Peninsula at mean high tide in 1630 with early colonial names for topographic features.

Serendipity or Divine Providence

On June 12, 1630, John Winthrop and his fel-

FIGURE 1-7. Boston Harbor islands in 1782.

low Puritans reached Salem and were greeted by a landscape of barren rock and little soil, a brutal contrast to their native, fertile southern England. Pressured by his followers, Governor Winthrop, after spending just five days in Salem, left for Charlestown where a group of

Englishmen had already settled in search of more promising land. By July 6, eleven ships had arrived at Salem or Charlestown, carrying the survivors of stormy seas and sickness, which had decimated their ranks. Within a couple of weeks, the new settlers at Charlestown were nearly defeated by sickness, death and lack of water. Winthrop blamed his troubles on the one source of water available, a brackish spring that was only exposed at low tide. Their sickness was compounded since the English traditionally drank water from springs rather than dug wells, although beer was apparently their first choice. Help came in the person of the hermit William Blackstone, a retired Episcopal minister who had been living alone across the Charles River for five years. Blackstone had been the chaplain of the unsuccessful Robert Gorges's Plantation, which had settled on the south side of Hingham Bay at Wessaguscus or Wessaguset (now Weymouth) in 1623 (see Figure 1-4). Blackstone was the first English settler on the Shawmut Peninsula and built a cottage on the south side of Beacon Hill near the Common, where Spruce Street now meets Beacon Street. Blackstone told Winthrop of the abundant and refreshing spring water available on his land. Accepting his invitation, Winthrop and his group moved across the river to the peninsula. According to Lathrop (1800), abundant spring water did exist on what was to become Louisburg Square on Beacon Hill, Pemberton Hill and Spring Lane east of Pemberton Hill (see Figure 1-6). The discovery of many old colonial wells in modern excavations attests to this gift of geology. The group settled near Spring Lane, the North End and at the Great Cove (Town Cove) at the bottom of what is now State Street. Winthrop built his house close to the "Great Spring" at what is now 276 Washington Street. Blackstone must have regretted the invitation, since he soon sold his property and moved to the wilds of what became northern Rhode Island, where he preached a tolerant Christianity and developed a new variety of apple.

Thus, Winthrop founded his "city on a hill." The hill was a mountain with three small rising hills on top of it called the "Trimontaine." This prominent feature (with various spellings) can be seen from Charlestown. At 8 A.M., September 7, 1630 (Julian calendar) by order of the Court of Assistants, Governor Winthrop presiding, it was so decreed "[t]hat Trimontaine shall be called Boston." The name came from Boston, England, in the parish of St. Botolph, and was a contraction of "Botolph's town," after "Bot" meaning boat, and "ulph" meaning help. St. Botolph was the patron saint of fishing. Boston's roots were thus established. So was its characteristic accent, shown by an alternate spelling "Baston," which reflected how settlers spoke the word. It was named for the home town of the Reverend John Cotton, who had sent them off with a farewell sermon, and being so honored, he came three years later. The choice was a goodly one since "[Shawmut] being a neck bare of wood, they are not bothered with the three great annoyances of wolves, rattlesnakes and mosquitoes" (Wood, 1634).

Topography

Excavation and filling, along with natural erosion, has greatly changed the topography within the sea-flooded basin holding Boston and the harbor islands since settlement. Fortunately, Boston is blessed by many early accurate maps and drawings that display the original features, thereby allowing an interpretation of their origin. The early hills of the Shawmut Peninsula are well known. Trimontaine was formed by three prominent coalescing hills rising 46 meters (150 feet) above its surroundings (see Figure 1-8). The westernmost hill was West Hill, later called Mount Whoredom on British maps, or Copley's Hill and finally Mount Vernon, when it was lowered and developed. The central peak was Beacon, or Sentry, Hill. And the easterly hill, separated by the small Valley Acre, was first called Pemberton Hill and then Cotton Hill (see Figures 1-6, 1-9 & 1-10). Place and street names in the town also tended to be casual and continually changing due to different ownership or activity. Several lesser hills also were scattered about the Shawmut Peninsula. Copp's Hill, also called Windmill Hill from the one built there in August 1632, or Snow's Hill, rising 15 meters (50 feet) in the North End, and Fort Hill, also called Corn Hill, rising 24

FIGURE 1-8. View north at Boston and Trimountain from east of the Shirley House, Roxbury on the road to Dorchester in 1775.

meters (80 feet), were situated on points of land facing the sea to the east (see Figures 1-5, 1-6, 1-11 & 1-12). Smaller hills or knolls were also found, such as Fox Hill and Powderhouse Hill (also known as Flagstaff Hill), situated to the southwest on the Boston Common (see Figures 1-6 & 1-13). Other high rounded hills rose up on the mainland such as at Charlestown to the north (Breed's Hill, Bunker Hill, Morton's Hill) and across Dorchester to the southeast (Telegraph Hill, Dorchester Heights, Savin Hill). The tops of many more rise above the water in the harbor to form islands, such as the nearby Castle Island in South Boston and Camp Hill in East Boston (see Figures 1-14 & 1-15). Most of the protect-

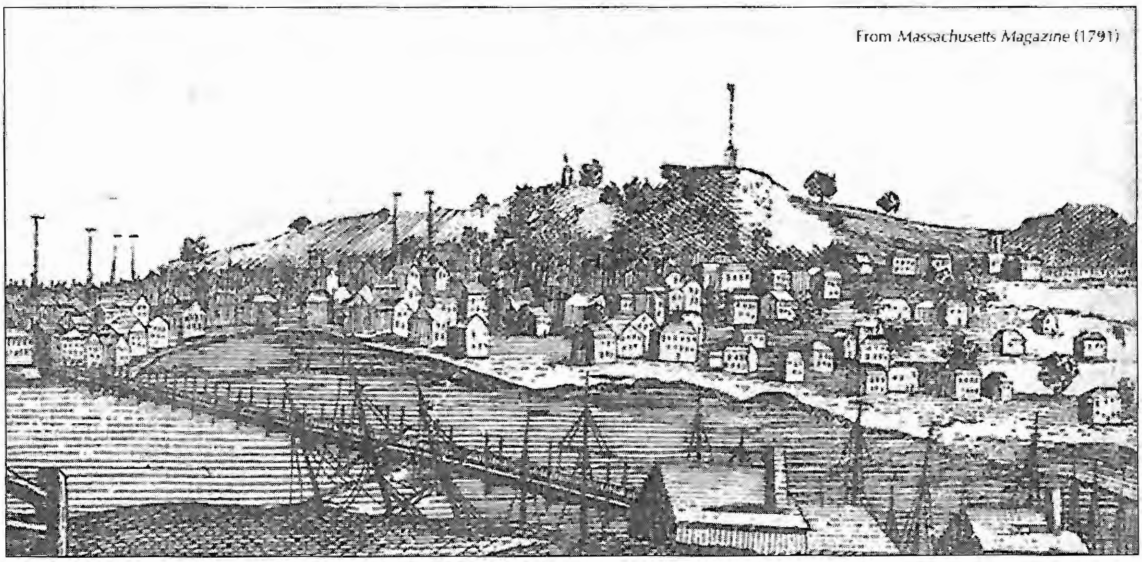
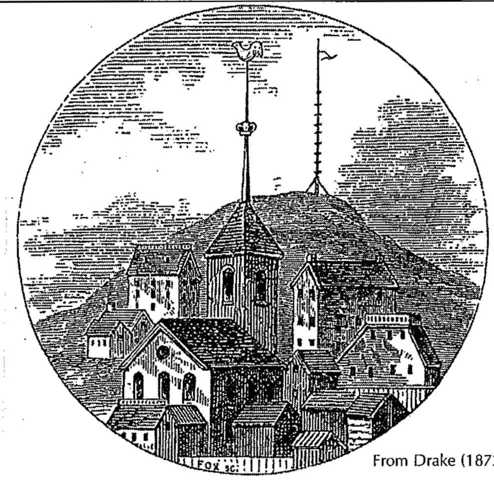


FIGURE 1-9. View south at Boston from Breeds Hill in Charlestown at Beacon Hill with Mill Pond in the foreground.

ed mainland shore was bordered by broad salt marshes and tidal flats (see Figure 1-16) except for the inner harbor area at Boston. Broad shoals surrounded the more exposed of the islands and many of the islands were actively eroding away and surrounded by bluffs, with the smaller ones eventually disappearing (see Figures 1-17, 1-18 & 1-19).

Geological Influences Affecting Settlement

There were several major geological influences that affected the founding of Boston (Kaye, 1976a). Being a seafaring people, the early settlers looked for a safe harbor. Boston's island-studded harbor is formed by a deep indentation in the coastline of Massachusetts (see Figure 1-7). This indentation exists primarily because the underlying rock, mostly argillite, is softer and more easily eroded than the hard highland conglomerate and granitic rock, which surround the Boston Basin (the name of this large topographic and structural depression). Glacial ice further eroded the broad valley and, with subsequent melting of the ice, the sea level rose and flooded the depression, thereby forming the bay and "a safe and pleasant harbor." "This harbor is made by a great company of island, whose high cliffs shoulder



From Drake (1872)

FIGURE 1-10. View west across Old Kings Chapel at houses on Pemberton Hill, with Beacon Hill rising behind it in the early eighteenth century.

FIGURE 1-11. View northeast across Long Wharf at Boston Harbor (circa 1790), with Beacon Hill in the center, Copp's Hill on the right and the rounded hills of the mainland in the distance.

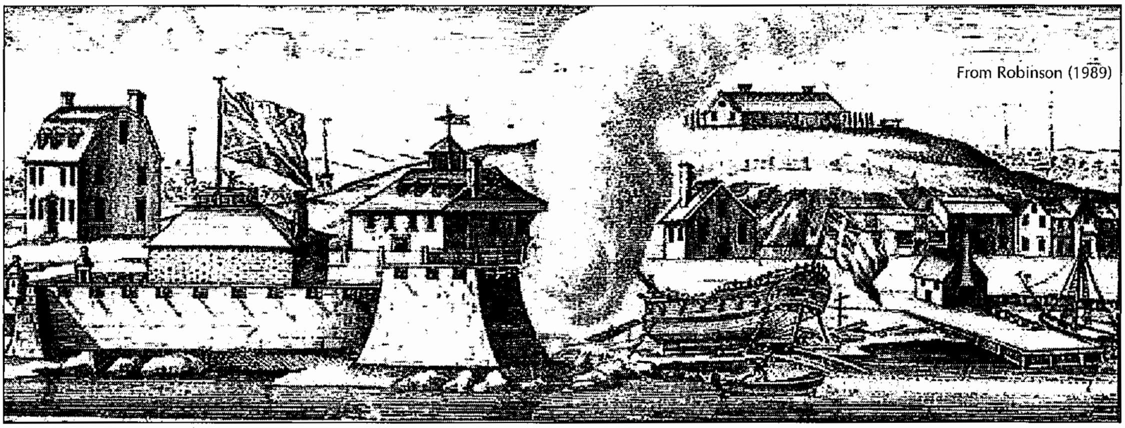


FIGURE 1-12. View south at South Battery with cliff-faced Fort Hill (behind) circa 1765.

out the boisterous seas, yet may easily deceive any unskilfull [sic] pilot; presenting many fair openings and broad sounds, which afford too shallow waters for any ships" (Wood, 1634). Three ships could sail abreast through the narrow inlet that protected the harbor and once within there was anchorage for five hundred ships (Wood, 1634). It was this safe harbor, which served as the chief port for numerous settlements of the hinterland, that made Boston the most noted and frequented city in the Northeast (as well as the seat of the Massachusetts Bay Colony), even though it was neither the greatest nor richest city in the region.

The second important factor was that the settlers looked to the land for protection from their enemies. Boston had many drumlin hills naturally situated for fortifications to protect it from attack from the sea, along with those forming the harbor islands. Trimontaine overlooked the harbor and sea coast to serve as the site of the warning beacon. Copp's Hill at the north end and Fort Hill to the east both served as locations for batteries (especially the latter) that commanded a view of any ship that sailed into the harbor (see Figure 1-12). Forts were built on Castle Island and many of the other islands over the next two centuries. Later, even the small Fox and Powerhouse hills on the Boston Common were used for defense. However, many of these drumlins, including Trimountaine (now only represented by Beacon Hill), are not the simple drumlins they first seemed.

Third, the Shawmut Peninsula was an island at high tide. The land to the south, called the Neck, which connected to Roxbury, was very narrow and low, and at best served as a causeway for travelers, but it was also easy to defend (see Figure 1-6). The British Regulars cut through the Neck in front of gun emplacements during the British occupation of Boston (see Figure 1-5).

Fourth, the primary and literally life-giving element was the abundant water available to the settlers. The Shawmut Peninsula became the Town of Boston because of sweet and pleasant springs, along with water of good quality under artesian pressure from shallow dug wells. Much of the area is underlain by a sandwich of thick, pervious sand and gravel between lodgement till and marine clay, and the thick deposits beneath Beacon Hill fed reliable springs at its base. The water was of such quality that some even preferred it to good beer and most to bad beer, whey and buttermilk (Wood, 1634).

Fifth, the surrounding salt marshes and mud flats provided the salt marsh hay preferred by the cattle. The marshes and flats also supplied abundant shellfish and smaller fish for the colonists. Some marshes also were dammed to power tidal mills (see Figures 1-5, 1-9, 1-16 & 1-17), as at the North Cove (Mill Pond).

Sixth, the hills in Boston provided suitable material to fill lowland and tidal flats.

Seventh, the stone and rock of the region provided for general building material, the split argillite for roofing, and the clay deposits for brick and tile. Boulders on the surface in Boston provided foundation material. Roofing was quarried from islands and promontories

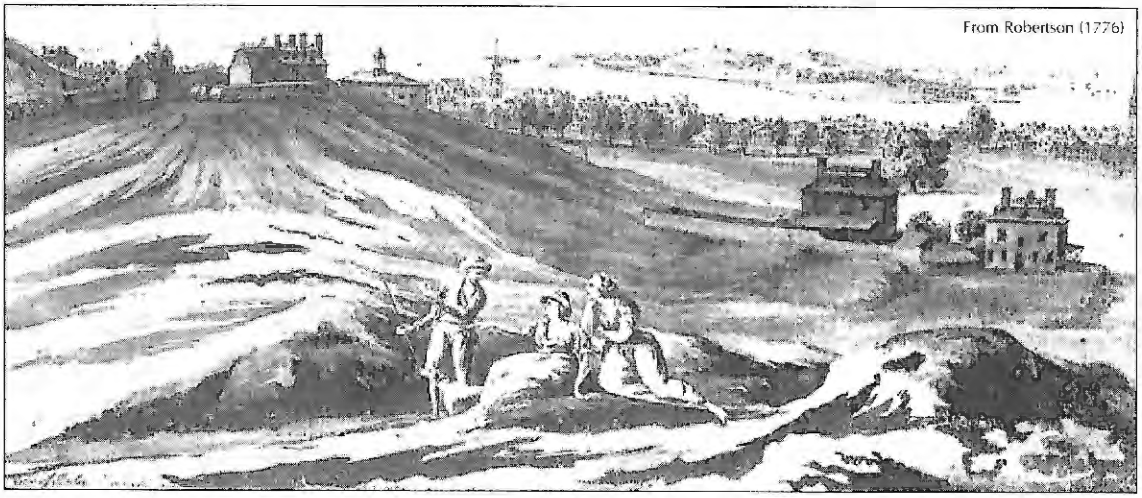


FIGURE 1-13. View east along the south edge of Beacon and Pemberton Hills from West Hill (later developed and named Mount Vernon) with the Common and Powderhouse Hill on the right.

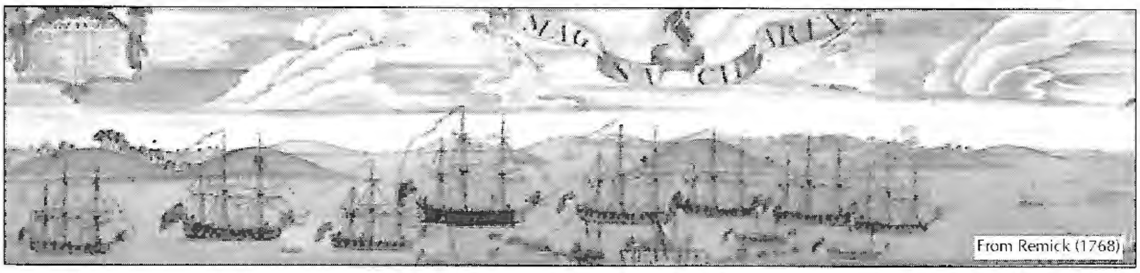


FIGURE 1-14. View east from the end of Long Wharf at English ships and islands in the harbor in 1768 (opposite view from Figure 1-12).

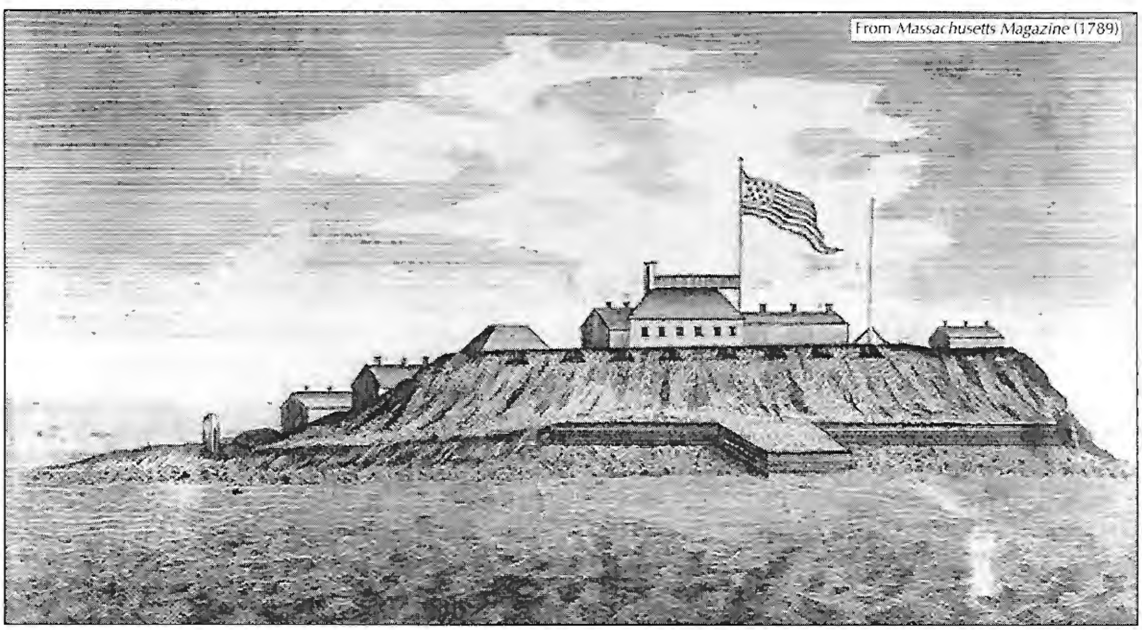


FIGURE 1-15. A north view of Castle William on Castle Island circa 1789.

(see color version on page 449)

FIGURE 1-16. Boston and the lower Charles River estuary showing marshes in 1775.

at the south side of the bay. In addition, clay for brickworks was found at Charlestown and elsewhere.

Lastly, the surrounding area had sufficient rivers and streams to power mills to grind corn and saw wood.

These factors all contributed to a notable population increase and considerable development of the Shawmut Peninsula (see Figure 1-20) during the seventeenth and eighteenth centuries (Krieger & Cobb, 1999; Seasholes, 2003; Haglund, 2003). To reclaim the surrounding marshy lowlands, early land developers looked to the hills. Fox Hill was the first to go when the shoreline was extended (see Figure 1-6) and then the three hills of Trimountain served as a ready source of fill. In 1799, about 15 to 18 meters (50 to 60 feet) of West Hill was excavated by the Mt. Vernon proprietors to fill in the cove at its base, thus creating Charles

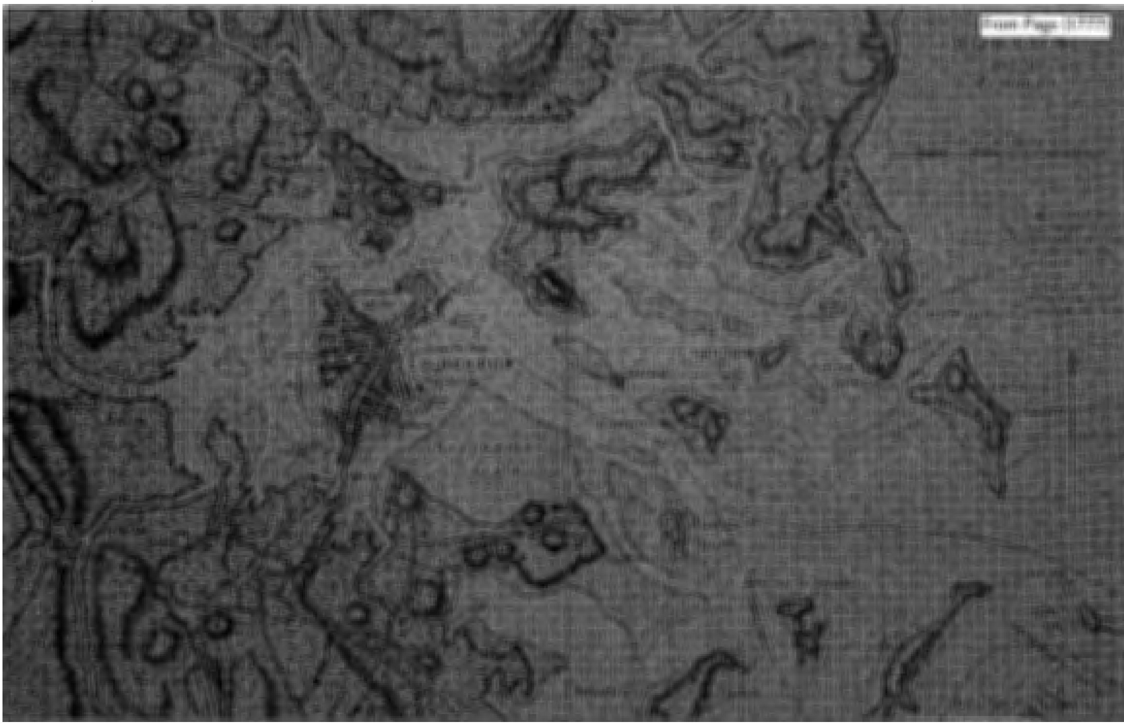


FIGURE 1-17. Boston and its environs showing marshes, tidal flats and shoals in the bay in 1775.

Street. The Mill Pond, created in 1643, was the next area attacked in the enthusiasm for increasing the land area of Boston (see Figure 1-5). The central peak of Beacon Hill, itself a source of gravel since 1758, was lowered by 18.3 meters (60 feet) by John Hancock's heirs and Mill Pond was filled in. The last hill, Pemberton Hill, had its top shaved off by Patrick Tracy Jackson, a railroad man, in 1835 to fill new land north of Causeway Street and develop Pemberton Square. The remaining ridge connecting the former peaks of Pemberton and Beacon hills was leveled in 1845 (Whitehill, 1968). A scheme developed during the War of 1812 to build a long Boston and Roxbury Mill Dam across the Back Bay for tidal power was finally carried to fruition in 1821 to serve as a road bed for a future railroad and then as Beacon Street (Marchione, 1996). The latter half of the nineteenth century saw the last major filling (see Figure 1-21), as the Back Bay was created from sand and gravel brought in approximately 13 kilometers (8 miles) by railroad from Needham to the west and dumped behind the mill dam (Newman & Holton, 2006).

FIGURE 1-18. Rocks on the east end of Little Brewster Island and the Boston Light prior to the erosion of the sides of the island.

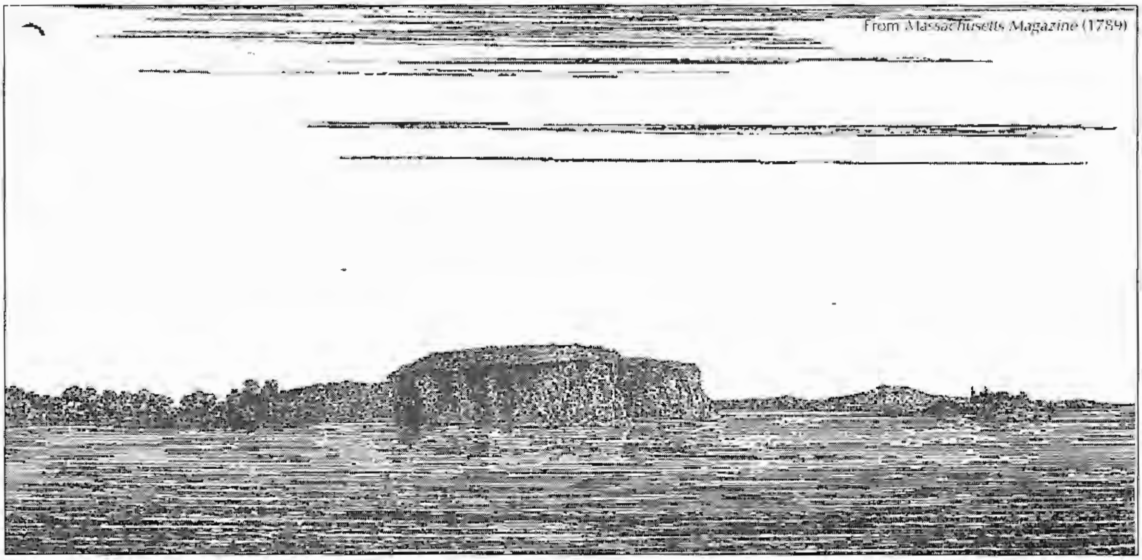


FIGURE 1-19. Nix's Mate Island circa 1789 before being eroded to a shoal.

FIGURE 1-20. Map of the colonial Shawmut Peninsula of 1700s (heavy line) superimposed on an 1880 map of Boston.

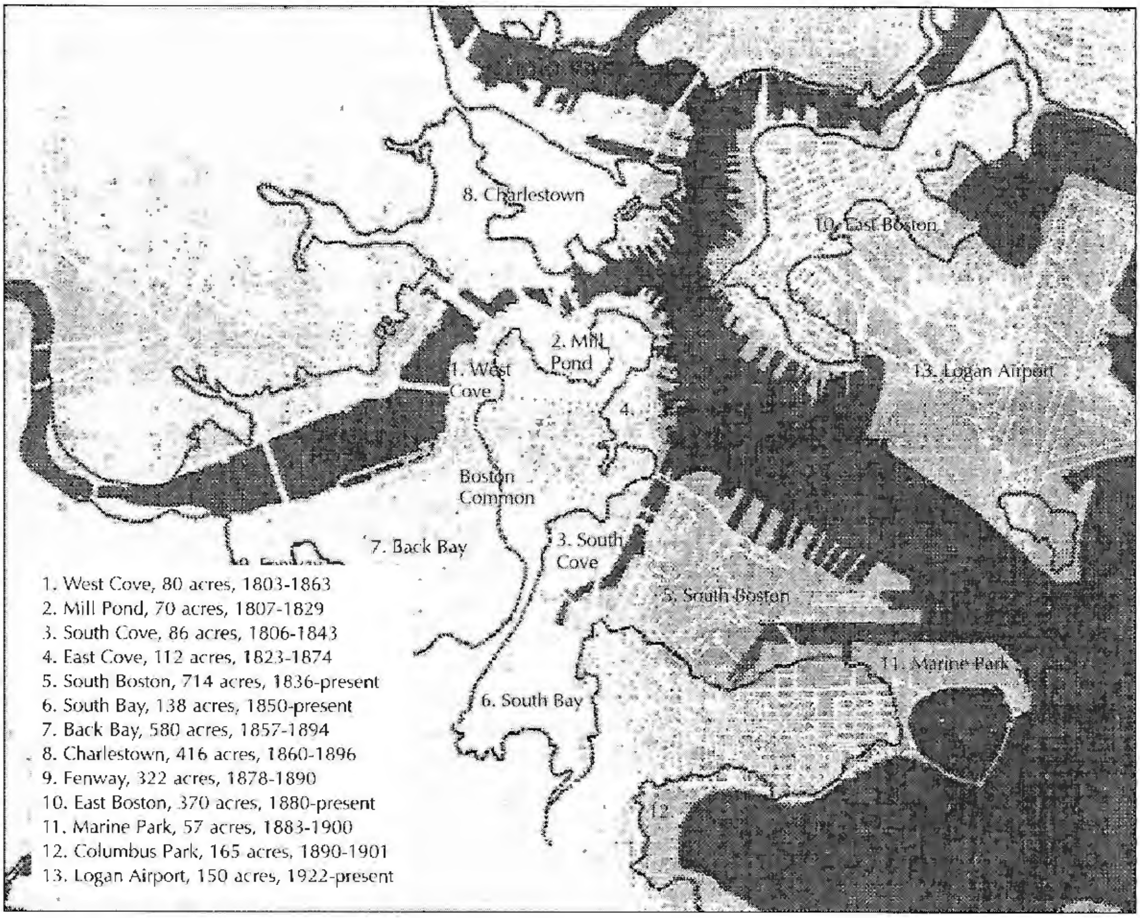


FIGURE 1-21. Map of the Boston metropolitan area showing the historic land filling that expanded the original 717 acres to over 3,000 acres in 1976. (Courtesy of the Boston Society of Architects.)

Other geologic factors helped guide development and helped shape the rugged independent character of the early inhabitants of the city and surrounding towns in Massachusetts. The lack of mineral resources and the limited fields that grew rocks every spring did not favor the development of large plantations with landed gentry and a subclass of farm laborers. Even lime for fields was lacking except in the western mountains, where it was then of limited value, and small deposits in Rhode Island. The drowned offshore coastal plain deposits, however, provided banks that suited the growth of cod and attracted whales. This fact led to Massachusetts developing offshore whaling and eventually becoming a leader in world-wide whale hunting and maritime trade, an endeavor aided by fine harbors at the home ports. The lowering of Beacon Hill and then quarrying of granite north and south of Boston led to the development of the first railways in the country. The latter connected the quarries to the docks, from which the stone was shipped to other East and Gulf Coast cities. The trade in overseas manufactured goods led to promoting local factories, which made full use of the water power at dams across streams in the many fault-controlled valleys. From the very first, settlers proposed modifying the sometimes hostile land to fit their needs. They drained coastal marshes for hay fields and built some of the first canals, railroads, railroad tunnels and water tunnels in the country. Large projects seemed to be ingrained in the populace. Soon after Concord was settled in 1635, it was proposed to either divert part of the Concord River to the south or blow up the falls to the north to tame the spring floods, and in 1639 part of the Charles River was diverted into the Neponset River to supply mills with greater waterpower. The bridge to Charlestown in the eighteenth century and the Hoosac Railroad Tunnel through the highest ridge of the Berkshire Hills, at the then-immense cost of $17 to 21 million, in the mid-nineteenth century were the Big Digs of their day. The tunnel project made an abortive effort to use the first tunnel-boring machine and introduced the use of nitroglycerin at a great cost in miners' lives. Now the nearly $15 billion Central Artery/Tunnel Project to depress and extend highways in Boston is the greatest one of its kind. All of these endeavors required an understanding of Boston's local and regional geology.

Evolution of Local & Regional Geologic Understanding

The foundations of American geology began around Boston, and the region has been a leader in research. The contributions of many eminent geologists helped unravel the area's complex geology, which has been a remarkable achievement. That evolution and refinement in geologic understanding continues today as new projects uncover and expose new details of the geology. Much of the information presented herein reflects the known body of knowledge and facts about the various bedrock and soil layers found throughout the Boston area and region. These "data" collectively support the theories expressed by several earlier researchers (as discussed herein). A more complete understanding can be acheived by tracing the evolution of geologic viewpoints, including various interpretations and re-interpretations about the geologic origins of the region and the Boston Basin, and its current status.

Boston and the surrounding region have been blessed by many outstanding geologists over the past two hundred years whose fieldwork revealed the geologic framework of eastern North America. Early noted geologists such as Edward Hitchcock, Charles Lyell, C.H. Hitchcock, Rafael Pumpelly, Charles Walcott, William Otis Crosby, Amadeus William Grabau, William Morris Davis, Nathaniel Shaler, B.K. Emerson, J.B. Woodworth, William Hobbs, Lawrence LaForge, Walter Goldthwait and many others made numerous fundamental discoveries prior to World War I. A short history of this work is presented by LaForge (1932). Much of this achievement was due to a concentration of effort in the region by the fledgling United States Geological Survey (USGS), building on the impressive earlier work. Massachusetts had the first state-funded geological survey, which was directed by Edward Hitchcock, who produced a state map and report in 1833. This effort was so successful that it was emulated quickly by Rhode Island (Jackson, 1840) and Connecticut (Percival, 1842; Foye, 1949), along with many other states in the United States and countries in Europe (Hitchcock, 1871), where the 1845 survey of Austria was one of the first on that continent.

Boston made its geological debut on Maclure's 1809 geologic map of the United States, which shows the Boston-Narragansett region described as Transition Rocks set into Primitive Rocks along with the Secondary Rocks of the Connecticut Valley (see Figure 1-22). E. Hitchcock's 1832 geological map of Massachusetts clearly shows the Boston, Norfolk and Narragansett basins. Hitchcock indicated that these basins contained wacke and graywacke of his 4th Group surrounded by various igneous rocks of his older 1st Group. Argillaceous and flinty rocks of the 4th Group also are shown along the inside border of the Boston Basin. In the compiled geologic map of the United States and Canada in 1847, Lyell showed these basins and listed the primitive metamorphic and igneous rocks of southern New England as mostly pre-Cambrian and showed them plunging under Paleozoic strata to the north in Maine and the Maritimes as well as to the west in New York (see Figure 1-23). The discovery of the Cambrian trilobite *paradoxides harlani* (see Figure 1-24) in eastern Massachusetts demonstrated that the ancient rock also was overlapped by Paleozoic strata on the east (Rogers, 1856 & 1857), as indicated on Hitchcock's greatly refined 1871 map of Massachusetts (see Figure 1-25). This map still shows most of the state as pre-Cambrian and blocks out the major geologic divisions within

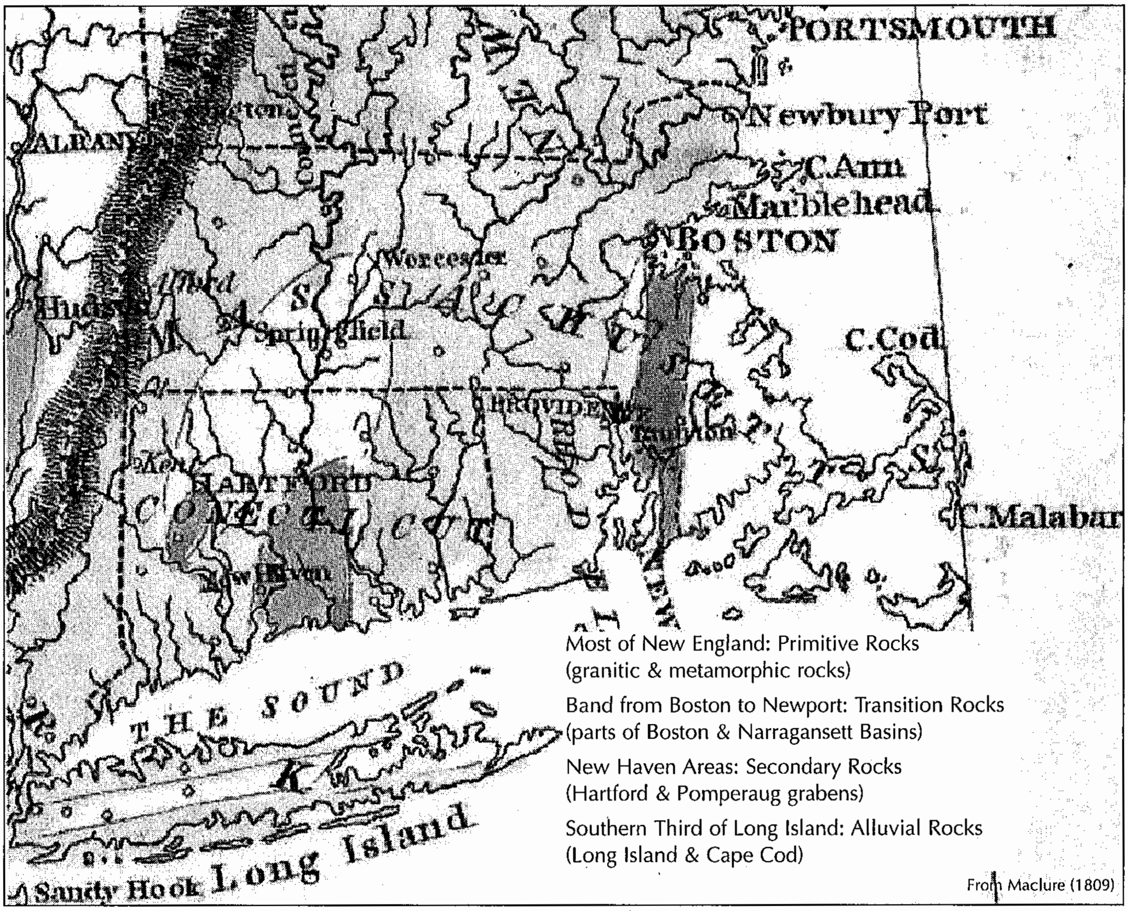


FIGURE 1-22. Southern New England portion of the geologic map of the United States of America.

the state, with assigned rock ages surprisingly similar to those found by modern work. The fossils in the Cambrian strata on either side of Massachusetts then were found to be very different by the studies of Walcott (1891a & 1891b), who found that a profound geographic barrier had existed between the two faunas along eastern North America. Thus began the understanding of ancient plate tectonics in the region.

The geology of the Boston Basin itself received early attention (Lathrop, 1800; Dana & Dana, 1818) and it was quickly found that the topographic basin also was a structural one (see Figure 1-26). The basin was considered synclinal and grouped with the Narragansett Basin to the south as Devonian (Lyell, 1845b). Hitchcock (1871) left the age of most of the Boston Basin as undetermined, although the Cambrian strata on the south side were considered to overlie the conglomerate fill in the basin (see Figure 1-25). Shaler (1869) noted that "the association of the several different sets of beds which are exposed in the neighborhood of Boston is very difficult to determine satisfactorily; being nearly destitute of fossils, and extremely complicated by disturbances, they have not presented a very inviting field for research." However, an explosion of research soon followed that lasted until World War I. W.O. Crosby met the challenge and produced the first large map of the Boston Basin (at a scale of 1:63,360) in 1877 and presented detailed traverses in his report in 1880 (see Figures 1-27 & 1-28). He found that the thick conglomerate in the center of the basin did not lie over the slate (argillite) in a syncline, but underlay it, although in part it was contemporaneous and interfingered with the slate. The conglomerate, in turn, was underlain by a

FIGURE 1-23. Southern New England portion of the United States and Canada.

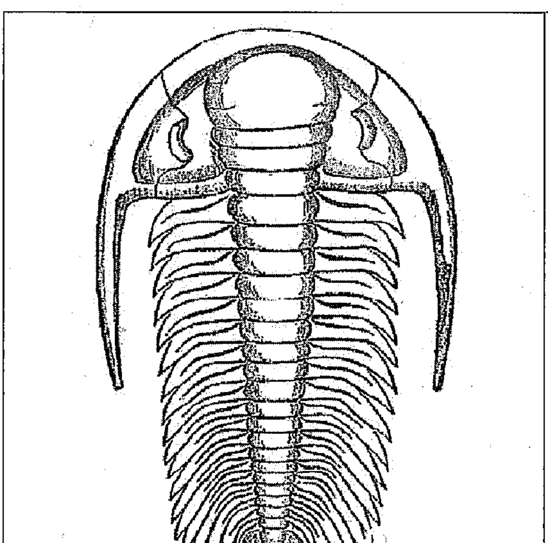


FIGURE 1-24. ***Paradoxides harlani.***

varied and complex volcanic rock sequence that sits unconformably on the granite. The conglomerate and argillite are considered to be basal Paleozoic and conformable beneath the fossiliferous Cambrian sequence, which overlaps beyond the basin. He noted that the basin consisted of faulted folds and extensive parallel and transverse faults were found to characterize a large part of the basin. Crosby interpreted the folds from both changes in dip and local stratigraphic sequences, considering the bands of conglomerate as cores of anticlines. The faults repeated the strata to produce large apparent thicknesses.

Other studies followed that Emerson (1917) summarized in a report on the geology of Massachusetts and Rhode Island. He used the work of LaForge, who was also mapping at the time, for the region around Boston. LaForge recognized that an area of volcanic rock over the granite, called the Framingham Basin, was a western outlier of the Boston Basin. He reverted to equating the conglomerate with that to the south in the fossiliferous carboniferous Narragansett Basin and stating its possible glacial origin, interpretations that were inconsistent with those of Crosby (1880), who thought otherwise. The argillite thus was considered basal Permian from Emerson's correlation and a pebbly lens within it, the Squantum Member, a tillite and part of a worldwide Permian glaciation following the interpretation of Sayles (1914 & 1916; Sayles & LaForge, 1910). Emerson further postulated that the basin was bordered by high relief during deposition in a mostly terrestrial setting. By now, a basin stratigraphy had been formalized: a basal Mattapan Volcanic Complex, above the granite, overlain by the Boston Bay Group. This group consists of

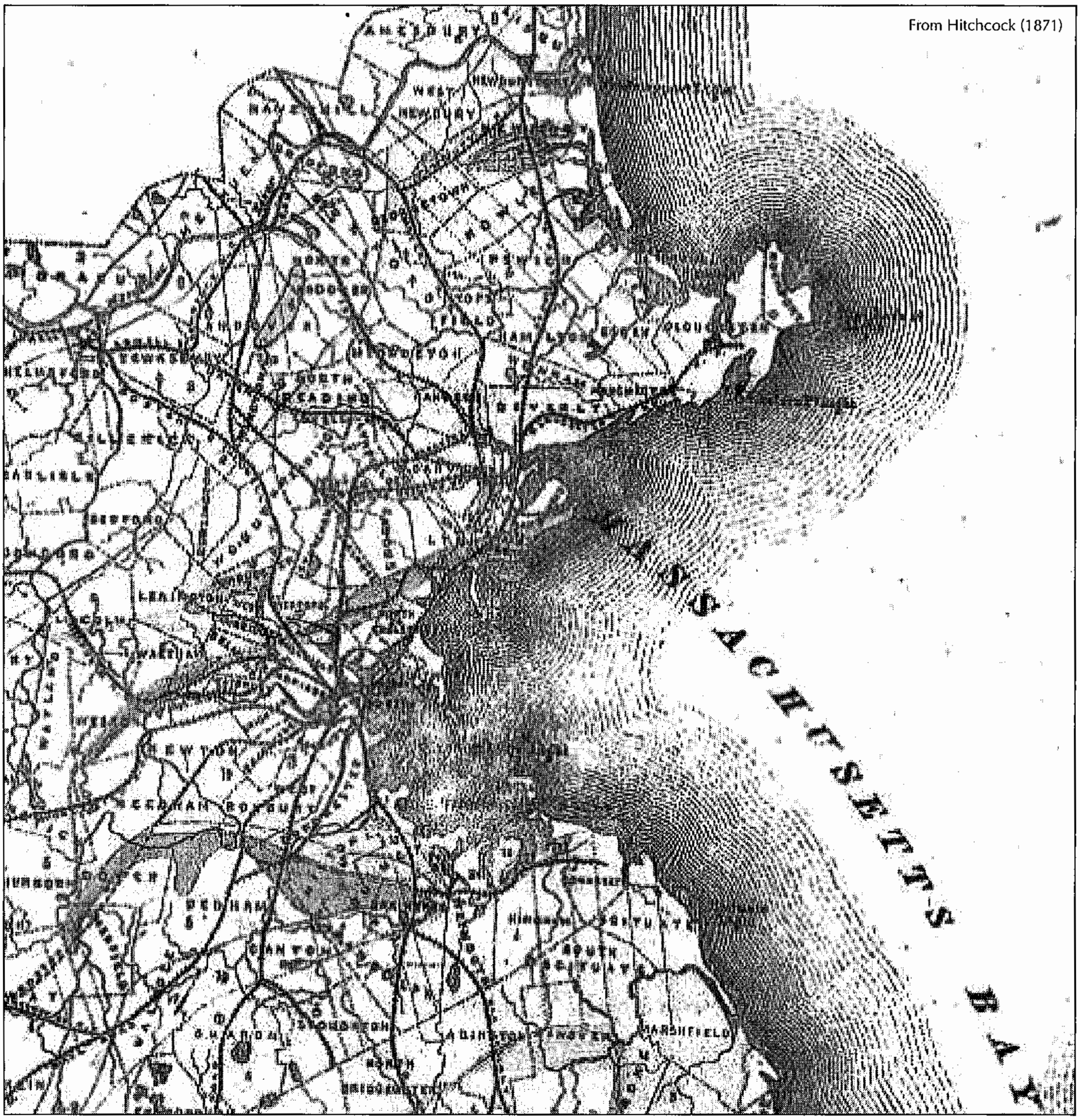


FIGURE 1-25. Boston and environs on the geologic map of Massachusetts by Hitchcock.

the Roxbury Conglomerate, which is composed of three members: Brookline Conglomerate, Dorchester Shale and Squantum Tillite, and an overlying Cambridge Slate (see Figure 1-29). The slate is usually an argillite or mudstone whose local fissility gave rise to it being mislabeled.

Laurence LaForge finished a detailed, 1:6,000 scale study of the northern part of the Boston Basin in 1903 and spent the next twenty-two years preparing the first modern geologic map of the entire basin and its environs (LaForge, 1932) at a scale of 1:62,500 (see Figure 1-30). He disagreed with Emerson's correlation with the Narragansett Basin, but still placed the basin strata as perhaps Devonian or Carboniferous in age on the basis of possible tree trunks in the conglomerate (see Figure 1-31). He thought of the stratigraphic units as relatively simple layers and accepted the interpretation of the Squantum as a tillite, although he did not consider it a mappable unit and useful for separating the argillite into two units. The Roxbury Conglomerate is found locally intruded by dark-colored porphyritic basaltic rock, referred

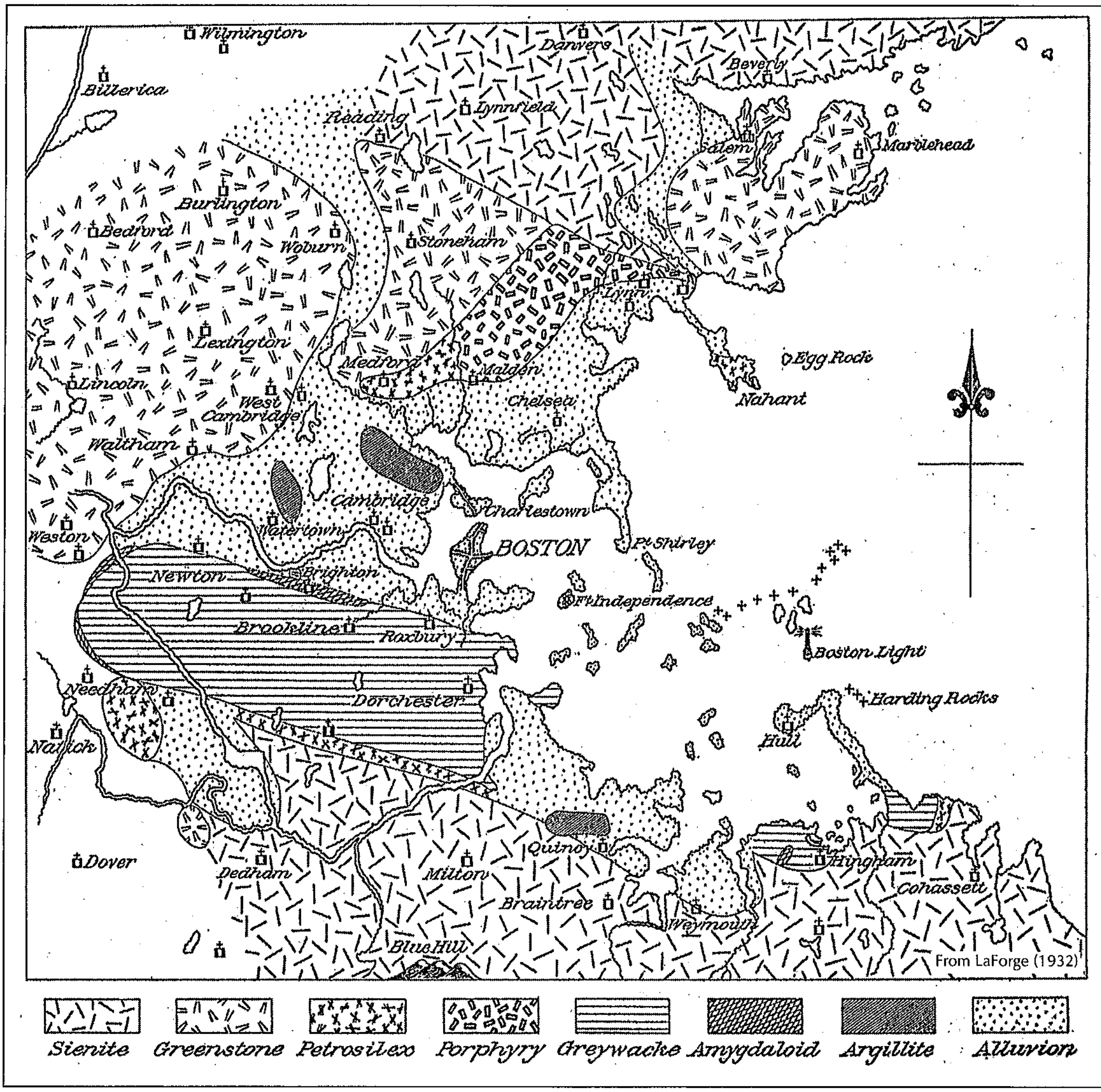


FIGURE 1-26. First geologic map of Boston and vicinity by Dana and Dana (1818).

to as melaphyre, which may or may not be a continuation of the earlier volcanism. Also, the basin rock is cut by numerous basic north-south and east-west dikes that commonly follow faults and may be offset themselves (LaForge, 1932). LaForge described the Boston Basin as essentially a fault-bounded synclinorium with a central, broad, east-plunging anticline. He found that the anticline to be faulted and that faults were the most abundant and characteristic structural feature of the basin. He noted that, in the southern half of the basin, "the strata have been fractured and tilted in different directions to form a patchwork of blocks without determinable structural relations to one another." However, folds also are shown in his generalized cross-section of the basin.

Faults had been noted as the principal structure in eastern Massachusetts by Crosby (1880), and Hobbs (1904a & 1904b) found indications of regional fault zones in southern New England. Hobbs observed that faults cutting Mesozoic strata could be followed into the metamorphic rock by their geomorphic expression. By a process of analyzing the topography and changes in geologic contacts, he eventually determined a series of regional structures that he referred to as lineaments. Their intersections

FIGURE 1-27. Simplified geologic map of Boston Basin and vicinity by Crosby.

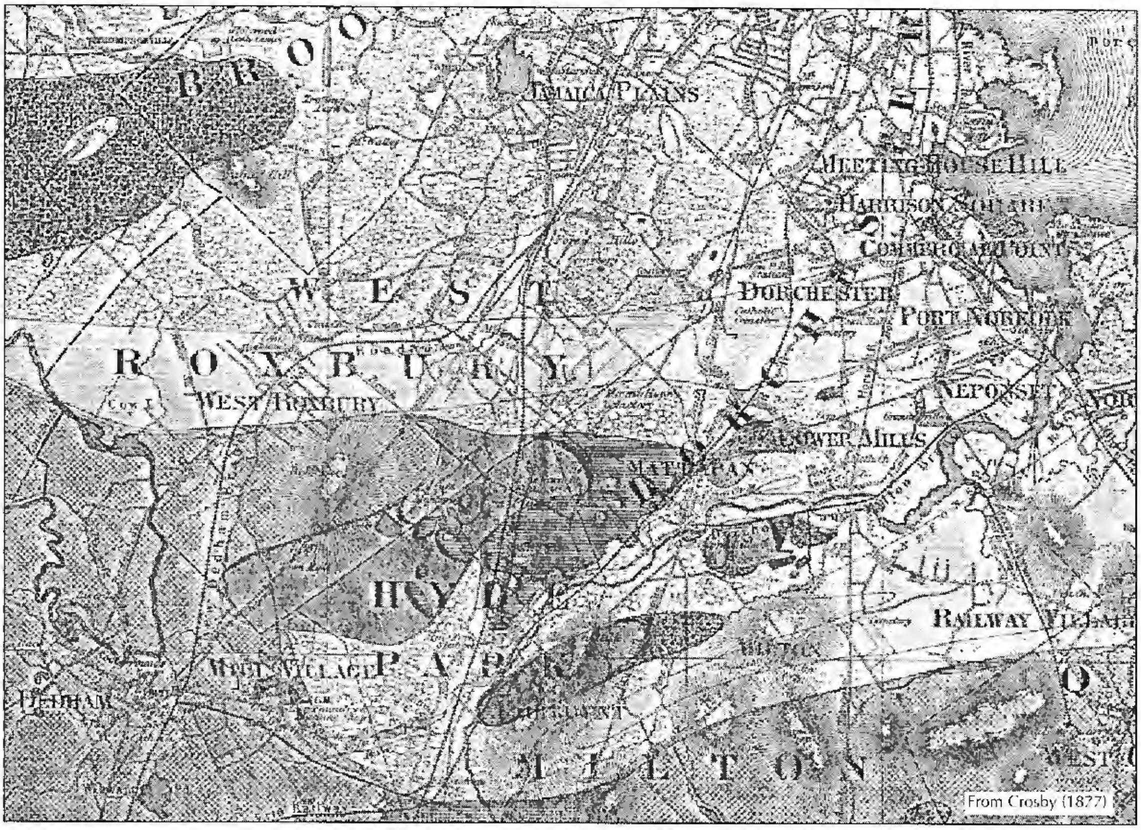


FIGURE 1-28. Portion of the southern part of the geologic map of Boston and vicinity by Crosby mapped at a scale of 1:63,360.

Age	Unit
	Cambridge slate Roxbury conglomerate 1. Squantum tillite member
Carboniferous Sedimentary Rocks	Unconformity (?) 2. Dorchester slate member 3. Brookline conglomerate member
Early Carboniferous Igneous Rocks	Mattapan volcanic complex (lower part called Lynn volcanics) Nephelite-bearing rocks Squam granite Quincy granite Blue Hills granite porphyry Beverly syenite Quartz syenite Nephelite syenite Essexite

From Emerson (1917)

FIGURE 1-29. Stratigraphic column for the Boston Basin by LaForge.

were later found to be spatially related with earthquakes in the region (Hobbs, 1907), a relation proven seventy years later (Barosh, 1989). Hobbs's work was based in large part on newly available topographic maps and was, in effect, the first remote sensing study. His technique was quickly adopted for guiding field work in the rest of the country and has continued in the use of aerial photographs and radar and satellite images. However, his contributions were not accepted by certain geologists in New England (Johnson, 1925) who believed that complex folds could explain changes in the geologic pattern.

This theory of folds rather than faults apparently derived from publications depicting large complex folds, due to soft deformation in gravity thrust sheets, in the Alps, and the myriad of small folds seen in New England road cuts. Each different trend of the small-scale folds was considered to represent a different regional fold set, regardless of their actual origin from drag, slump or local slip. The lack of confirmation of the folds by attitudes of the rock in the field was thought to be due to their complexity and that local rock attitudes were unimportant (Stanley, 1975; Robinson, 1963; Ratcliffe & Harwood, 1975). Such folds found no support in detailed field mapping (Schnabel, 1976; Peper *et al.*, 1975) nor in geophysical data (Barosh *et al.*, 1977b). Thus began an antipathy between theoretical-laboratory and field-oriented studies in the region.

Many universities in the region had turned largely away from field geologic reconnaisance work by World War I and began to concentrate on laboratory studies as the modern way to explain geologic processes. This change in philosophy seems to, at least in part, have prevented several of the USGS's map sheets of the state from being published in the 1920s. Excellent work in mineralogy, x-ray technology and geochemistry continued at the universities and a new specialty — metamorphic geology — emerged to study mineralogical transformations.

However, these lab research developments were poorly integrated with the field data. New concepts evolved in which the metamorphic rock began to be described by mineral content rather than the appearance of the rock, its sedimentary features, or stratigraphic relations (Toulmin, 1964; Abu-Moustafa, 1969). Furthermore, the sedimentary features were being attributed to metamorphic changes. In addition, the differences due to regional and contact metamorphism were blurred and separate metamorphic events were not fully understood. This laboratory approach, favored by many, combined with theoretical structure, evolved into a unique geology very different from that used elsewhere in the world but one that many New England geologists of the day felt was on the cutting edge.

LaForge presented lectures on the results of his mapping of the Boston Basin at Harvard in 1925 while preparing his report that was eventually published by the USGS in 1932. Meanwhile, Marland Billings, who as a student assisted LaForge at Harvard, published a synopsis of part of Boston in 1929, with a page-sized map (see Figure 1-32). This map is apparently a modified version of LaForge's page-size summary map (see Figure 1-30) with some data from Billings's work and sev-

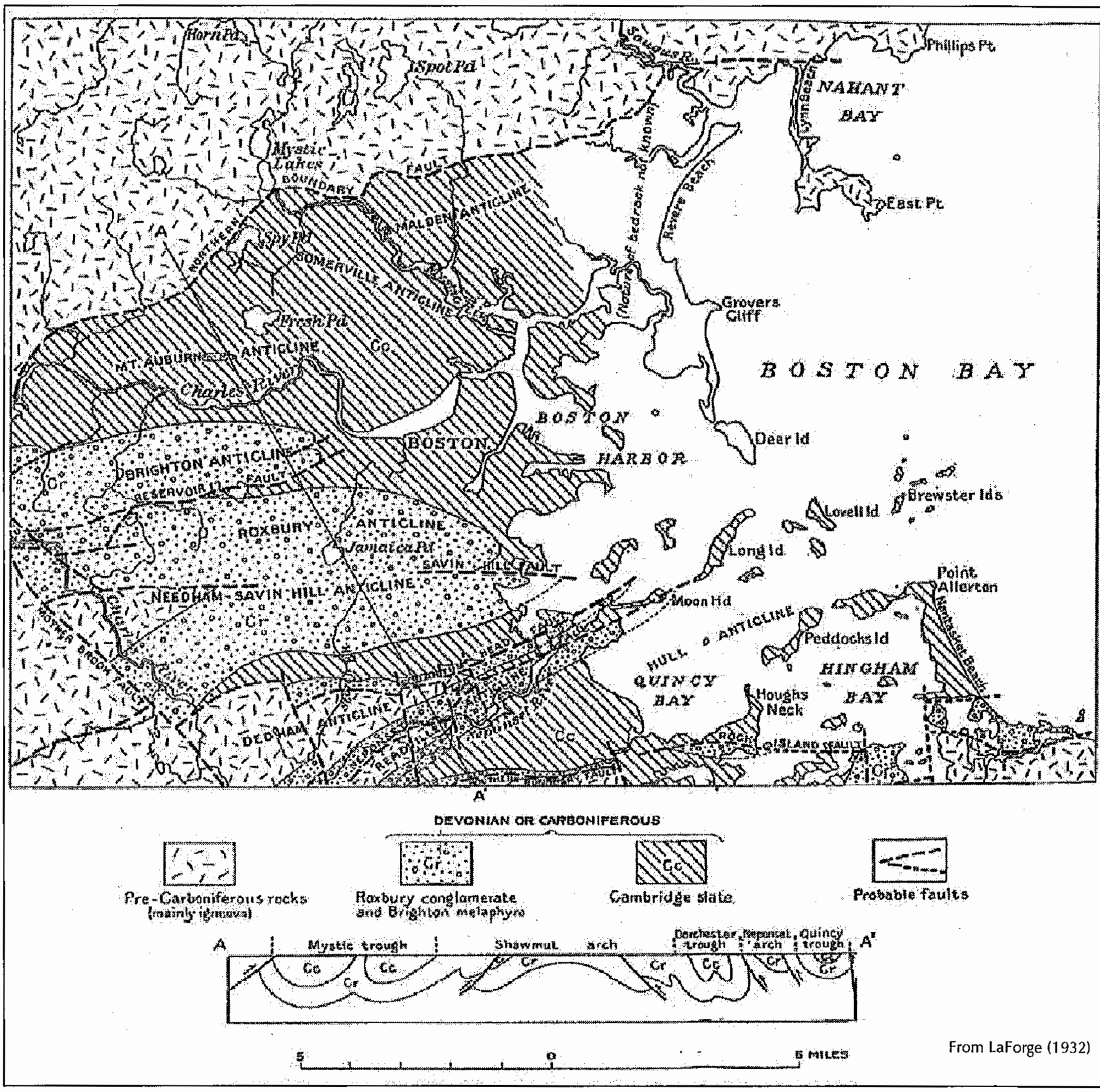


FIGURE 1-30. Geologic map of Boston and vicinity by LaForge (simplified from his 1:62,500 scale map).

eral others (Billings, 1929). Billings' synopsis paper became the standard geology cited for Boston. Billings simplified LaForge's data to develop what he considered to be a more cohesive picture of the Boston Basin. He reinterpreted LaForge's structure by changing some faults into folds, renaming structures and reverting to some of Emerson's, and perhaps Crosby's, stratigraphic usages. Billings (1929) placed all of the Boston strata in the Permian above a Pennsylvanian Mattapan on the basis of the possible tree trunks and emphasized the use of Squantum Tillite as a stratigraphic member in opposition to LaForge's findings.

While the differences in geologic theories were evolving, the very practical problem of building in Boston in the varied and unstable glacial and later surficial material (and the hazards they posed) was being recognized. The relative stability of the material was demonstrated by the earthquake of 1755, which resulted in most damage occurring on fill around the harbor. A map showing the relative stability across Boston by I.B. Crosby in 1932 was one of the first, if not the first, earth-

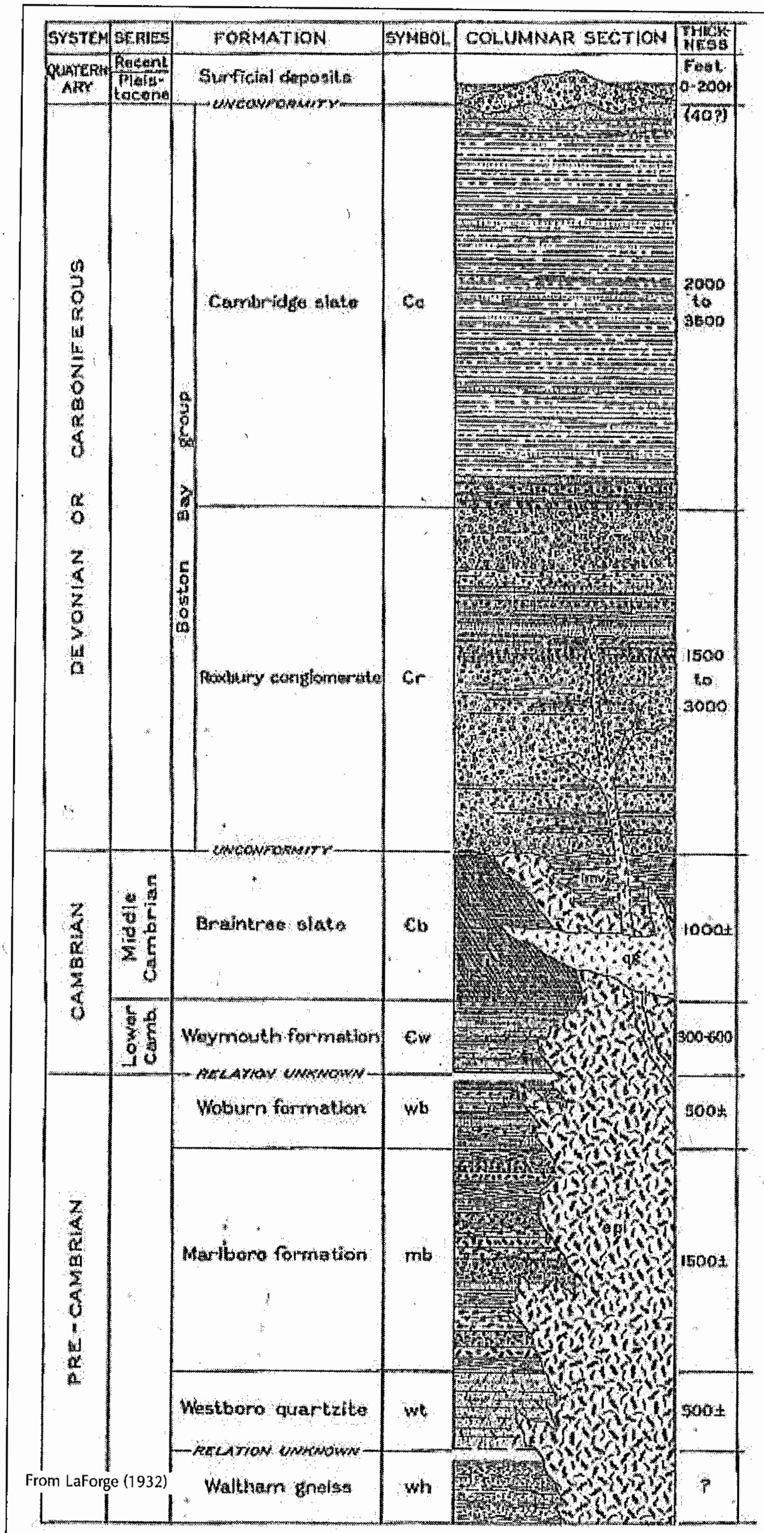


FIGURE 1-31. Stratigraphic column for the Boston Basin by LaForge.

quake hazard maps in the country. The instability of the cover material found in the building of the Massachusetts Institute of Technology (MIT) was studied by Terzaghi, Casagrande and others, and led to the development of soil science (Lambe & Whitman, 1969; Peck *et al.*, 1974). These and other studies laid the foundation for the successful engineering geology that has greatly benefited the city.

The fold-versus-fault controversy continued through the construction of several bedrock tunnels in and adjacent to the city during the 1960s. Some geologic mappings of tunnels showed numerous faults. However, the role of folding in the summaries for other tunnels appears to have been exaggerated, apparently influenced by drag and slump folds. The sketch map of the Boston Basin shown by Billings in 1976 (see Figure 1-33) still shows an essentially folded basin with a few north-dipping thrust faults in the southern part, but without the high density of faults found by Crosby (1880), LaForge (1932) and others. Crosby (1899a) mapped the numerous exposed faults of the Clinton Newbury Fault Zone (one of the largest fault zones in North America) during construction of the Wachusett Aqueduct. However, Billings (1962) only mentioned that unmapped small faults were present

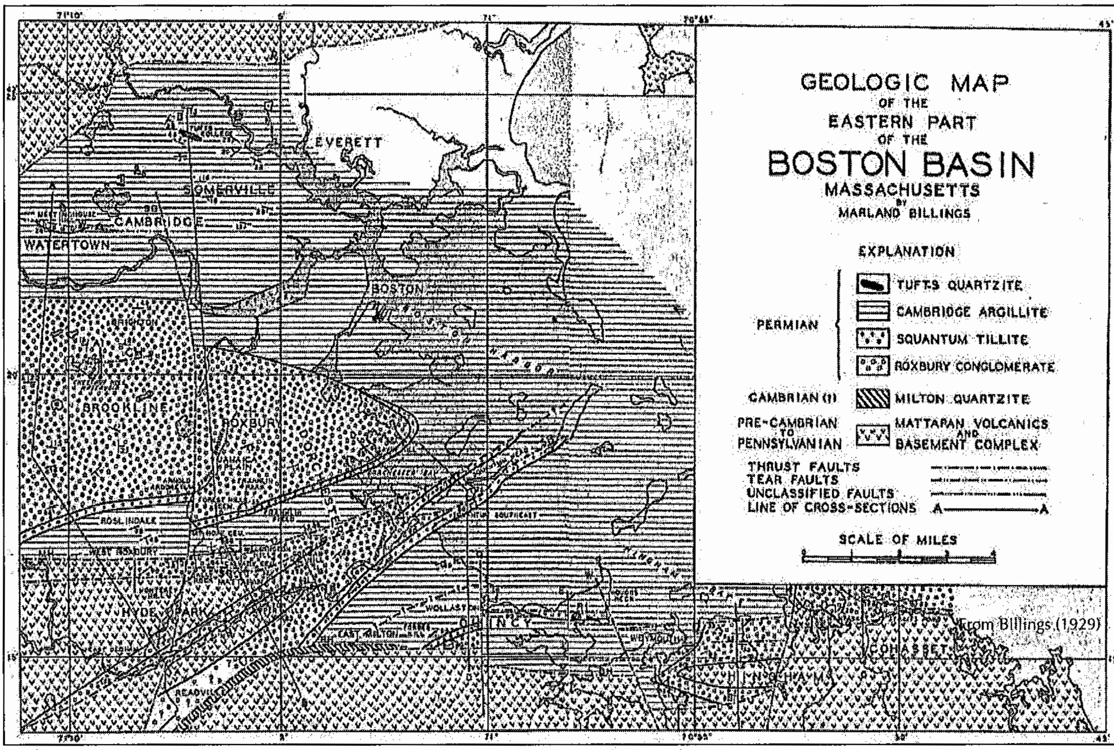


FIGURE 1-32. Geologic map of Boston and vicinity modified from LaForge by Billings. (Courtesy of the Geological Society of America.)

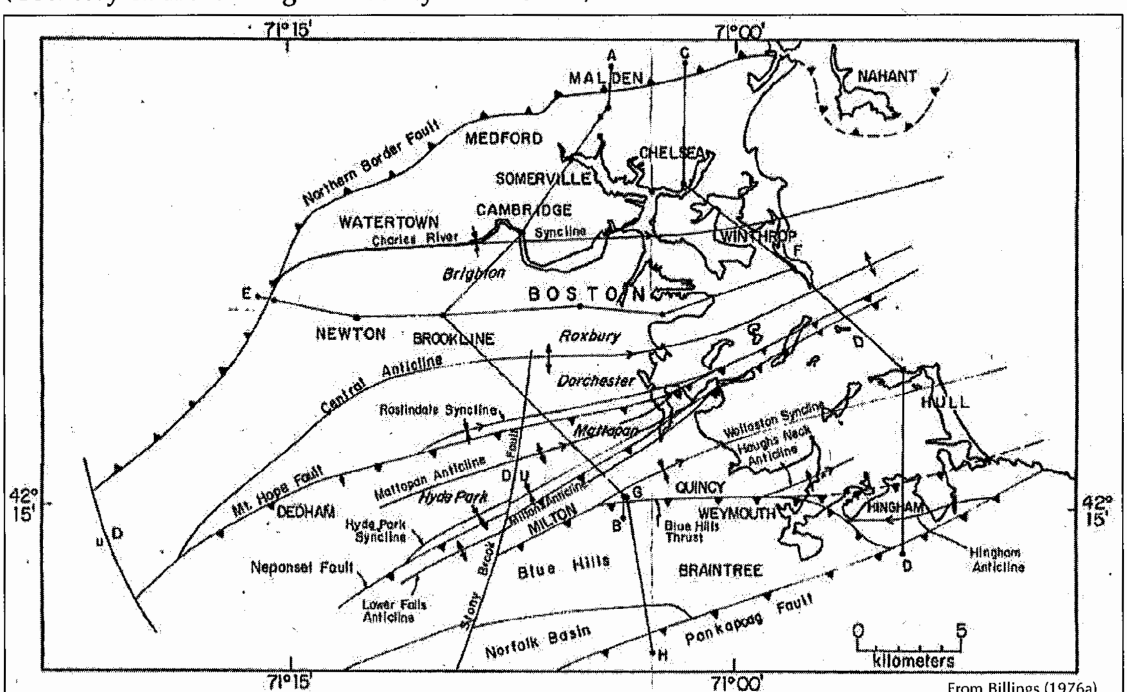


FIGURE 1-33. Structural map of Boston and vicinity by Billings. (Courtesy of the Geological Society of America.)

in the nearby Cosgrove Tunnel constructed in the mid-twentieth century. The difference in observations is remarkable.

The USGS had begun mapping again in Massachusetts and adjacent states in 1940, but this effort was put on hold by World War II until the 1950s. These cooperative studies with the states, along with the work at the Nevada Test Site and in Kentucky, were the last major mapping efforts by long-experienced field geologists of the USGS. The study using 7.5-minute quadrangles began in eastern Massachusetts by W.R. Hansen, R.H. Jahns, N.E. Chute, N. Cupples and others, and in Rhode Island by Alonzo Quinn, G.E. Moore and others. Eastern Connecticut was mapped by M.H. Pease, T. Feininger, R. Dixon and others, and much of the western part of that state was covered by R.M. Gates, C.W. Martin and others through the State Geological and Natural History Survey of Connecticut. This effort began defining mappable stratigraphic units in the metamorphic strata and began collecting structural data. Major structures started to be revealed as mapping progressed. These discoveries increased as other experienced geologists were brought in by the USGS, and more detailed field and stratigraphic data became available to provide control. This geologic mapping was reinforced by the use of aerial photography and aeromagnetic data.

More and more primary sedimentary features were recognized in the highly metamorphosed rock as the mapping progressed. A major discovery was that despite metamorphic changes, sufficient sedimentary features were preserved to allow the subdividing of the rock into mappable units as in unmetamorphosed strata and to understand their environments of deposition. A series of modern stratigraphic studies, following the formal Stratigraphic Code — which dictates how formations are to be described (NACSN, 2005) — were started in the late 1960s to measure and describe the formations and establish type sections (Peper *et al.*, 1975; Bell & Alvord, 1976). These were the first such detailed studies in New England and provided a basis for much more accurate mapping. The defined mappable units west of Boston were found by D.C. Alvord and K.G. Bell in 1970 (Alvord *et al.*, 1976) to conform very closely to the pattern shown by the aeromagnetic data, which also showed additional discontinuities due to fault offsets (Barosh *et al.*, 1974 & 1977b). Gradually more structural features were recognized with the refined control. The region was revealed to be offset by large thrusts and cut up by a mosaic of smaller faults (Bell & Alvord, 1976), as Crosby (1880) and LaForge (1932) noted earlier. Previously theorized folds, such as those by Robinson (1963) and Dixon and Lundgren (1968), have not been found. Interestingly, the one area found to be highly folded, the Connecticut-Rhode Island border region, had not been previously theorized to be folded (Feininger, 1965; Barosh, 1972; Barosh & Hermes, 1981). Furthermore, the proven large ancient folds that are present may be bent slightly, but are not refolded.

Thus, the USGS's work established that:

- metamorphosed strata retain abundant sedimentary features;
- mappable stratigraphic units can be established for the metamorphosed strata by measured and described type sections following the Stratigraphic Code;
- folds are described by attitudes in the rock as in unmetamorphosed strata;
- faults are shown by offset contacts, exposed fault zones, discordant features, drag folds, juxtaposition of rock of different metamorphic grade or degree of deformation, discontinuities in geophysical data and other such features as in other regions;
- significantly different degrees of regional metamorphic grade and deformation reflect different periods of deformation;
- the geomorphology (topographic maps, aerial photographs, satellite data, radar maps) closely reflects the structure, except where the surficial material is very thick; and,
- magnetic and gravity data closely reflect rock units and structure given sufficient detail.

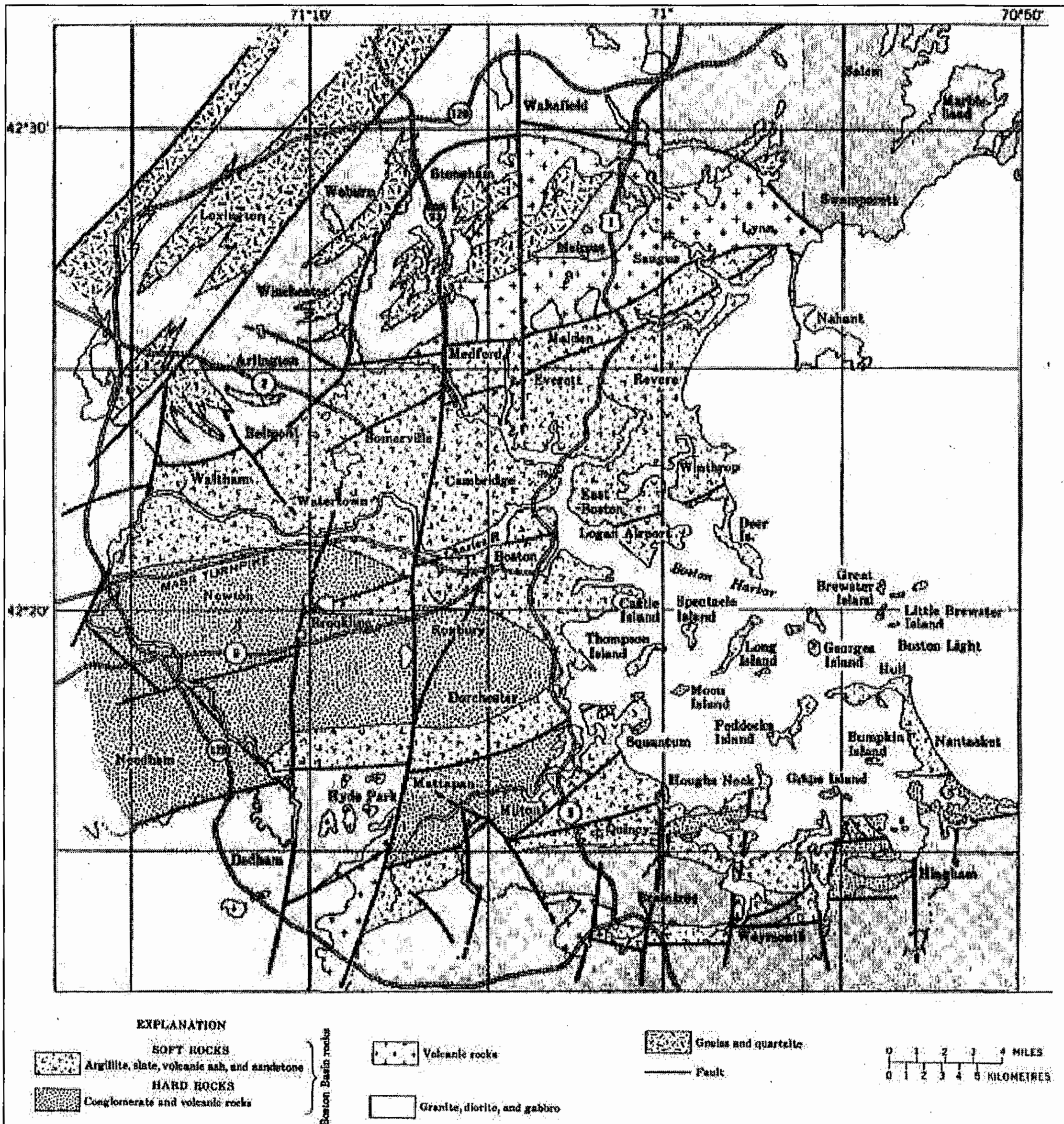
The concurrent detailed surficial mapping was, in many cases, done as a specialty and J.P. Schafer, J.H. Hartshorn, C.A. Kaye,

C. Koteff, R. Oldale and F. Pessl worked out new principles in mapping and understanding the glacial deposits. Their efforts built upon the pioneering work of W.M. Davis (1890), J.W. Goldthwait (1905) and S.S. Judson (1949) to reveal more of the complexity of the Pleistocene material (White, 1949). It was demonstrated how the deposits formed repeated sequences with each ice stand during the retreat of the Late Pleistocene glacier margin, formed vast lakes at times and were later tilted from rebound.

This program of modern mapping was done from the Boston Office of the Geologic Division of the USGS under L.R. Page and his successor M.H. Pease, Jr. The program produced a virtual explosion of new information that completely changed the understanding of the region, as well as the Appalachian orogen. Major goals were to provide data for engineering and environmental work, to demonstrate how geologic information can be used for planning and to gather geologic data for practical application for construction in Boston, influenced by the early teachings of Goldthwait (White, 1949). One pioneering study years ahead of its time was the Connecticut Urban Pilot Study, which demonstrated the many ways to apply geologic work in the Connecticut River Valley to environmental studies and town planning.

The important development for Boston was the establishment of the position of a City Engineering Geologist under the USGS's Greater Boston Urban Geology Project (Kaye, 1967b) — a position capably filled by Clifford A. Kaye, who began preparing a 1:12,000 scale geologic map of Boston. He was aided by the work of Kenneth G. Bell, who continued the mapping of the Boston area (Bell, 1948) that he began for his doctoral thesis at MIT. MIT had developed excellent field-oriented geologic training, which ended later in the 1960s when geophysical studies were emphasized. Kaye and Bell's work brought a new understanding of the Boston Basin whose strata were proven to be much older, Eocambrian (Proterozoic Z), as had been interpreted by Crosby (1880) and not the Carboniferous or Permian age of LaForge (1932), Billings (1929) or others (Pollard, 1965). Kaye's work also revealed the extreme complexity of the glacial geology and the hazards posed by soft alteration zones in the underlying argillite. The Cambridge Argillite was found to contain many slump structures (Rahm, 1962) and the Squantum Tillite member was shown to be scattered lenses of pebbly mudstone that represent slump deposits (Dott, 1961; Kaye, 1982b), similar to ones commonly seen in California coastal strata. Neither the Squantum Tillite nor other features in the Cambridge Argillite are consistent with a glacial origin (Caldwell, 1981). Kaye also determined that several formations previously interpreted as folds were actually longitudinal faults cutting through the basin (see Figure 1-34) and the basin itself was found to be dropped into a Late pre-Ccambrian batholith that underlies southeastern New England (Barosh *et al.*, 1977a).

The mapping played a major part in the understanding of plate tectonics that was not fully appreciated. To the west of Boston, it was recognized by 1960 that the parts of the Clinton-Newbury and Bloody Bluff faults (Crosby, 1899a; Novotny, 1961; Cupples, 1961) constituted major fault zones (Page, 1994). These and other faults in New England found by the USGS contributed to J.T. Wilson's (1966) formulating the concept that a predecessor of the Atlantic Ocean had closed against an ancient plate collision zone that extended from the Canadian Maritimes to west of Boston. This general concept of plate movements in New England was elaborated on by Bird and Dewey (1970), but the stratigraphic and structural data were still too sparse to show this well. Continued detailed mapping by the USGS refined the position of the zone and the stratigraphic changes across it. This "type collision zone" was found to cross coastal New Brunswick, lie just off shore of Maine and New Hampshire, traverse east-central Massachusetts (approximately between Route 128 and Interstate 495) and eastern Connecticut to turn south and pass beneath mid-Long Island and seaward (see Figure 1-3). The pre-Silurian stratigraphy and structure are strikingly different on either side of this plate collision zone (Barosh, 1977a & 2005; Barosh *et al.*, 1977a), which makes a profound structural, stratigraphic and geophysical break not seen else-



From Kaye (1976a)

FIGURE 1-34. Simplified geologic map of Boston and vicinity by Kaye.

where in the northeastern United States (Barosh & Pease, 1974; Alvord *et al.*, 1976). Thus, Boston was recognized as a former part of northwest Africa left dangling on the North American side when the Atlantic Basin opened later. It became clear that the two defining events that shaped the structure of New England were a plate collision that peaked near the end of the Proterozoic and the opening of the North Atlantic Basin in the Mesozoic.

When detailed large-scale state geologic maps of Connecticut and Massachusetts were being prepared under the direction of M.H. Pease, Jr., at the Boston office of the USGS for publication in 1978, the office was closed and the mapping program ended. Only the preliminary map sheet for eastern Massachusetts was completed and released (Barosh *et al.*, 1977a). The publication of about twenty Massachusetts geologic quadrangles that had been completed, or nearly so, also were halted. A few revised maps were released, but the emphasis appeared to be on folds, again resurrecting the old fold-versus-fault controversy. A substitute smaller-scale geologic map of Massachusetts (Zen *et al.*, 1983) and its description (Hatch *et al.*, 1991) were later produced by the USGS's main office in Reston, Virginia. These maps reintroduced many hypothetical structural features and stratigraphic usages that found no support by the USGS mapping and geophysical data. Also, the compiled data of eastern Massachusetts were altered and most of the faults on Barosh *et al.* (1977a) were omitted. The result carried on two incompatible geologies with different structures, stratigraphy and ages being described simultaneously for the same area.

Kaye did release preliminary maps for Boston (Kaye, 1982b), as did Bell, but was unable to complete his studies. In these maps, Kaye abandoned the earlier stratigraphic terminology as inadequate and described the units by their lithology as a first step in reassembling them into a new stratigraphic framework that better described the relations. Kaye, as well as Bell, recognized the complex intertonguing relations of the units both toward the center of the basin and laterally. This feature, however, is very difficult to describe in formal stratigraphic nomenclature, which was to have been Kaye's next step.

The cause of earthquakes in the region in the 1950s was attributed to a non-fault origin, such as stress associated with granite plutons. This approach changed with the building of the first nuclear power plants and the need for a better evaluation of the earthquake hazard. Studies in the 1970s for the Boston Edison nuclear power plant did discover faulting in the plutons that released stress buildup, causing earthquakes.

The concern for nuclear power plant safety ushered in a series of evaluations of the seismic hazard at specific sites in the region that included compilation of more complete records and finding discrepancies in the older ones (Fischer & Fox, 1967; Devane & Holt, 1967). Investigations for the Pilgrim Nuclear Power Plant site in Plymouth, Massachusetts, and the nuclear plant site at Seabrook, New Hampshire, provided new information and important re-evaluations of earthquake data. A study of many of the historic earthquakes to improve intensity assignments and epicentral locations and assemble isoseismal maps was a major contribution (Boston Edison Company, 1976a, 1976b & 1976c). The pluton theory was adopted by Boston Edison, but during this same period the non-fault causes of earthquakes became suspect as geologic mapping revealed that the region is similar to California in the number and size of faults (Bell & Alvord, 1976; Barosh, 1976d & 2005).

The emerging awareness of the hazard and uncertainties as to the cause and distribution of the seismicity and the complexities of the geologic structure aroused further concern for power plant safety. The U.S. Nuclear Regulatory Commission began, in 1976, a program under Neil B. Steuer to expand research on earthquakes in the eastern United States. The Northeastern U.S. Seismic Network began a much-needed expansion and the New England Seismotectonic Study was begun to investigate the cause of seismicity and formulate an earthquake zonation map of the northeast United States under the direction of Barosh (Barosh, 1981b & 1982a; Barosh & Smith, 1983). This large cooperative study, supported mainly by the U.S. Nuclear Regulatory Commission, involved university and state geological survey personnel to make detailed geological, geophysical and historical investigations of the individual seismically active areas. This program continued much of the work of the USGS, which by then was more focused on offshore mapping than onshore mapping in the Northeast. It produced a vastly improved epicentral map and earthquake catalogue (Nottis, 1983), found the causative zones of faults, identified source areas and estimated the maximum probable earthquakes for each area (Barosh, 1986c, 1986d & 1990a). This mapping established the general structural and tectonic control of the large 1755 earthquake northeast of Boston.

No significant mapping program to gather geologic data on land has occurred since the mid-1980s, and the 1977 geologic map of the Boston 2-degree sheet is still the latest regional geologic map (Barosh *et al.*, 1977a). Other studies have continued under the USGS Water Resource Division and Office of Marine Geology. The marine geology group, headquartered in Woods Hole, Massachusetts, has carried out extensive studies of the stratigraphy and structure offshore to aid in the evaluation of potential petroleum resources in the 1970s and 1980s. More recently, the work has shifted closer inshore to provide basic information for environmental needs. Several surficial quadrangles on Cape Cod were completed under the auspices of the Office of Marine Geology to aid the study of serious environmental problems (Oldale & Barlow, 1986). Some temporary USGS and state funding allowed the completion of three quadrangles covering Cape Ann (Dennen, 1991a, 1991b & 1992), the Georgetown quadrangle (Bell *et al.*, 1977 & 1993) and three south of Worcester (Barosh, 1974, 1996a & 2005), but the funding for publication ended after the first group was printed.

During the past twenty years the dominant geologic programs in and adjacent to Boston have been those associated with both the new water and sewer tunnels and facilities of the Massachusetts Water Resources Authority and the Central Artery/Tunnel Project construction to depress the expressway through the city and connect it to the airport (Miller, 2002). In addition, considerable valuable information has been obtained by the myriad engineering, environmental and water resource investigations, as well as some seismic evaluations for the U.S. Army Corps of Engineers. This work has greatly expanded our understanding of the complexities of the glacial deposits underlying Boston and the harbor. The structural and stratigraphic data from the many new tunnels provides a much clearer understanding of the bedrock and interpretation of the structure, showing a highly faulted basin with few folds. However, the massive amount of data generated has presented a challenge to its preservation and accessibility. A newly re-established Office of the Massachusetts State Geologist is tasked with creating a well inventory and data set, saving unpublished geologic files and establishing a core repository. In addition, this office is trying to complete and publish geologic quadrangle maps, but is hindered by the lack of experienced field geologists. Recently, the USGS has begun making major revisions of the geology, stratigraphic and age changes west of Boston (Wintsch *et al.*, 2007) that are incompatible with the previous mapping by the USGS, but which are more in line with those proposed earlier by Billings.

The geology described herein makes full use of the quadrangle maps in eastern Massachusetts that have been mapped, although many are as yet unpublished and only available in open-file reports, as well as in scattered files and reports. This summary also incorporates the mapping of a great many people whose work could not be all cited here (much of that earlier work is listed in Barosh *et al.* [1977a]). The references cited tend to represent summary reports and newer findings based on field mapping. The geology is presented in two parts, the overall geologic framework of southeastern New England and the geology of the Boston Basin, followed by sections of the geotechnical and environmental implications. The regional geology was first compiled in 1977 (Barosh *et al.*, 1977a) using all the USGS mapped data and then modified in 1981, 1984 and 1991 as new information became available (Barosh & Hermes, 1981; Barosh, 1984a; Woodhouse & Barosh, 1991). These revisions incorporate many clarifications on stratigraphy, structure and ages found since and completes a preliminary earlier version (Barosh & Woodhouse, 2006).