

# IDENTIFICATION OF A NEW ENGLAND BOLIDE IMPACT SITE: *A Geologic Reckoning with the Ground-Zero for the Younger Dryas Event*

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## **ABSTRACT:**

This paper began as an attempt to understand the geology of the Boston Basin for purposes determining a risk profile and remediation plan as part of a Clean Water Act legal notice. That research resulted in an assessment that no coherent, evidence-based explanation for the geology of the Boston Basin exists in the published literature. However, the literature captured extensive evidence that could be analyzed under new theories and methodologies.

Over a century of geological surveys, engineering boring logs, and geotechnical investigations have documented a suite of anomalies that the prevailing glacial framework cannot explain: fault-controlled kaolinization to depths exceeding 300 feet, rock recrystallization at 175–250°C with no documented heat source for 400 million years, a chondritic mineral fingerprint, shock-hardened megacrysts, varve-less fossil-less marine clay, and platinum group elements at five times background concentrations.

Reconstructing the geology from original data and modern impact science, this paper concludes that the most parsimonious and only coherent explanation for the full suite of documented anomalies in the Boston Basin is a bolide swarm impact. Further, existing geological consensus already dates the mass debris event that shaped most of the superficial geology in the area at 12,900 years before present – already acknowledging the timeline is consistent with the Younger Dryas Impact Hypothesis.

The revelation this paper presents is simply a new analysis of the same underlying data – but this time through impact science rather than glacial theories. The Boston Basin presents a comprehensive case study of hydrothermal/shock impact caused by a bolide swarm hitting a thick ice sheet in a marine environment.

If this revised analysis is correct, then the Boston Basin is not a glacial landscape. Boston is an impact site. Further, by the dates already established in Boston geological consensus – Boston is ground zero for the Younger Dryas Impact Hypothesis – the previously missing impact crater.

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# INTRODUCTION

The findings in this paper arise out of separate research preparing a Clean Water Act Citizen Suit legal notice and a petition for a CERCLA risk assessment for the South Bay in Boston, Massachusetts. (Gjovik, 2026). Legal actions demanding extensive environmental mitigation and remediation require a comprehensive understanding of the geology and hydrology of the location at issue.

Because there is no consensus or evidence-based theory explaining the geology of Boston, I had to analyze original reports and laboratory data, review the literature, and try to piece together a geologic theory for Boston that I felt confident arguing as a lawyer and researcher. Comparing Boston's geological data to modern geological knowledge – it became evident that Boston is a bolide impact site and that impact science is the only geological science capable of explaining most of Boston's geology.

What we know today as “Boston proper” (the prior Town of Boston) consists of development on the Shawmut peninsula – a small, narrow, long island of sorts with an isthmus (the “neck”) upgrading it to peninsula only during low tide. (Shurtleff 1871). To its east, the South Bay was a large bay directly connected to the ocean tides from the Bay of Massachusetts and Gulf of Maine. (Thwing 1920). To its west, a swamp known as “Back Bay,” and the Charles river. Shawmut was actually likely at least two islands, primarily consisting of a group of three “drumlin” hills and otherwise marshy tidal land.

The native Massachuset nation referred to the Shawmut island/peninsula as “*Mushawwomuk*” (“*the boat landing place*”). The Massachuset were known to look for food at the location, but otherwise did not view it as land fit for settlement. The English settled the location around 1625 and named it Trimountain or Tremont, referring to the three largest drumlins. (Potenza, 2026), (Winsor, 1822).

The Boston Basin is a formation categorized as a complex, east-tilting, asymmetrical rift basin. The Basin is bordered by the Bloody Bluff Fault Zone on the northwest, measures 24 kilometers north/south from the coast, then widens offshore as it extends to the east where it is buried beneath the Stellwagen Bank deposits in the Massachusetts Bay. (P. J. Barosh 2011). The basin is roughly 50 km long, and its eastern side is submerged by Boston Harbor and Boston

Bay. (Billings, 1979).

It's unusual that there is not already an established consensus narrative for the geology of Boston. Boston is a major city with large universities and a century of extensive studies of its geology, yet there is still no generally accepted evidence-based explanation for many fundamental elements of the geology of the Boston Basin. This knowledge deficit may be partially explained by the fact that it is extremely difficult to reference the Boston landscape to establish theories about past events because Boston has dramatically modified, reorganized, and distributed the natural landscape to an extent that likely pushes Boston into a global list of the most artificial cities in the world.

Boston started its alterations in the 17<sup>th</sup> Century, and the land became unrecognizable prior to the creation of maps which could document the natural state. Boston did not just drain its wetlands or fill the sea (both of which are major alterations on their own), but Boston created more land through filling then what originally existed at Shawmut, installed hundreds of miles of drainage infrastructure, severely polluting the natural and unnatural land, and deformed the superficial geology to the extent that “artificial fill” is a formal geological category for soil and “sewers” are a formal feature in Boston's hydrology.

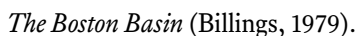
Further complicating the proper identification of the Boston Basin, marine bolide impact craters/ejecta are also difficult to find. We know of around 170 meteorite impact craters on Earth's surface, but only ~20% are marine. That means the total impact crater count is far too low as oceans cover 70% of Earth and it could be thousands of marine craters larger than 20km. (Dypvik, H. & Jansa, L.F., 2003).

This article presents evidence for anyone studying the geology and minerology of the Boston Basin and Boston Harbor. Now that it's possible for researchers to pull together centuries of scientific observations and news coverage, and decades of boring reports and laboratory reporting we can easily complete the full picture of the Boston Basin: it is a bolide impact site.

Boston's drumlins are ejecta mounds. The tillite and diamictite are ejecta. The boulders are impact fractured bedrock and surviving bolide fragments. The bays and marshes filled with flour-like, varve-less clay fill the impact craters. The “tuff” is suevite. The mineral and element signatures align with chondrite bolides. The surface geology

The existence of decades of self-reporting by geologists studying Boston that the current perplexing landscape was almost entirely formed around 12,900 years ago during the Younger Dryas period – meant that upon identifying sufficient evidence to support a hypothesis that Boston is a bolide impact site, the existing consensus already explains when the bolide hit the surface and the associated impact events. Boston appears to be one of, or the, missing Younger Dryas impact site – finally validating the Younger Dryas impact hypothesis.

The “basin” is categorized as such despite the “disappearance” of its northern and western sides, shortened length, unknown width, “large displacement,” and irregular borders. (P. J. Barosh 2011). The Boston Basin is thought to have originated as a half-graben in the ancient Iapetus Ocean during the Ediacaran period. It may have developed as a failed rift/successor basin during the opening of the Iapetus Ocean. (P. Barosh 2016). The Boston Basin is thought to have shared topography and a structural setting with Saint Johns in New Brunswick. (P. J. Barosh 2011).



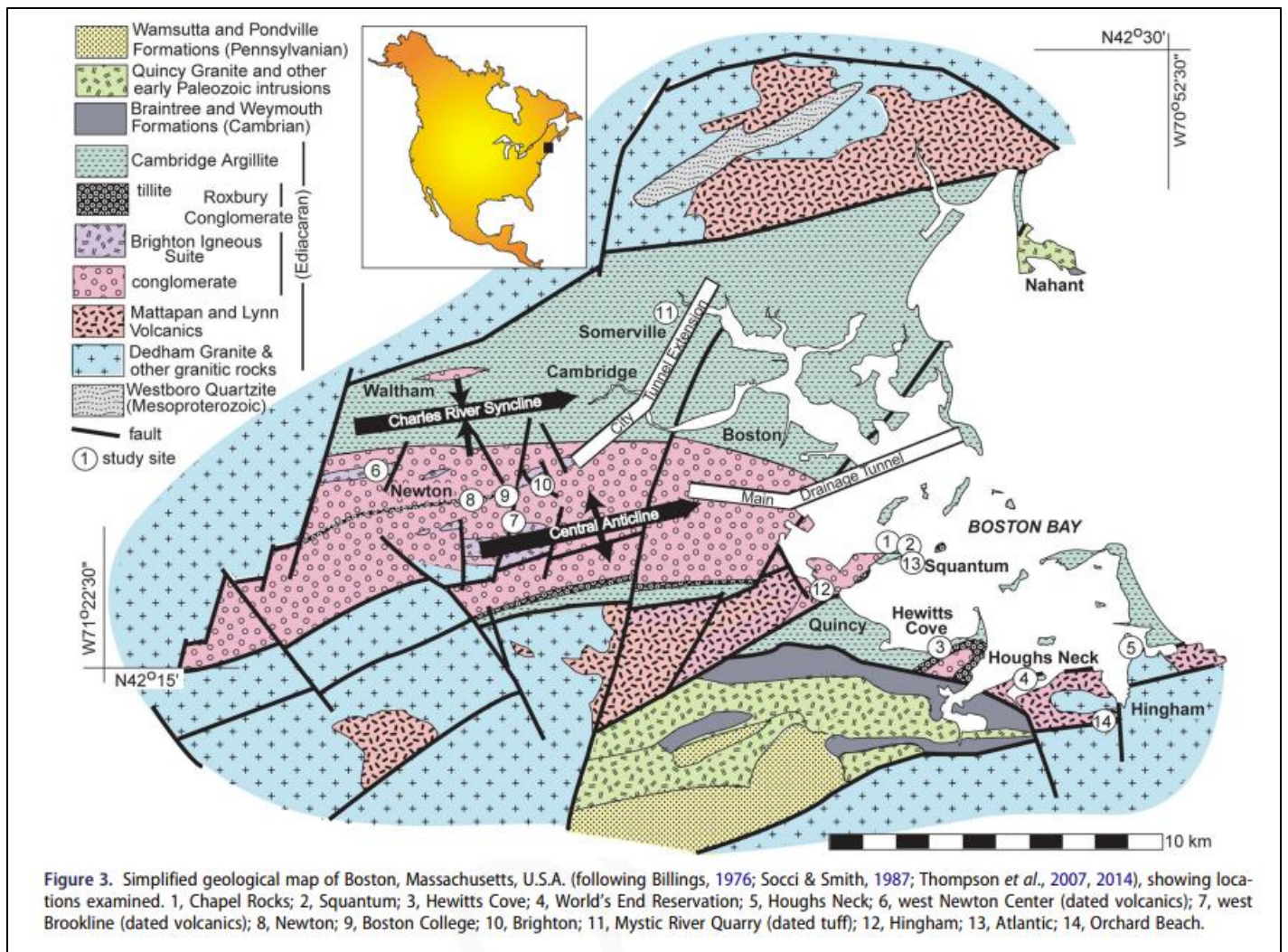
of the Boston Basin's rocks and minerals are most similar to those in Morocco (Anti-Atlas) and New Brunswick (Avalonia). (Murphy 2010). Magnetic data further indicate that these formations are an exotic terrane, some of which (i.e., Boston Basin, New Brunswick, Newfoundland) were later accreted onto Avalonia prior to Avalonia's accretion onto Laurentia. (F. Wu 1986).

Very little is known about the geological history of the Town of Boston, and the area is generally described as chaotic, complex, extreme, confused, and generally unknowable. (“Although Boston was the first city of the United States to be mapped geologically it probably will be one of the last to be mapped satisfactorily.”). (Kaye 1984) The superficial deposits atop the City of Boston are described as a “bewildering array of strata that may change abruptly over a short distance” and “probably the most complex in the country.” (P. J. Barosh 2011).

There is conflicting and erratic historical data but it all generally indicates dramatic fluctuations in land elevation and sea level. (Horner 1929), (Johnson 1942), (P. J. Barosh 2011). Based on findings during the prior deep tunnel activities, the sediment around Boston is estimated to be up to around 100-300ft deep and the bedrock is estimated to be over 15,000 feet deep and mostly argillite mudstone.

The bedrock of the Boston Basin is 75-295 ft below the surface and is “highly irregular,” with “knobs,” “ridges,” deep grooves, “enclosed basins,” “closed depressions,” and a “interrupted and irregular trough.” (P. J. Barosh 2011). The basin is thought to be east-tilting into the Gulf of Maine, and southward slumping. (P. J. Barosh 2011).

The most common rock in Boston is argillite (frequently referred to as Cambridge Argillite or Cambridge Slate). Boston's argillite mudstone is thought to have been formed in a "deep marine basin" with terrigenous and volcanic sediments, which was then "connected to the open ocean very early in its history." (Socci 1987). Deposition of the argillite probably began after ~584 Ma in the western Avalonia terrane, following the formation of most of the Boston Basin basement, and continued for some duration of around 30-80 million years.



*Simplified geological map of Boston, Massachusetts, U.S.A. (Retallack, 2021).*

The argillite is thought to be volcanic ash sedimentation produced as submarine fan and slope-related turbiditic mudstones and siltstones up to 5,700 m. A probable source for the ash that became this argillite mudstone is the “exceptionally voluminous magmatism” eruptions from 566-550 Ma in the adjacent Avalonia terranes of the Coldbrook Group in what is now Caldonia, New Brunswick and St. John’s Group in what is now Newfoundland. (Escribano 2021), (M. D. Thompson 2020). This would have occurred around the closures of the Iapetus Ocean and formation of the Gulf of Maine. All three areas share argillite mudstone deposits of similar depth and siliceous composition. (Misra 1971).

The Argillite is “relatively unmetamorphosed” (Billings, 1979), but there are many igneous rocks in the Boston Basin. The most recent source of igneous rocks is theorized be volcanism in/around Avalonia during the arc-to-platform transition. (M. D. Thompson 2014). Multiple areas around

the Boston Basin also contain Ediacaran and Cambrian fossils, demonstrating the establishment of stable platform conditions and the end of volcanic activity at least ~400 million years ago.

The argillite of the Boston Basin consists of a variety of forms of a hard, strong, solid, low-grade metamorphic rock. Argillite is a general classification of mudstones, however the rocks in the Boston Basin termed argillite also include “fine-grained argillaceous sandstones, tuffaceous argillites, calcareous argillites, gypseous argillite, and other types of fine-grained sedimentary rocks.” They range in color from “cream through light to dark shades of gray.” (Kaye 1984). The rock may present as claystone, mudstone, and/or fine sandstone. (P. J. Thompson 2014).

Studies of Boston’s argillite frequently report a high percentage of silicon dioxide and aluminum oxide. The rocks at/around the site generally have 61-67% silicon

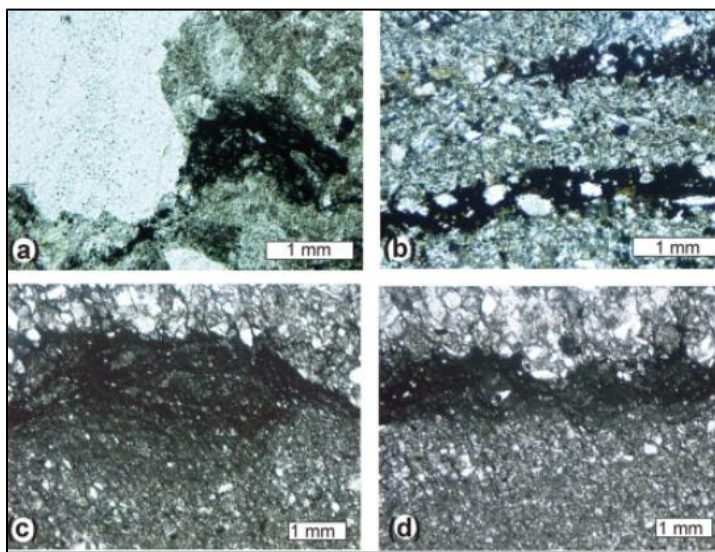


dioxide (compared to 28% background) and 16-20% aluminum oxide compared to 8% background). (Kaye 1984).

A chondrite mineral fingerprint is present throughout the Boston Basin argillite formation, including albitic feldspar (Ab84), ilmenite in three alteration stages, Fe-Ni metal oxidized to magnetite/maghemite/goethite, troilite converted to pervasive pyrite, Cl-apatite, chromite with Cr at 1,763 ppm and Ni at 1,040 ppm, and olivine (Fo71Fa29) altered to Fe-rich chlorite.

Hitchcock's 1841 geological survey describes a rock found in the Boston Basin he calls "varioid wacke," noting "its mode of formation seems involved in much obscurity." He could not classify it as porphyry because its rounded masses lacked crystalline structure, and could not classify it as amygdaloid because the nodules could not have been introduced by infiltration — they were "rounded masses of compact feldspar" that "must certainly have been the result of igneous fusion." (Hitchcock, 1841).

These are chondrules. Chondrules are rapidly cooled igneous droplets, 0.01–10 mm, rounded, of variable crystallinity, representing "the most abundant constituents of chondrites" formed by "intense high-temperature nebular storms." (Scott, 2003). Hitchcock observed them in the Boston Basin in 1835, filed the observation under "obscure origin," and no one has examined them under that framework since. The varioid wacke warrants immediate reexamination as chondritic material. (Hitchcock, 1841).



*Argillite*, (Retallack, 2021)

When chondrite impacts a sedimentary target at hypervelocity, the meteoritic minerals are mixed into the

target rock, subjected to extreme temperatures and pressures, and then altered by the subsequent hydrothermal system. Each chondritic mineral follows a predictable alteration pathway. The minerals documented in the Boston Basin match these pathways.

If chondritic material was mixed into the target rock during impact, the albite is partly meteoritic in origin: chondritic albite distributed through the formation by the impact event, with additional albite produced by hydrothermal albitization of any remaining calcic plagioclase. The uniformity is explained: both meteoritic addition and hydrothermal conversion converge on the same end product. Every plagioclase grain in the formation is now albite because the system was flooded with both meteoritic albite and albite-producing hydrothermal fluids.

The primary way to differentiate a submarine bolide impact and a disaster like an earthquake "is the admixture of various melt particles and possible enrichments in iridium in the former." (Dypvik, H. & Jansa, L.F., 2003).

### KAOLINIZATION IS HYDROTHERMAL ALTERATION

One of the most diagnostic anomalies in the Boston Basin is the extensive kaolinization of the Cambridge Argillite bedrock. Kaolinization—the conversion of feldspar and other aluminosilicate minerals to kaolinite clay—has been documented to depths exceeding 300 feet below the surface. Kaye and Reed (Haley & Aldrich) documented kaolinized argillite at locations throughout the site area, including: the South Station Postal Annex, the Stone & Webster Building site, Washington Street at Water Street, Atlantic Avenue, Boston Common, Castle Square, the Gillette Safety Razor plant in Fort Point Channel, and Pier 2 in South Boston.

At the Ames Building in downtown Boston, F. G. Clapp documented kaolinite clay at 27.11% by weight, with silica in the kaolinized sample at 59.18% by weight. Clapp labeled this material "clay of probable Cretaceous age," a designation reflecting the difficulty of explaining deep kaolinization within the prevailing geological framework.

The characteristics of the kaolinization are particularly significant. Kaye (1967–1984) documented that the alteration is: (a) "limited to certain beds" with no consistent stratigraphic control; (b) "abrupt and unpredictable," changing "from sound to kaolinitic weak argillite in very

short distances”; (c) present *beneath* zones of sound rock, ruling out simple downward weathering; and (d) more closely associated with “shear zones and faults” than with any stratigraphic horizon. Kaye described the cause as “conjectural,” suggesting either hydrothermal alteration or Tertiary weathering, but acknowledging that neither explanation was adequate.

This pattern—deep, patchy, fault-associated alteration that overprints existing stratigraphy without regard to original bedding—is a hallmark of hydrothermal systems driven by the intense, short-duration heating associated with bolide impacts. Impact events generate extreme temperatures and pressures that produce hydrothermal fluids circulating along fracture networks, preferentially altering rock along pre-existing faults and shear zones. The resulting alteration pattern is exactly what the Boston Basin exhibits: unpredictable, fault-controlled, and extending to depths far greater than any surface weathering process could achieve.

The diabase dikes that intrude the Cambridge Argillite further illustrate this pattern. These vertical, north-south trending dikes are reported to “yield readily to kaolinization” and to “pass by spheroidal weathering to rusty brown earth.” Diabase is a dense, crystalline igneous rock; its deep and thorough conversion to clay is not explicable by surface weathering alone, but is consistent with pervasive hydrothermal alteration along fracture-controlled pathways.

Several areas of the Boston Basin, including Boston and Cambridge, have frequent geological anomalies. In 1984, Boston Basin geological expert Clifford Kaye noted that in this argillite there are “many zones of penecontemporaneous deformation” and “small depositional unconformities are common.” (Kaye 1984).

In plain terms, this means that there are many sites of hyper-local deformation and/or alteration of these rocks and that while each area is small, it appears most of these deformities and alterations occurred around the same time, and they occurred after the formation and placement of the original rock. This is unusual, especially for a very strong and solid rock.

The “abrupt and unpredictable change from the sound Argillite to the kaolinitic weak Argillite occurs in very short distances” and the kaolinitic downward zones occur along with superficial kaolinized rock. “The erratic occurrence of

the weathered and altered zones, in conjunction with the steeply dipping bedding planes typical of the Argillite, causes difficulty in characterizing the bedrock.” (Brown, 1997).

Boston’s argillite bedrock exhibits extensive kaolinization at multiple documented locations including the South Station Postal Annex, the former Stone & Webster Building, Washington Street, Atlantic Avenue, Boston Common, Castle Square, Gillette Safety Razor plant, and Pier 2. (Kaye & Reed, Haley & Aldrich). Under a new MIT building in Cambridge the argillite was “rotted to a whitish and more or less plastic clay” (Worcester, 1914), (Barosh P. J., 2011).

At the Ames Building, kaolinite clay reaches 27.11 wt.% in argillite that also contains 59.18 wt.% SiO<sub>2</sub>, and ranges from “very soft and putty-like material to hard as a rock.” Kaolinite was also found in borings of -44 to -180 ft msl around Boston Company Building on Court Street, the New -England Merchants Building on Tremont Street and the 60 State Street. (Barosh P. J., 2011).



*Kaolinized conglomerate with large crystals of kaolinite replacing quartz (Kaye, C. A., 1967).*

This kaolinization penetrates to over 300 feet depth, is fault-controlled rather than stratigraphic, and transitions abruptly from sound rock to fully altered material – a pattern diagnostic of impact-generated hydrothermal circulation rather than surface weathering. (“Kaye.... recognizes the

possibility that the [kaolinized] alteration is hydrothermal in origin.” (Barosh P. J., 2011)). Multiple researchers noted that the altered argillite appeared limited to certain beds (Kaye 1967), (Rahm 1962), (Billings 1964).

Kaye’s (1967) study of thin-sections from the altered zone revealed that the commonly present rock minerals, including quartz, have been replaced by sericite and kaolinite at varying levels. (Brown, 1997).

Kaye describes, “veinlets of pure white kaolinite as much as 4 millimeters thick were also cored” at the Stone & Webster site. (Kaye, C. A., 1967). Kaolinite veinlets cutting through rock are a hydrothermal injection feature, not a weathering feature. Weathering produces kaolinite in place by replacing existing minerals — it doesn’t inject kaolinite into fractures as veins—but a bolide impact could.

He also notes “a number of veins, mostly of milky quartz but some partly of drusy milky quartz and partly of massive white kaolin, cut the sandstone.” Drusy quartz (quartz crystals lining a cavity) forming alongside kaolinite veins is a hydrothermal signature. (Kaye, C. A., 1967).

The claystone is mostly altered to illite, chlorite, mica, or other phyllosilicate with 0.1–3 mm thick grey/black laminae. Microscopic structures include intraclasts, load casts, injection structures, tiny dikes, and intrastratal microfaults. (P. J. Thompson 2014).

In 1818, Dana wrote about a version of Argillite found around Boston that they called “Novaculite” and which is a cloudy grey/green color, glimmering, amorphous, translucent at the edges, with a greyish white streak, and that “fuses into a greenish or blackish grey enamel” if heated. (Dana, J.F. & Dana, S.L., 1818). Novaculite (or “Arkansas Stone,” “Turkey stones,” “sharpening stone,” etc.) is an ultra hard cryptocrystalline silica chert created by “pressure metamorphism.” (State of Arkansas, 2026). Novaculite is a pressure metamorphism product – found around Boston – without explanation, but which could be explained by a bolide impact event.

In the Charles River area, “two borings (30-A and 31) penetrated several hundred feet of material reported as gray-white shale and some sandstone, which is unusual. Pearsall (1937) suggested that this gray-white shale may be sediment of Cretaceous or Tertiary age filling a “preglacial gorge,” (Upson, 1964).

The formation of kaolinite through hydrothermal alteration of feldspar-bearing rocks (kaolinization) is a well-established process in impact structures, occurring at temperatures of approximately 175–350°C. (Anderson, 2008). Research on hydrothermal kaolinization in analogous settings confirms a diagnostic geochemical signature: enrichment of Zr, U, Th, Y, La, and Pr, with depletion of Rb, Ba, V, Cr, Zn, Eu, and Ce, resulting from the breakdown of feldspars during hydrothermal alteration. (for example, the Vali-Janlou kaolin deposit in Iran). Negative Europium anomalies during kaolinization specifically indicate plagioclase destruction by high-temperature hydrothermal solutions. The coexistence of kaolinite with pyrophyllite, dickite, and diasporite indicates maximum hydrothermal fluid temperatures of around 350°C.

Kaolinite interbedded with “massive conglomerate and arkose” and diabase dikes/sills cut the soft rock. 40ft long with quartzite, purple argillite, sandstone and conglomerate in Allston south of Charles River at 225 deep (Barosh P. J., 2011). Kaye also found a vein of “very fine grained siderite” on the Shawmut Peninsula over 120 ft thick with “soft white altered rock” which “did not get firmer with depth.” (Kaye 1967).

At confirmed impact sites including Chicxulub, Ries, and Vargeão Dome, kaolinite and related clay minerals form through identical mechanisms: hot, impact-generated fluids circulating through fractured rock along zones of high permeability.

Anderson (2008) reported that Boston’s argillite siltstone and slates have “clearly undergone considerable recrystallization” at temperatures estimated between 175°C and 250°C. This temperature range falls squarely within the documented range of impact-generated hydrothermal systems (generally peaking at ~350°C per Chicxulub data, and persisting below 100°C for millions of years for larger craters). There is no documented source of 175–250°C heating in the Boston Basin since the end of Avalonian volcanism over 400 million years ago.

Boston argillite consistently reports SiO<sub>2</sub> at 61–76 wt.% (crustal average: 28%) and Al<sub>2</sub>O<sub>3</sub> at 15.57–19.51 wt.% (crustal average: 8.1–8.3%). This extreme silica-alumina enrichment is consistent with the predominant alteration assemblages at impact-generated hydrothermal systems, where the



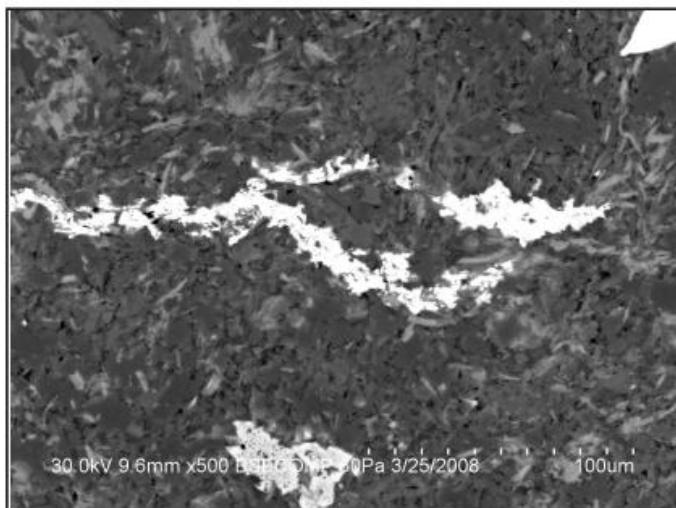
dissolution of feldspars and precipitation of siliceous and aluminous phases – including kaolinite, sericite, and amorphous silica – is driven by circulating heated fluids.

At Chicxulub, quartz dissolution and Ca-Na-K metasomatism are defining features of the hydrothermal system. The pervasive sericite in Boston's argillite (15.9–22 wt.% at the Main Drainage Tunnel) represents the hydrothermal alteration of feldspars to white mica, a process directly parallel to what is documented at Chicxulub, Ries, and other confirmed impact structures.

### **CHLORITE & SERICITE ENRICHMENT; OLIVINE ALTERED TO FE-RICH CHLORITE**

Dana describes the chlorite around Boston as “blackish green,” “faintly glimmering,” “opaque” and “amorphous,” “very soft” with a “mountain green streak,” and that it “exhales a faint argillaceous odour when breached upon.” They note it “occurs massive in Quartz at Brookline and Brighton.” The “Potter's clay” version “melts into a slag” (Dana, J.F. & Dana, S.L., 1818).

Thompson (2020) found Fe-rich chlorite (chamositic,  $\text{Fe/FeMg} = 0.60\text{--}0.75$ ) pervasive in the argillite, including as opaque laminae. Wu included chlorite among the secondary minerals produced by “some kind of hydrothermal force.” (Wu F., 1986). The iron enrichment of the chlorite above normal sedimentary values is explained if some of the iron source is chondritic olivine (iron-bearing) and Fe-Ni metal, rather than purely terrestrial.



*“dark lamina”, Boston Basin, (Anderson, 2008)*

Boston Basin rocks have been found to have “numerous

crystals of chlorite... displaying characteristic anomalous blue birefringence.” “Reflected light microscopy revealed a pale yellow, reflective mineral comprising segments of some of the dark layers” which was identified as a “silicate that contains cerium, neodymium, and possibly lanthanum, and thus is likely allanite” with rutile, ilmenite, zircon, and apatite. Unlike rocks from the other two localities, almost all the dark laminae were composed of a weakly reflective pale yellow mineral. EDS analysis suggests that these layers, rich in titanium and silica, are sphene. No pyrite framboids were found in BB-HC-C. (Anderson, 2008).

Olivine ( $\text{Fo}_{71}\text{Fa}_{29}$ ) is the dominant mineral in ordinary chondrites. Olivine alters readily to chlorite and serpentine in the presence of hydrothermal fluids (La Forge, 1932 ) documented that across the basin, “in the granites and syenites the dark minerals have been very largely altered to chlorite and limonite.”

The presence of fresh, unweathered olivine documented in the Main Drainage Tunnel requires explicit explanation. Olivine is among the most chemically unstable rock-forming minerals at surface conditions — it weathers to clay and iron oxides within thousands to tens of thousands of years. The Boston Basin has had no active volcanism for over 400 million years. Fresh olivine cannot exist here under conventional geology. The impact explanation is direct: olivine delivered by chondritic bolide 12,900 years ago has not yet completed its alteration pathway to Fe-rich chlorite. Rahm (1962) documented it in the same rock body as altered chlorite, kaolinite, and magnetite — recording the chondrite alteration sequence mid-process, exactly as expected for recently emplaced chondritic material. (Rahm, 1962).

In the MDT there was fresh augite, labradorite, and olivine and altered chlorite, kaolinite, epidote, calcite, and limonite, with accessory minerals pyrite and magnetite. (Rahm 1962).

Petrographic microscopy of the argillite shows “scattered angular to subangular particles of quartz of silt size... in felty or fibrous matrix of intimately intergrown clay-size minerals” consisting of “sericite, chlorite, and some kaolinite.” (Rahm 1962).

The principal minerals in the Boston Basin's argillite are sericite, chlorite, and quartz. (Kaye 1984). The argillite rocks contained coarse silt-sized quartz, plagioclase (feldspar) clasts, sericite (white mica), chlorite, phengite

(mica), iron-rich clay, and calcite lenses. Sericite (altered from feldspar) was found in a matrix of chlorite and iron-rich clay (Anderson 2008).

Argillite's flaky materials are often arranged in a "triaxial decussate structure." There is also occasionally schistose foliation. (Kaye 1984). There was also argillite with "small, dark-green porphyroblasts" that are diamond shaped, around 0.4 mm x 0.2 mm, and surround tiny chlorite grains. (Rahm 1962).

### **SHOCKED QUARTZ, QUARTZ ENRICHMENT, & CALCITE/K- FELDSPAR DEPLETION**

In 1818, Dana reported on the quartz around the Boston Basin as greyish and yellowish white, reddish orange, greyish black, and greenish grey." It's shining, glistening, glimmering, vitreous, resinous, and often drusy. They are "very hard" and "in six-sided pyramids "the edges and angles of the prisms are variously beveled... sometimes transversely striated" and "sometimes imbedded twin crystals... united longitudinally" (Dana, J.F. & Dana, S.L., 1818).

In 1818, Dana described the quartz around Boston as "phosphorescent when two pieces are rubbed together, exhaling a peculiar odour" that is "very hard" and "difficultly frangible" They describe quartz nodules that project from greywacke stone, and will fall out leaving behind "rounded depressions or cells." (Dana, J.F. & Dana, S.L., 1818).

Supposed fossilized tree trunks were reinterpreted as inorganic sandstone "pipes" formed by "rapid deposition and high energy" from "upward flowing sand and water mixtures" that were "injected rather quickly," covered in "laminae composed of sparse grains of magnetite." (Bailey R.H, 1978). Injection structures, microfaults, and magnetite-bearing rapid deposition features are established characteristics of impact ejecta deposits and impact-disturbed sediments at confirmed crater sites. The argillite has "scour marks" (Rehmer, 1976)

Within the argillite is also a hard, white quartzite which is 400-500 ft thick. This was named "Milton Quartzite" by Billings in 1929. The quartzite is visible for about two miles in Quincy. Scattered throughout the Boston Basin are the Mattapan/Brighton Volcanics. These are hard, dense white, pink, and red rhyolites. Also included are

"melaphyres" (which are altered basalts and andesites) which are dark to light green and are composed chiefly of secondary minerals albite, hornblende chlorite and epidote. (Brenninkmeyer 1984 ).

A 1952 Woods Hole Oceanographic Institution study of Boston Harbor sediment mineralogy documented "alteration" minerals at frequencies of 24% to 64% across sampling stations. This is a remarkable proportion of altered material in marine sediment and is consistent with a basin-wide alteration event rather than localized weathering. (Butcher, 1953).

The same study documented very low calcite frequencies (0–2% versus a crustal norm of 2–4%) and very low K-feldspar (microcline) frequencies (0.4–2% versus a crustal norm of approximately 12%). The near-complete destruction of calcite and K-feldspar, combined with extreme quartz enrichment, is consistent with the differential mineral survival expected in high-temperature impact processing, where quartz (high melting point) survives while carbonates and feldspars are destroyed. (Butcher, 1953).

They also describe a "greywacke" consisting of "nodules" of petrosilex, and quartz, and also argillite, feldspar, porphyry, and sienite with foliated fractures. Dana describes it as translucent or opaque, "intimately connected with" amygdaloids, and is "imperfectly granular or compact fracture." The greywacke is "always very much altered," and is unusually lacking in metals other than traces of iron and "dendritick impressions of Oxide of Manganese" (Dana, J.F. & Dana, S.L., 1818).

"Planar deformation features are probably the most important shock criteria. They are narrow-spaced parallel sets of amorphous lamellae oriented along specific crystallographic directions." (Kenkmann, T., et al., 2014).

The 33-ton Salem gabbro-diorite boulder found embedded in marine clay in the Fort Point Channel displayed extreme hardness – "four times stronger than granite" – that broke diamond-headed chisels and snapped drill bits (Schimek, 2007), (Associated Press, 2003). Shock metamorphism from bolide impact events is a known mechanism for dramatically increasing the hardness and fracture resistance of igneous rocks through the generation of high-pressure mineral phases. Normal glacial transport does not produce this degree of hardening.

Kaye describes “pebbles of granite are altered entirely to kaolinite, and quartzite pebbles are partly replaced by kaolinite.” (Kaye, C. A., 1967). Quartzite is extremely resistant to chemical alteration under normal conditions and normal weathering does not replace quartzite with kaolinite. Hydrothermal fluids at impact-level temperatures can, however.

Calcareous argillite was identified in Boston Harbor east of the Shawmut Peninsula and under the Shawmut Peninsula ranging from ~3-4 centimeters to 1.5 meters and intermixed with normal argillite. The calcareous argillite is “slightly lighter gray,” the fresh rock “effervesces readily with dilute hydrochloric acid,” and turns then “dull brown” when weathered due to the leaching. (Kaye 1984).

The argillite in Boston, Cambridge, and the Inner Boston Harbor is often “densely sprinkled with small gypsum crystals, about 0.5 mm or smaller in length” and also may “contain clusters of larger crystals of dolomite.” (Kaye 1984). Myrmekite quartz growths were found in the argillite of the Braintree Weymouth Tunnel and Inter-Island Tunnel. (M. D. Thompson 2020)

The claystone is mostly altered to illite, chlorite, mica, or other phyllosilicate with 0.1-3 mm thick grey/black laminae. Microscopic structures include intraclasts, load casts, injection structures, tiny dikes, and intrastratal microfaults. (P. J. Thompson 2014).

“Shock melting of rock-forming minerals such as quartz or feldspar occurs during shock unloading of strong shock waves with pressures exceeding 45-60 GPa. The products of impact melting at terrestrial impact structures range from small glass spherules, over melt lumps within suevitic breccias to thick sheets of coherent impact melt rock.” (Kenkmann, 2014).

### **TITANITE & TITANIUM DIOXIDE (TiO<sub>2</sub>-II)**

Argillite accessory minerals include rutile (TiO<sub>2</sub>), titanite/sphene (CaTiSiO<sub>5</sub>), and zircon (ZrSiO<sub>4</sub>). (M. D. Thompson 2020), (Anderson 2008).

One Argillite sample in 2008 had dark laminae from a slightly reflective pale yellow mineral rich in titanium (Ti) and silica (Si) which may be titanite/sphene (CaTiSiO<sub>5</sub>). Framboids were located just above or below dark layers. The siltstone and slates had “clearly undergone

considerable recrystallization” likely heated between 175°C–250°C. (Anderson 2008).

Lower depth titanium dioxide ranges from 0.6–1.08 wt.% (crustal average: 0.56–0.63%) but higher level samples were “relatively high” ranging from 1.76–3.66% wt % and the NW trending dikes containing the highest levels, as well as the highest levels of Nb (Ross 1990).

TiO<sub>2</sub>-II is thermally stable to about 550 C and at 600 C the onset of the transformation to rutile is observed. A hydrothermal environment at 6 GPa and 650°C provides appreciable rates for producing single phase bulk samples of TiO<sub>2</sub>-II. (Spektor, 2013)

Where high-temperature hydrothermal fluids (400–700°C) fully mobilized the titanium, it reprecipitated as titanite in the presence of calcium and silicon from the dissolving host rock. TiO<sub>2</sub>-II is a high pressure polymorph of TiO<sub>2</sub>, forming at shock pressures ~5 to 12 GPa (Bendeliani et al., 1966; Spektor et al., 2013) (Osinski G. R., 2022)

La Forge (1932) reported titanite as “an almost universal though not abundant accessory mineral” across the entire basin. Ross (1990) documented TiO<sub>2</sub> enrichment of 1.76–3.66 wt% in the upper portions of NW-trending dikes, compared to 0.6–1.08 wt% at depth—a factor of 3–6x enrichment in the shallow zone. If the dike magma intruded through impact-processed rock containing mobilized titanium, the upper portions (passing through the most altered shallow zone) would have absorbed more titanium than the deeper portions (passing through less altered rock). The dike chemistry is sampling the impact alteration gradient.

A comparison of Boston Harbor islands (Calf Island and Middle Brewster Island) to Nahant found the Boston Harbor islands had higher Titanium Oxide (TiO<sub>2</sub>) and zinc (Zn). (P. J. Thompson 2014). Analysis of samples from Calf Island reported a TiO<sub>2</sub> composition of 3.44 and Ti of 3.28 (10-1-C). (Thompson P. J., 2014).

Zirconium in the Boston Basin argillite ranges from 193–281 PPM (crustal average: ~130 PPM). Titanium dioxide ranges from 0.6–1.08 wt.% (crustal average: 0.56–0.63%). Potassium oxide reaches 6.69 wt.% at South Boston (crustal average: 2.09%). This pattern – Zr and Ti enrichment with K metasomatism – is consistent with the geochemical signatures of impact-generated hydrothermal alteration,

where zircon and titanite are among the most resistant accessory minerals and become concentrated during alteration while potassium is mobilized during the sericitization of feldspars.

The same sample also reported elevated composition of FeO of 15.30, P<sub>2</sub>O<sub>5</sub> of 0.52, Zirconium of 281, Yttrium of 46.6, Zinc of 156, Vanadium of 324, Barium of 379-389, Lanthanum of 27-29.3, Cerium of 66.74, Niobium of 21.51-42, Ytterbium of 5.1, Holmium of 1.7, Dysprosium of 9.9, Terbium of 1.5, Gadolinium of 10.5, Samarium of 9.5, and Erbium of 5.6 (10-1-C). (Thompson P. J., 2014).

### **ILMENITE, CHROMITE, RUTILE, & Fe-Ni METALS**

Argillite accessory minerals include rutile (TiO<sub>2</sub>), ilmenite (FeTiO<sub>3</sub>), and zircon (ZrSiO<sub>4</sub>). (M. D. Thompson 2020), (Anderson 2008). Previous analysis of typical argillite around Boston reported higher than background levels of iron oxide, rubidium, titanium dioxide, selenium, zinc, zirconium, and potassium oxide. (Kaye 1984).

Since 1991, following the Boston Harbor clean-up, carbon, copper, and lead contents have significantly decreased in Harbor sediments. However, chromium and Zn have shown smaller decreases while Fe, and Mn, have remained relatively constant. (Zago, 2001). Zinc is elevated in Boston Harbor reporting up to 2,200 mg/kg. (NOAA, 1987).

Boston Harbor sediments contain chromium at 20–437 mg/kg (22x spatial variation), and at Calf Island, the picro-basalt shows Cr at 1,763 ppm and Ni at 1,040 ppm. (Ross, 1990), (Boston Harbor Seminar Series , 1987). Testing shows chromium (Cr) is elevated in Deer Island and Dorchester Bay at 191-192 µg/g. (NOAA, 1986-1989). Its elevated in Boston Harbor at 437 mg/kg (NOAA, 1987). Boston Harbor nickel is around 750 mg/kg (NOAA, 1987).

Chromite (FeCr<sub>2</sub>O<sub>4</sub>) is an accessory mineral in ordinary chondrites and is used as a meteoritic tracer in marine sediments. Chromium and nickel together at these concentrations—Cr approaching meteoritic values in an ultramafic-composition rock within an otherwise sedimentary basin—are consistent with meteoritic chromite and Fe-Ni metal contamination of the target rock. The extreme spatial variability (22x for Cr, 69x for Zn) is inconsistent with uniform anthropogenic input and consistent with heterogeneous meteoritic contamination of the substrate.

Ilmenite (FeTiO<sub>3</sub>) is an accessory mineral in ordinary chondrites. Boston's argillite contains three separate titanium-bearing phases: ilmenite, rutile (TiO<sub>2</sub>), and titanite (CaTiSiO<sub>5</sub>). (Anderson 2008; Thompson 2020; La Forge 1932). These are not three unrelated minerals. They are one original mineral in three stages of post-impact alteration.

“Rutile is the most abundant in the Farmington L-group chondrite. There it occurs in fine lamellae in ilmenite. meteorite although wherever it does occur it is in moderately large clusters - up to 0.5 mm in diameter - and it then is usually associated with chromite as well as rutile.” (Buseck, 1966)

Where chondritic ilmenite survived relatively intact, it is identified as ilmenite. Where it was partially altered under shock or moderate hydrothermal conditions, it converted to rutile—the stable TiO<sub>2</sub> polymorph.

The 22x spatial variation in chromium and 69x variation in zinc in harbor sediments (Boston Harbor Seminar Series 1987) reflect both anthropogenic source distribution and, beneath that, the heterogeneity of the leaching substrate. Areas where impact-processed bedrock is closest to the harbor floor—where the most severely altered, sulfide-rich rock is in most direct contact with circulating groundwater—receive the highest natural metal flux. The contamination map of the harbor is the superposition of two patterns: anthropogenic contamination from above and natural impact-derived leaching from below.

Chromium at 1,763 ppm at Calf Island, with extreme spatial heterogeneity. Nickel at 1,040 ppm co-located with the chromium. Each of these—platinum group elements, chromium, nickel—is independently used as a meteoritic tracer in impact studies.

Fe-Ni metal is a major constituent of ordinary chondrites. When oxidized, it produces magnetite (Fe<sub>3</sub>O<sub>4</sub>), maghemite, goethite, and other iron oxide and hydroxide phases. The Boston Basin contains iron in extraordinary abundance and ubiquity: “minute magnetite crystals” in igneous bodies (Kaye, C. A., 1967); magnetite grains (0.15–0.20 mm) lining injection pipes (Bailey 1978); iron staining on joint surfaces in every boring log; chamositic chlorite with Fe/FeMg ratios of 0.60–0.75—far above normal sedimentary values of 0.30–0.50 (Thompson M. D., 2020); universal siderite (FeCO<sub>3</sub>) replacement of all iron-bearing minerals in the

diabase; and “relatively abundant ferric iron from unknown mineral” (Rahm, 1962).

Chondrites are broadly ultramafic in composition, consisting largely of iron, magnesium, silicon, and oxygen. The most abundant constituents of chondrites are chondrules, which are igneous particles that crystallized rapidly in minutes to hours. They are composed largely of olivine and pyroxene, commonly contain metallic Fe,Ni and are 0.01-10 mm in size. nearly all chondrules have porphyritic textures and are composed largely of forsterite (white grains), enstatite (gray), and metallic Fe,Ni (black) (Scott, 2003).

Rahm could not identify the iron source because it did not match any standard terrestrial sedimentary mineral. Oxidized meteoritic Fe-Ni metal would not match standard identification keys. It is the “unknown mineral.”

The sheer volume of iron in the system—pervasive magnetite, universal siderite, iron staining on every fracture surface, iron-enriched chlorite throughout the formation—exceeds what the original argillite could supply. The argillite is a mudstone, not an iron formation. The excess iron is consistent with the addition of meteoritic Fe-Ni metal to the basin, subsequently oxidized and redistributed by the hydrothermal system into every mineral phase that could accommodate it.

## **FERRUGINOUS IRON & HYDROUS IRON OXIDES**

There is no lack of iron around the Boston Basin. A variety of forms of iron were reported in the earliest mineralogy reports of Boston including “sulphuret of iron,” “magnetick oxide of iron,” “micaceous oxide of iron,” “ochrey brown oxide of iron,” “nodular ironstone,” and “carbonate of iron” The Iron mica is described as “highly spendent,” “amorphous,” “in thin diverging plates which often intersect each other and form cells,” and straight fractures and curved foliation. (Dana, J.F. & Dana, S.L., 1818).

Sulphate of iron is noted as white and green, glimmering, acidic, and with saline consistence. Sulphuret of iron is “pale brass yellow and yellowish grey,” “shining” and “glimmering” and “crystallized in cubes” with a “faint sulphureous odour when rubbed.” Some also “show a diverging radiated fracture which arises from a peculiar aggregation of cubick crystals.” Dana believed it was

“decomposed by atmospherick exposure and converted into a Sulphate of Iron” and was “very rare” (Dana, J.F. & Dana, S.L., 1818).

The surface of Argillite is also noted as having a “glimmering.. lustre” and is “pavolnue, irised, and chatoyant from the presence of Oxide of Iron.” (Dana, J.F. & Dana, S.L., 1818).

Hitchcock (1841) describes two distinct varieties of concretion in New England clay beds: one composed of carbonate of lime and clay, and one of hydrate of iron and clay. He notes the iron concretions resemble organic remains but he “thinks must be given up” as organic. These ferruginous concretions occurring in the clay beds — iron hydroxide nodules in a clay matrix — are consistent with the impact-derived iron mobilization.

“Solitary specimens of “nodular” ironstones were also reported colored brown, with concentric stripes, “concentrick lamellar distinct concretions,” with a “nucleus of a gall-stone yellow...colour,” and occurring in “rounded and ovate masses, from the size of a hen’s to that of an ostrich’s egg” that “exhales an argillaceous odour when breached upon” and when heated “fuses into a black scoria and becomes magnetick” (Dana, J.F. & Dana, S.L., 1818).

Edward Hitchcock wrote the first formal geological survey for the Commonwealth in 1833-1841 and documented a large number of anomalies in the Commonwealth and New England which could not be explained by standard geological processes including unusual and expected presentation of clay and clay stones, ferruginous concretions and nodules, and the detailed fossilization of organic matter in argillite as iron core with no remnant of organic matter remaining. (Hitchcock, 1833), (Hitchcock, 1841).

Within the argillite, fine grain materials sit on felty or fibrous matrixes with quartz, pyrite, hematite, and hydrous iron oxides. (Rahm 1962). Rock samples have contained “abundant minute, opaque spheres” with a “very thin coating of pyrite” around what is thought to be “spherical cells,” “multicellular filaments of cylindrical form,” and “dense colonies of minute spherical cells.” (Kaye 1984). The subspherical bodies were “interspersed” with pyrite “laminae.” (Lenk, 1982).



The islands in the Central Boston Harbor were found to have light, smooth argillite pebbles with small siderite (iron carbonate) crystals located within the “drumlin till” of those islands. (Kaye 1984). Hematite red pebbles were identified in the “glacial till” of “some of the drumlins” in Winthrop and Deer Island and at the surface of Revere Beach. The Revere Beach pebbles also contained “small, irregular masses of limestone” that were assumed to be Ediacaran trilobite fossils. (Kaye 1984), (Clark 1921-1923).

Crosby & Ballard describe “etched or half-dissolved lumps and concretionary masses of till” in the oxidized zone, with “lithified matrix” that is “much darker colored from usual gray tint of till through dark brown to nearly black — darkest near shell” due to “interstitial deposition of carbonate of lime from dissolved shells and peroxidation of the iron oxide in the till.” (Crosby, 1894). This secondary iron and carbonate mobilization in the till layers, producing localized cementation and color changes, is consistent with ongoing geochemical activity in impact-processed material and not typical of inert glacial till.

### **PYRITE & SULFIDES**

Pyrite and sulfides are reported in the earliest mineralogy reports of Boston including “pyritous copper,” “sulphuret of iron,” “sulphur of lead,” (Dana, J.F. & Dana, S.L., 1818).

Pyrite is pervasive throughout the Cambridge Argillite: as euhedral crystals (hydrothermal growth), as framboids, as the “thin coating” on Kaye’s microspherules, and as the now-dissolved cubes leaving “cubic holes” throughout the formation. The hydrothermal sulfide system also produced the polymetallic ore assemblage—arsenopyrite, galena, chalcopyrite, sphalerite—distributed as accessories throughout the rock. (Thompson M. D., 2020).

Ehrenfried documented pyrite crystals that “have rusted completely away, leaving behind nothing but holes”—this process is ongoing. (Ehrenfried, 1991). There is also hematite, hydrous iron oxides, and “scattered pyrite euhedra.” Chemical analysis also reported “relatively abundant ferric iron” but from an unknown mineral. (Rahm 1962).

In the MDT there was fresh augite, labradorite, and olivine and altered chlorite, kaolinite, epidote, calcite, and limonite, with accessory minerals pyrite and magnetite. (Rahm 1962).

The sulfur budget of the basin—sufficient to produce

pervasive pyrite plus a full polymetallic sulfide suite—is consistent with meteoritic troilite as a primary sulfur source, supplemented by sulfur mobilized from the target rock.

### **PLATINUM & PALLADIUM**

Platinum and palladium are at five times background in Boston Harbor sediments, with ratios that “cannot preclude other sources” than anthropogenic. (Tuit, 2000). After the Boston Harbor clean up, (Tuit, 2000) found that platinum and palladium in Boston Harbor was not “decreasing with cessation of sludge input as rapidly as other metals.” Platinum and palladium are not decreasing because their primary source is not the sludge—it is the bedrock.

Chondrites often have an abundance of the highly siderophile elements Rhenium (Re), Osmium (Os), Iridium (Ir), Ruthenium (Ru), Platinum (Pt) and Palladium (Pd). However, Absolute abundances of the HSE vary by nearly a factor of 80 among the chondrite groups. (Horan, 2003).

Platinum (along with iridium, osmium, and gold) are common as siderophile elements at impact sites and typically have “extremely low abundances in terrestrial crustal rocks.” (French, 1998).

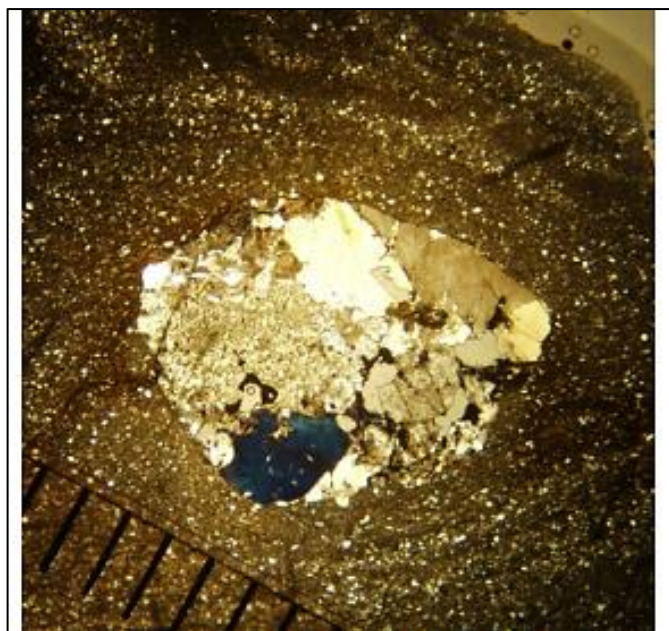
### **ALBITE FELDSPAR**

Albite is found around Boston including in and around granite, argillite “tuffs” and feldspar, up to 59.75 %, including around Qunicy and Blue Hills. Around Clinton there is a “white pegmatite made up of quartz, albite, and coarse, twisted muscovite, and full of finely granular, deep ultramarine-blue apatite.” At that granite bed, the “the microcline is sericitized, the albite is saussuritized, and the thin intrusive tongues of granite are commonly separated from the schist by trains of rhombohedral crystals of ankerite.” (Emerson, 1917).

Between Boston and Cambridge, around Brighton, there were unique rocks and mines included: red shale, amygdulites with epidote, rocks with actinolite, barite, chalcocite, bornite, white prehnite, calcite, specular hematite, malachite, chrysocolla, titanium oxides, gray chalcedony, and albite crystals and twinning (Palache, 1947).

Albitic feldspar (Ab<sub>84</sub>) is a major constituent of ordinary chondrites. Thompson (2020) found that plagioclase

throughout the Cambridge Argillite sequence is “uniformly pure albite.” This has been interpreted as sodium metasomatism—hydrothermal fluids replacing calcium with sodium in original plagioclase. That interpretation is not wrong, but it is incomplete.



*“deformed laminae” on “dropstone” with “blue crystal” quartz and “albite twinning in the plagioclase” Hewitt’s Cove Argillite, Boston Basin (Williams, 2008).*

Shock metamorphism can create planar microstructures in feldspars including fractures, deformation bands, kink bands, “albite twinning,” and planar deformation features. (French, 1998). Albite twinning is reported frequently around Pine Hill near Boston. (Zarrow, 1978). In 2008, Williams identified “albite twinning” on a assumed “dropstone” found at Hewitt’s Cove near Boston which had a “deformed laminae” with blue-crystal quartz. (Williams, 2008).

The Chelyabinsk meteorite (an LL5 ordinary chondrite) consisted of olivine ( $\text{Fo}_{71}\text{Fa}_{29}$ ), enstatite, diopside, albitic feldspar ( $\text{Ab}_{84}\text{An}_{11}\text{Or}_5$ ), Fe-Ni metal, troilite ( $\text{FeS}$ ), chromite, ilmenite, and Cl-apatite. (Ozawa, 2014).

### **APATITE, PHOSPHATE, PHOSPHORUS PENTOXIDE, & MONAZITE**

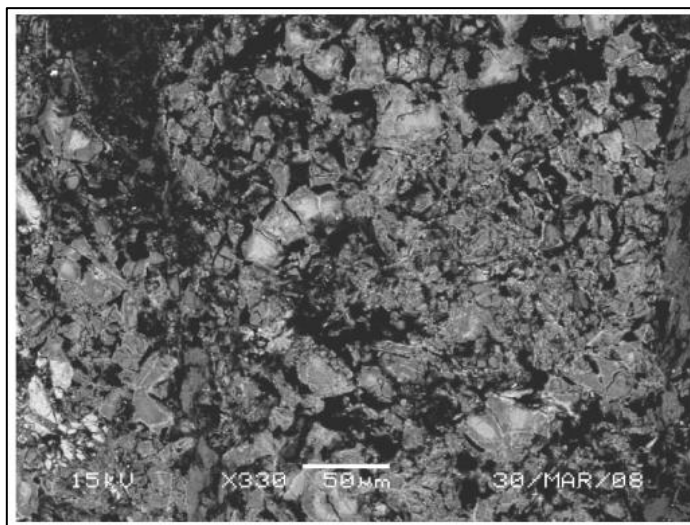
Apatite is found around Boston with one of the earliest reports in 1818 describing a celandine and mountain green stone with “short six-sided prisms” that is “glimmering and vitreous,” “translucent,” “soluble in nitric acid “with effervescence,” and “phosphoresces when laid on heated iron” (Dana, J.F. & Dana, S.L., 1818). Thompson wrote that

“apatite, monazite, rutile” are “ubiquitous” in the Boston argillite. (Thompson M. D., 2020). Apatite is a “calcium-phosphate mineral (table 2), is an important source of phosphate.” (Van Gosen, 2019).

Cl-apatite is an accessory mineral in ordinary chondrites. Thompson (2020) found apatite to be “ubiquitous” throughout the argillite sequence. EDS analysis of argillite with pale yellow allanite and titanite (sphene) also featured “euhedral apatite” and found “well-formed crystals that grew freely from a fluid or melt” (Anderson, 2008)

Argillite accessory minerals include zircon and euhedral apatite (phosphates). (Anderson 2008). Boston Harbor islands (Calf Island and Middle Brewster Island) have elevated Phosphorus pentoxide ( $\text{P}_2\text{O}_5$ ) (P. J. Thompson 2014).

Monazite ( $\text{Ce,La,Th}\text{PO}_4$ ), a phosphate mineral, was found in the argillite of the Braintree Weymouth Tunnel and Inter-Island Tunnel. (M. D. Thompson 2020). The high pressure polymorphs of phosphate mineral, ( $\text{La, Ce, Th}\text{PO}_4$ ) is an impact crater fill deposits (Osinski G. R., 2022). The Main Drainage Tunnel samples showed  $\text{P}_2\text{O}_5$  enrichment at twenty times the crustal average. (GEI Consultants, Inc., 1998).



*weathered phosphate, Boston Basin, (O'Donnell, 2008).*

Monazite is a rare earth element and phosphate mineral. “Monazite is one the heaviest minerals in the heavy-mineral suite” and “is mainly derived from the erosion of igneous and high-grade metamorphic rocks that lie inland of the rivers and coastal plain.” (Van Gosen, 2019).

Argillite with a “white silt laminae” under energy

dispersive spectrometry is shown to “contain iron, aluminum, silicon, and phosphate.” The same sample also shows “detrital monazite and authigenic framboidal pyrite” (O'Donnell, 2008).

The extreme phosphorus enrichment has three converging impact-related sources: chondritic Cl-apatite distributed through the target rock; reactive phosphorus produced by impact-generated fulgurites (Hess, 2021) and hydrothermal mobilization and reprecipitation of phosphorus from both sources as euhedral apatite.

## **THE LEXINGTON SUBSTAGE IS THE YOUNGER DRYAS IMPACT**

There is a hypothesis that proposes that approximately 12,800 years ago, fragments of a large comet or asteroid struck the Laurentide ice sheet and surrounding areas of North America, triggering the ~1,200-year Younger Dryas cold period and contributed to the extinction of Pleistocene megafauna. (Firestone, 2007). The hypothesis was first formally proposed by Firestone, West, Kennett, and colleagues in 2007, and despite early criticism based on disputed replication attempts, the hypothesis has been substantially corroborated by independent research over the subsequent seventeen years with a deluge of new supporting evidence over the last several years especially.

As of 2026, the hypothesis is supported by scores of peer-reviewed articles in dozens of journals from hundreds of researchers who have identified some combination of synchronous impact proxies (nanodiamonds, exotic microspherules, platinum enrichment, meltglass, shocked quartz, and elevated iridium) at more than fifty Younger Dryas boundary (“YDB”) sites on five continents. (Sweatman, 2024), (Powell 2022), (Sweatman 2021). A 2023 article in the journal *Science Progress* compared the premature rejection of the YDIH to the premature rejection of continental drift and meteorite impact cratering – both of which were dismissed for decades before achieving scientific consensus. (Powell, 2022).

The established YDB impact proxies, confirmed across dozens of sites, include: iron-rich and glassy microspherules (cooled metallic droplets formed under extreme temperatures ) which have been identified in peak abundance at the YDB layer at sites across North America, South America, Europe, Asia, and the Greenland ice sheet.

These microspherules consist primarily of melted terrestrial material. Similar microspherule layers have been accepted as evidence for cosmic impact events at twenty-eight other confirmed impact sites. (Moore, 2024), (Wittke, 2013).

Anomalous peak abundances of platinum (a rare element abundant in asteroids and comets but scarce in Earth's crust) have been established as a chronostratigraphic marker for the lower YDB dating to 12,800 years ago. Platinum anomalies have been confirmed at sites including Wakulla Springs, Florida; White Pond, South Carolina; Parsons Island, Maryland; Newtonville, New Jersey; Flamingo Bay, South Carolina; and in Baffin Bay marine sediment cores. (Moore, 2024).

In 2024, Moore, Kennett and colleagues reported the first identification of shock-fractured quartz at multiple YDB sites in the eastern United States. The shocked quartz grains display fissures filled with amorphous silica (meltglass), similar to shocked grains found at twenty seven accepted impact craters (including Meteor Crater, Chesapeake Bay, Chicxulub, and Manicouagan) and produced in eleven laboratory shock experiments.

Unlike the parallel planar deformation features typical of direct-impact craters, the YDB shocked quartz displays irregular, web-like fracture patterns with subparallel and subplanar deformations consistent with lower-pressure “touchdown” airbursts – explosions occurring above the ground but close enough that the shockwave and heat melt and fracture surface sediments. (Moore, 2024).

High-temperature meltglass has been found at multiple YDB sites. At Abu Hureyra, Syria (the oldest known archaeological site catastrophically destroyed by cosmic impact) meltglass comprising 1.6 wt.% of bulk sediment was found with melted grains of quartz, chromferide, and magnetite indicating exposure to temperatures of 1,720°C to over 2,200°C. The meltglass's low water content (0.02–0.05% H<sub>2</sub>O) is consistent with tektite formation processes and inconsistent with volcanism or anthropogenic fire. (Moore A. M., 2020).

Bunch et al surveyed multiple YDB sites and identified impact patterns including siliceous scoria-like objects, abundant micro spherules, corundum, mullite, and suessite (Fe(3)Si), melted SiO(2) glass, or lechatelierite, with flow textures (or schlieren) that form at > 2,200 °C, and particles

with features indicative of high-energy interparticle collisions. These findings supported a theory of multiple impactors with cosmic ejecta and creating concurrent airburst. (Bunch T.E. 2012).

Cubic diamonds, n-diamonds, i-carbon, and lonsdaleite-like crystals have been identified in the YDB layer at multiple sites. The only previously known co-occurrence of nanodiamonds, soot, and extinction in the geological record is the Cretaceous-Tertiary (K/T) impact layer associated with the Chicxulub impactor. (Kinzie, 2014). (Kennett D. , 2009).

The comet responsible for the Younger Dryas event is estimated to have been approximately 100 kilometers wide, much larger than the object responsible for the 1908 Tunguska event in Siberia, and it is theorized to have fragmented into thousands of pieces before impact (Firestone, 2007). The 2-3-km thick Laurentide ice sheet would have taken the impact initially, changing the typical dynamics of meteorite impacts and would have foreseeably left behind exactly what we find in Boston.

The fragmented comet is hypothesized to have struck or exploded over the Laurentide ice sheet in northeastern North America, with individual fragments creating “touchdown” airbursts – explosions at low altitude that generate devastating shockwaves, extreme overpressure, and temperatures exceeding 2,000°C at ground level without necessarily leaving identifiable craters in the surface geology (Moore, 2024).

Computer simulations have confirmed that cometary fragments can explode before reaching the ground while generating shockwaves capable of widespread surface impacts. (Moore, 2024). The 2–3 km thick Laurentide ice sheet would have absorbed the initial energy of the impacts, changing the typical dynamics of meteorite impact events and explaining the apparent absence of traditional crater morphology. The shockwave from such an event would have created “intense winds traveling across North America at hundreds of kilometers per hour, accompanied by powerful, impact-generated vortices.” (Firestone, 2007).

The impact would have destabilized the glacial ice sheet, triggering the collapse of massive glacial meltwater lakes and subsequently disrupting the Atlantic Meridional Overturning Circulation, which initiated the Younger Dryas cooling. (Wu Y. , 2013). This “airburst on ice”

mechanism is directly relevant to the Boston Basin, where the Laurentide ice sheet is believed to have been around two km thick at approximately 12,900 years ago.

If fragments of the hypothesized comet struck the ice sheet over what is now the Boston Basin, the resulting thermal and collision reactions would have simultaneously rapidly melted overlying ice, vaporized and obliterated surface rock into fine particles, driven ejecta and meltwater into the fractured substrate, created high-pressure shockwaves that compacted and deformed subsurface materials, and initiated hydrothermal circulation through the newly fractured and heated rock.

It is now well-established in the scientific literature that bolide impacts into hydrous planetary bodies initiate transient hydrothermal systems. These impact-generated hydrothermal systems have been extensively documented at terrestrial craters including Chicxulub (180 km diameter), Sudbury (~200 km), Puchezh-Katunki (80 km), Haughton (23 km), Ries (24 km), Manson (35 km), and Vargeão Dome (12 km)., (Alsemgeest, 2026), (Svensson, 2025), (Osinski, 2013), (Zurcher, 2004), (Naumov, 2002).

At Chicxulub, the best-preserved large impact crater on Earth, International Ocean Discovery Program drilling confirmed that the impact-generated hydrothermal system chemically and mineralogically altered approximately  $1.4 \times 10^5$  km<sup>3</sup> of Earth’s crust. Peak hydrothermal temperatures reached 300–400°C, and independent paleomagnetic signatures indicate the system persisted at temperatures possibly above 250°C for at least 200,000 years. The predominant alteration assemblages consist of Fe-Mg clay minerals, zeolites, alkali feldspars, calcite, sulfides, sulfates, opal, and Fe-Ti oxides. Alteration is especially intense proximal to lithologic contacts and in areas of high porosity. (Simpson, 2020), (Kring, 2020).

At the Ries impact structure in Germany, the contact between hydrothermally altered impact melt-bearing breccia and post-impact crater lake deposits contains kaolinite, illite, and smectitic clay minerals with clast-wrapping textures, framboidal pyrite, iron oxide staining, and structural alterations including deviations of laminae, sedimentary load structures, and faulting. (Svensson, 2025). At Vargeão Dome in Brazil, kaolinite and halloysite form in impact-reactivated hydrothermal veins within fractured basalt alongside hematite, goethite, and other

alteration minerals. (Alsemgeest, 2026).

Thermochemical modeling of impact-generated hydrothermal systems demonstrates that for a range of host rock lithologies, the principal alteration minerals produced by impact-heated water-rock interaction include feldspar, zeolite, chlorite, clay minerals (specifically nontronite and kaolinite), and hematite – with kaolinite forming as a consistent product across basaltic, lherzolitic, and ultramafic precursor compositions. (Schwenzer & Kring, 2013).

### **BOSTON'S MYSTERIOUS MASS DEBRIS EVENT ~12,900 YEARS AGO**

In the 1830s, Hitchcock noted the devastation to Boston's landscape occurred recently, around when it was "nearly its present elevation above the ocean." He also addressed a "hypothesis to which some have clung" where "the shock of a comet" may have caused many of these "diluvial actions" however he did not believe it was possible at that time specifically because the science at that time thought that comets were "composed of matter thinner and lighter than air." (Hitchcock, 1833), (Hitchcock, 1841).

In 2011, Barosh explained that earthquakes in New England have been ascribed to volcanism, glacial rebound, thrust fault reactivation, and also "rebound from a meteorite impact." (Barosh P. J., 2011).

Barosh also noted that "the origin of glacial deposits [in Boston] was a mystery to early geologists and one geologist even considered them debris from a comet impact" citing (Donnelly, 1883) and adding "note: a version of the comet theory has been resurrected by West et al. [2006] and several colleagues who believe a comet or asteroid exploded over central Canada 12,900 years ago to trigger the last Younger-Dryas, glacial event, which is known in Boston as the Lexington Substage..." (Barosh P. J., 2011).

The destruction of Boston around Younger Dryas is referred to as the Lexington Substage and the term "Lexington Outwash" is used to describe the debris flow during that time, including the laying of the thick clay. "The sea level was relatively low following the deposition of both the Boston Clay and the Lexington outwash, although whether or not there were two separate episodes of lower sea level is not known." (Upson, 1964).

In Boston the "Lexington Substage" refers to a Younger-

Dryas-timed "glacial ice re-advance extended from the north and invaded just into the western and northern edges of the city ... where it pushed up two moraines (moraine deposit) near Fresh Pond, and sent tongues of sand and gravel, and clay outwash down river systems and onto low areas of the marine clay. Lake clay, in-part-reworked marine clay, filled in behind the moraine during the retreat along with outwash sand farther north." (Barosh P. J., 2011). The clay across Boston Harbor "was submerged about 10,000 years" (Kaye and Barghoorn, 1964).

It was during the Younger Dryas "period during which the level of the sea rose following deposition of the Lexington outwash and during which the sequence of peat, marine silt, and peat of Judson was laid down" and also "corresponds to the episode of estuarine deposition" (Upson, 1964).

The "terminal readvance" of the glacier previously attributed to the "Lexington Substage... only extended into valleys north and west of Boston" but not Boston itself. "This substage appears to coincide with a short, abrupt cooling and glacial re advance about 12,900 to 11,500 years ago named the Younger Dryas in Europe." (Barosh P. J., 2011), (Judson, 1949).

The hypothesized Younger Dryas impact event would have "created a devastating, high-temperature shock wave with extreme overpressure, followed by underpressure, resulting in intense winds traveling across North America at hundreds of kilometers per hour, accompanied by powerful, impact-generated vortices." (Firestone 2007).

A Younger Dryas Impact interpretation of Boston validates the modern, emerging hypothesis that the Younger Dryas impact event as it provides the first "ground-zero" impact site. The hypothesis suggests the impact consisted of multiple bolides to the Laurentide ice sheet, centered in the northeastern United States, and which triggered a massive vapor/shock event, rather than effects typical with direct land impacts. (Y. Wu 2013).

Boston easily represents a foreseeable outcome for that impact, would provide the first case study to develop formal criteria to identify other impact sites in the North Eastern United States, and this hypothesis is the best and only coherent explanation for Boston's geology. No natural process produces all these anomalies simultaneously – all within a single basin with radiocarbon dates of 12,200–14,400 years BP – has no known explanation other than



bolide impact and its consequent effects.

### **SURFICIAL & BORING LOGS DOWNWARD-DIRECTED IMPACT DAMAGE**

“Shock-induced damage beneath craters formed by oblique impacts is stronger in the downrange direction than in up range direction... Stress wave measurements in oblique impact experiments showed that the magnitude of peak stress is about twice as large in the target in the downrange direction” (Kenkmann, T., et al., 2014).

Nearly all systematic geological investigation of the Boston Basin has been conducted in deep infrastructure tunnels: the Main Drainage Tunnel (MDT), the City Tunnel Extension, the Inter-Island Tunnel, the NMRT. These projects penetrated well below the bedrock surface into the deeper portions of the argillite and underlying formations. The geologists working these tunnels encountered fractured argillite with some alteration, some intrusions, and interesting mineralogy—but they were seeing the basement of the destruction zone, not its epicenter. The deepest, least damaged rock gave the impression that the basin was well characterized.

The worst destruction is concentrated at and near the bedrock surface: the zone where the impact energy was highest and the hydrothermal fluids had the greatest access. This is exactly the zone that is buried under fill, clay, and buildings, where no systematic geological investigation has ever been conducted. The shallow borings that encountered the worst damage (the Gillette wells, the Seaport borings, the Ames Building drill, the Stone & Webster site, the MIT campus) were engineering projects. Their data went into geotechnical files to design foundations, not into geological papers to characterize the basin. The engineers saw finger-crushable bedrock, white clay with boulders, RQD of 0%, and they designed around it. No one asked why the bedrock was destroyed.

The result is that the most important evidence sits in boring logs that geologists have never assembled. Kaye (1967) recognized this: nine of thirty-three NMRT borings encountered “badly altered material” and no one noticed during the project. The alteration “did not show up in MDT” because the MDT was deep enough to be below the worst of it. Boston’s geology was studied from the bottom up, and the bottom told a fundamentally different story than

the top.

Kaye’s (1967) State Street Tower diabase shows a complete gradient from “partly altered hard dark-gray diabase” to “soft white material.” This gradient exists within a single rock body. The outer margin—nearest the fracture or fluid pathway—is completely altered; the interior is only partially altered. This is a preserved fluid front: the boundary between rock that was fully penetrated by hydrothermal fluid and rock that was only partially reached. At confirmed impact structures, such fluid fronts are used to calculate fluid temperature, flow rate, and duration. This single diabase body contains sufficient information to model the Boston Basin’s hydrothermal system.

### **BORING LOGS & ROCK QUALITY DESIGNATION**

The most consequential error in the conventional model is the treatment of bedrock as the bottom of the contamination problem. In the standard CSM, contamination is assessed down to the bedrock surface and no further. Bedrock is assumed to be intact argillite with negligible permeability. The actual bedrock has Rock Quality Designations (ROD) of 0%=25% around the basin center—more fractured than the till above it. Zero intact pieces longer than a hand’s width across twenty-five continuous feet of coring (MW-809B) next to Fort Point Channel. At MW-404B, RQD varies from 0% to 93% over short distances—the transition from the damage zone to relatively intact rock.

At confirmed impact structures, RQD measurements are used to map the damage zone: RQD decreases toward the impact center. If RQD were mapped systematically across the Boston Basin, the resulting contour map would delineate the crater. It also contains fracture-controlled aquifer zones 410 feet thick (East Berkeley Street), with water-transmitting fractures confirmed to 1,000 feet depth (Harrison Avenue).

MW-808DB recorded “calcite healed joints, cross foliation and are offset by microfaults.” The time between fracturing and microfaulting is constrained by calcite precipitation rate in hydrothermal systems and the log records active structural adjustment during ongoing hydrothermal circulation—exactly what occurs in an impact crater during post-impact settling. If these were separate tectonic events millions of years apart, the calcite would have been

recrystallized or dissolved before the microfaulting. (GEI Consultants, Inc., 1998).

MW-808B contained both quartz-healed and calcite-healed joints. Quartz precipitates from hydrothermal fluids above approximately 200°C; calcite predominantly below 200°C. (GEI Consultants, Inc., 1998). Their presence in different joint sets at the same location records a system that cooled through the quartz-calcite transition: early fractures (formed during or immediately after impact) filled with quartz while the fluid was hot; later fractures (from crater settling) filled with calcite as the fluid cooled.

The microcrystalline siderite at 0.002 mm grain size Kaye records “rapid quenching” of iron-carbonate-saturated fluid—slow formation would produce larger crystals and “the iron silicates of the original rock (mostly augite and biotite) were completely altered to siderite; the feldspars are somewhat less altered but are densely clouded with sericite and kaolinite”. (Kaye, C. A., 1967).

Siderite was also reported in Cambridge, north of Charles River, to a depth of 300 ft, with a 150ft section of “soft-light-purplish-gray kaolinized argillite.. underlain by soft sideritized magnetite-bearing fine grained tuffaceous rock.” (Aldrich, 1970). The Boston geological system experienced rapid thermal pulses followed by cooling, consistent with episodic fluid release during crater adjustment.

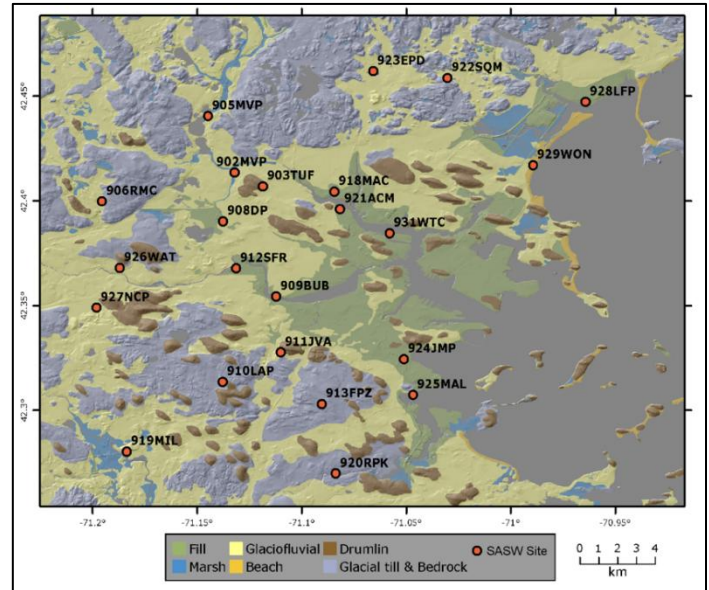
## TRANSLATING GLACIAL TERMINOLOGY TO BOLIDE IMPACT SCIENCE

In 2011, Barosh wrote that “the thick glacial deposits of the Boston Basin are probably the most complex in the country.” (Barosh P. J., 2011). This is likely because they are not glacial deposits – it is bolide impact ejecta and related damage from a bolide swarm hit ~12,900 years ago.

Traditionally, there are two basic models for the sedimentation of the Boston Bay Group, either: “as a glacio-alluvial-lacustrine complex; or as a complex of subaqueous gravity-transported sediment resulting from mass movements (grain flow, debris flow, and turbidity currents” (Rehmer, 1976).

More recently, it has already been found that “the depositional setting of the Squantum ‘Tillite’ appears to be that of a submarine slope/fan setting in an open marine

volcanic arc basin receiving large volumes of poorly-sorted sediment on the mid-latitude active margin of Gondwana” and “no direct glacial influence is apparent.” (Carto & Eyles, 2012). A 2010 paper also found lack of evidence for glacial influence and further noted “the chemical index of alteration... for the non-volcanic rocks requires significant exposure of land surfaces to allow chemical weathering” (Passchier, S. & Erukanure, E., 2010).



Thompson, Eric & Carkin, Bradley & Baise, Laurie & Kayen, Robert. (2014). Surface wave site characterization at 27 locations near Boston, Massachusetts.

We look instead to impact science including impactites and shock metamorphism. In fact, “shock-metamorphic effects are distinct from features produced by normal geological deformation, and they are now generally accepted as unique products of impact event” (French, 1998).

Impactites (rocks produced during an impact event) include distal impactites (microcrystite, microtektite, and tektites) are thrown into the air and generally fall outside the impact site. Proximal impactites can be shocked or unshocked, and vary based on source and process (target rock breccia at the crater floor, cataclastic breccia and breccia with and without melt particles, and melt rock with or without clasts, including crater fill, ejecta blanket, and dikes at the crater floor). (French, 1998).

**THE DRUMLINS, TILLITE, AND DIAMICTITE ARE EJECTA; THE BOULDERS ARE BOLIDES & BEDROCK**  
Most of Boston’s drumlins have argillite boulders underneath and/or within them, with evidence of upward

thrusting of materials. (Barosh P. J., 2011). Around the Site, erratic boulders are embedded in marine clay at the clay-till contact, surrounded by white altered rock (kaolinized argillite). Drumlins sit atop these formations. This stratigraphy – impact-altered substrate with embedded megaclasts, overlain by compacted ejecta mounds – is consistent with impact breccia deposits where target rock fragments settle into disturbed substrate and are overlain by fallback material.

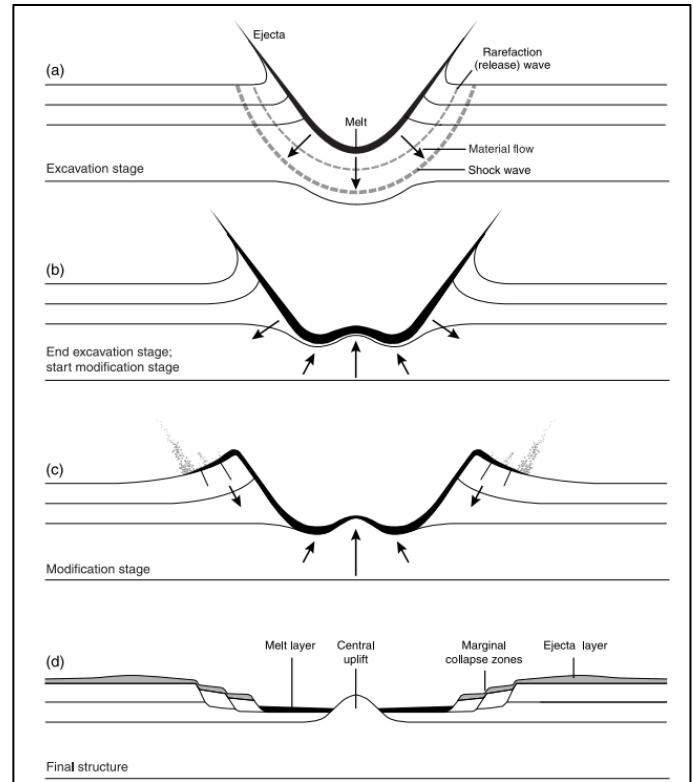
There are unpredictable “outcrops” of argillite reported as “bedrock.” Argillite pebbles, cobbles, and boulders are also present. There is also ~30–40 ft of “extremely coarse cobbly” gravel in this area. Most of Boston’s drumlins have argillite boulders underneath and/or within them, and some show evidence that the materials were thrust upwards. (P. J. Barosh 2011). Around Massachusetts, there are an unprecedented amount of “erratic boulders” on the land, in the sea, and underground. These boulders are sometimes massive in size and found placed in locations where there is no reasonable explanation as to how they arrived.

Around Boston, an apparent false “bedrock” is often found around -70ft with nearby bedrock generally deeper than 100ft, and boulders also frequently found around 70ft. The “refusal” noted in boring reports likely indicates boulders, bolides, and/or bedrock fragments all around 70ft below surface around South Bay and Shawmut Peninsula.

(“For refusal borings, it commonly cannot be determined whether the boring ended on bedrock, a boulder or cobble, or even in some instances on a manmade obstruction...In some areas it is clear that boulder-bearing sediments, such as till or coarse gravel, are responsible for most refusals.” (Kaye C. , Preliminary map of bedrock surface under parts of Boston, Cambridge, and Brookline, Massachusetts, 1970/USGS)).

Boulders are common in bolide impact sites including as bedrock fragments, megaclasts, bolide remnants, and boulder beds (a Chesapeake Bay “boulder bed was formed by a powerful bolide-generated wave train...”).

At Chicxulub, the suevite (impact breccia) consists of polymict breccia containing clasts of variably shocked crystalline target rocks within a matrix of impact-altered material – a description that could equally describe the boulder-bearing, kaolinized, clay-mantled drumlins of the Boston Basin.



*Complex impact structure, (French, 1998).*

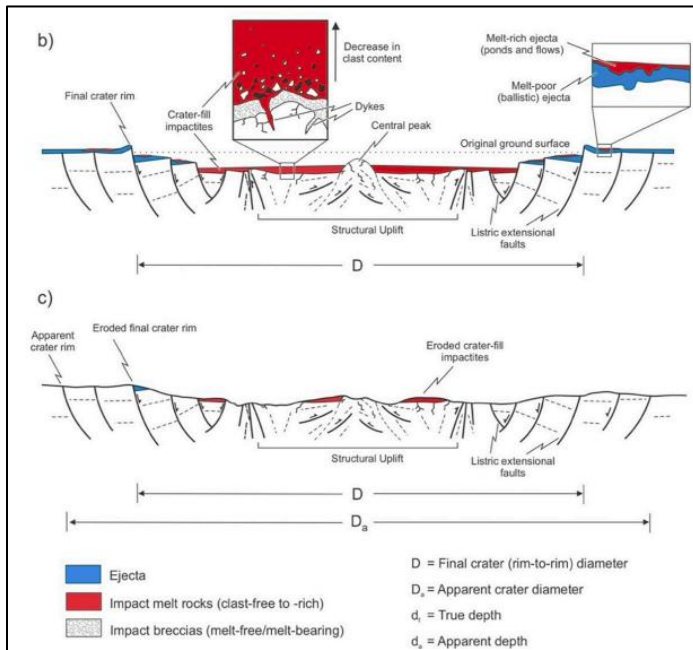
There are extensive “drumlins” around the Great Lakes. These “drumlins” also feature pressure-created “laminae,” filled with “till” that is “rather compact,” and with “numerous” associated “boulders.” (Leverett, 1928). This area also includes the Sudbury impact event with a enormous bolide creating a 120 mile (200 km) crater around 1.8 billion years ago. (NASA, 2021)., (Rousell, 2003).

In Canada, “the collision punctured Earth’s crust, allowing material from the mantle to well up from below and fill the basin with melted rock. Then after a shockwave shattered the surrounding rocks, minerals from the melted rock below infiltrated the cracks.” (NASA, 2021). In New York, around Lake Ontario, is “one of the largest drumlin fields (on the North America continent consisting of some 10,000 drumlins located between Lake Ontario in the north and the Finger Lakes” and “drumlin-like bedforms have also recently been discovered in deep water on the nearby floor of the Rochester Basin in Lake Ontario.” (Kerr, 2005).

Recent evidence also indicates the “tillite” in Ontario which was frequently compared to Boston, and both attributed to glacial activity, is non-glacial in origin. (Molén, 2021).

Glacial transport does not produce shock-hardened boulders. Glaciers transport erratic boulders, but glacial

transport does not quadruple the hardness of igneous rock. The extreme hardness of the Fort Point Channel gabbro-diorite boulder is consistent with shock metamorphism from impact, not with glacial deposition.



*Impact crater*, (Osinski G. R., 2022)

The boulder could also be a bolide fragment – rather than terrestrial rock Gabbro-diorite is compositionally consistent with stony-iron meteorites and many chondrites. Its presence embedded in marine clay at the clay-till contact, with no local bedrock source for Salem gabbro-diorite, requires transport from distance. The MBTA reported they would “never know how deep the thing goes,” suggesting the exposed mass was the surface of a much larger body.

Bolide fragments surviving atmospheric entry are extraordinarily hard and structurally coherent — compressed and hardened by the entry process itself. The extreme hardness is consistent with both shock metamorphism and bolide fragment survival, which are not mutually exclusive: a bolide fragment would be shock-hardened by entry and then shock-metamorphose the surrounding target rock on contact. The boulder was removed in pieces before any geochemical analysis was conducted. (Associated Press, 2003), (Schimek, 2007).

A swarm stony bolide impact site explains the erratic boulders, unnamed faults, mysterious river valleys and/or obstructions, and the otherwise inexplicable drumlins. If we imagine the theorized Younger Dryas bolide event occurring at Boston, we would see bolide impacts occurring

on the massive ice sheets which would cause thermal and collision reactions leading to rapid melting of the ice and extensive vaporization. We would also see bolides make contact with the frozen land under the melting ice.

Maybe there are impact waves that obliterate some of the existing mudstone into ash-like particles, or the bolide itself is obliterated into ash-like particles. Either way, we would see meteor fragments cutting into wet, cold, soft clay and till; with what might look like boulders settling into the clay and wrecked earth. We would see shock waves as the surrounding area is unable to compensate for the new underlying mass must push ejecta up anywhere there is existing open space under the un-melted glacier – deeply compacting the displaced soil and rock into what we call drumlins.

A bolide impact event could be why there are giant erratic boulders in the Fort Point Channel, why the Channel’s path is lined with drumlins, and why Shawmut looks like a drowning person’s hand reaching up for help with only three fingers breaching the water. It could be why the Dorchester Neck looks like it was peeled away from the Shawmut Peninsula and twisted hard to the right; and why the Boston Neck is a strange narrow wedge of clay acting as a reluctant, part-time isthmus while concurrently remaining part of the sea. It could also be why the Shawmut Peninsula’s strange, deformed landform inexplicably lays in nearly perfect obstruction of the Charles River’s outflow.

This impact theory aligns with the modern, emerging hypothesis that the Younger Dryas impact event consisted of multiple bolide impacts to the Laurentide ice sheet, centered in the northeastern United States (Y. Wu 2013). The hypothesized Younger Dryas impact event would have “created a devastating, high-temperature shock wave with extreme overpressure, followed by underpressure, resulting in intense winds traveling across North America at hundreds of kilometers per hour, accompanied by powerful, impact-generated vortices.” (Firestone 2007). The 2–3-km thick Laurentide ice sheet would have taken the impact initially, changing the typical dynamics of meteorite impacts.

One outcrop documented by Kaye (1967) at the western margin of the Boston Basin appears to be a *prima facie* bolide fragment. Kaye tentatively identified it as Brighton Melaphyre but could not determine its origin. Under the



microscope it showed poorly crystallized albite, very fine white mica, chlorite, minute magnetite crystals dispersed uniformly throughout the matrix, and patches of microcrystalline siderite. This is not a volcanic mineral assemblage. (Kaye, 1967).

Kaye's example represents the complete chondrite alteration sequence: chondritic albite incompletely recrystallized, feldspar altered to sericite, olivine altered to chlorite, Fe-Ni metal oxidized to magnetite, troilite converted to siderite. Every mineral. In one rock body. Kaye noted the siderite was secondary alteration formed at the same time as the surrounding kaolinite — meaning this rock body is the heat source for the alteration field around it, not a bystander to it. The megascopic texture Kaye describes — sparse small phenocrysts in an aphanitic groundmass — is the outcrop appearance of chondrules in an interchondrule matrix. The rock must be analyzed for platinum group elements, osmium isotopes, and meteoritic mineral textures.

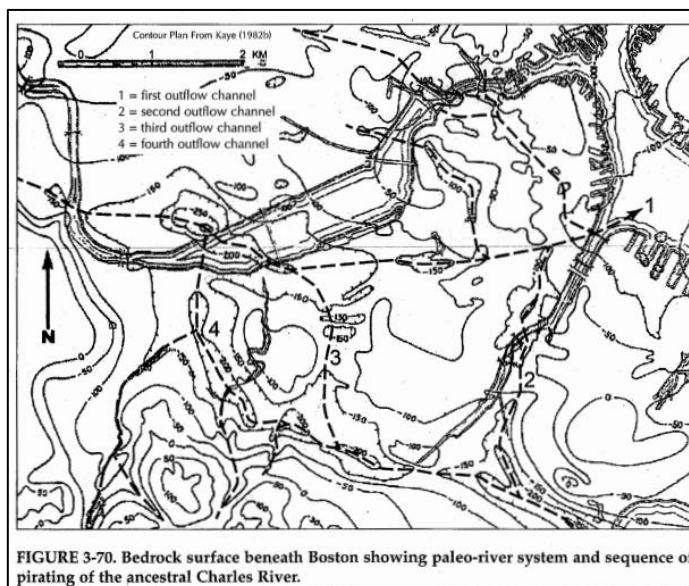
In 2011, Barosh wrote: “many drumlins consist of two tills with a zone of very compact thinly stratified clay and silt in between. Kaye 1984 . Lenses of stratified material found at depth within the till along the east side of Boston form a separating unit, which apparently thickens to the west to form a thick wedge of deformed material” (Barosh P. J., 2011).

The “glacial till” in Boston is “typically a dense, heterogeneous unsorted and generally non-stratified mixture of all particle sizes composed of a clay and silt matrix, with coarser fractions up to cobble and boulder size. The rock fragments are often broken pieces of the underlying bedrock material” (Barosh P. J., 2011).

Rampino's 2017 paper “Are some tillites impact-related debris-flow deposits?” explains that formations designated as “tillites” are comparable to debris-flow ejecta of known impacts “marked by mildly shocked clasts showing evidence of plastic behavior with brittle failure, commonly resulting in multiple, partially displaced fractures, grading into crushed and brecciated clasts” and “these deformation features entail brief periods of high confining pressures, in accord with a hypervelocity-impact origin.” (Rampino 2017). See also, (Oberbeck 1992).

Rampino has argued for an interpretation of “diamictite” and “tillite” as impact debris since 1994 including in NASA

sponsored articles. Over thirty years ago he wrote that “recent calculations of the predicted volume and distribution of impact-generated diamictites suggests that they should be common in the geologic record” and “a few diamictite deposits formerly interpreted as glacial or questionably glacial in origin are already known to be impact ejecta” (M. Rampino 1994). Carto also confirmed a non-glacial origin for Squantum tillite in 2011. (Carto 2011).



*“paleo-river system”* (Barosh P. J., 2011).

“A glacial influence is not readily identified and revolves around early interpretations of the diamictite as being ‘till-like’, the presence of laminated horizons that resemble glaciolacustrine ‘varvites’ and the disputed recognition of ice-rafted dropstones.” (Carto, 2011). The placement of clay and sediment in Boston was confidently described by La Forge nearly a century ago as “incoherent.” (La Forge, 1932 ).

In 1993 Young wrote, “diamictites and associated deposits widely interpreted as glacial, should be reassessed in the light of recent advances in the understanding of impact-related phenomena.” (Young, 1993). In Boston, there's evidence of mass debris at Younger Dryas, but no evidence of glacial presence. (Oldale, 1990).

What was called “glacial till” is impact ejecta and fallback breccia—shattered bedrock with “broken pieces of underlying bedrock material” (Barosh 2011) exhibiting cubic cooling joints up to 50 feet (volumetric contraction of hot ejecta, not glacial compaction) and containing siderite crystals in its pebbles (hydrothermally altered clasts). What was called “drift” dispersed through a 135-degree arc



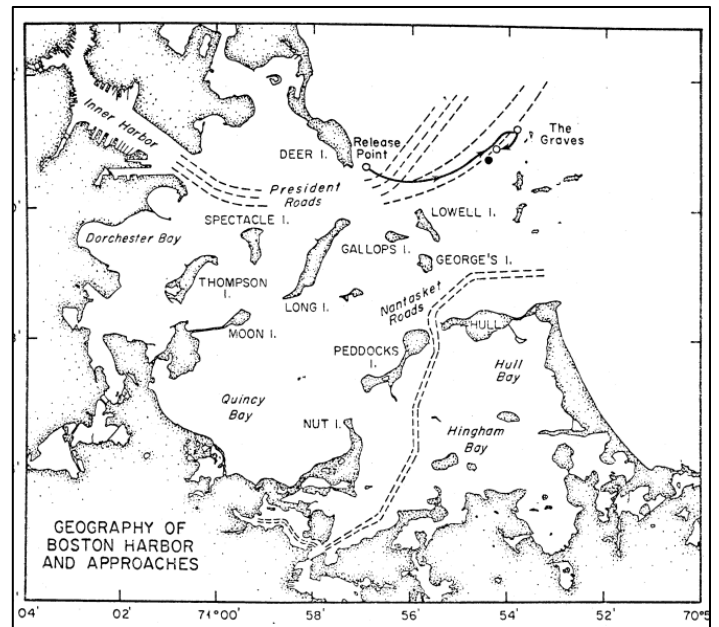
Brenninkmeyer is material radiating from a point source—an ejecta pattern, not an ice-flow pattern. (Brenninkmeyer, 1984 ).

The elongation of the drumlins is also an indicator. La Forge noted they can be located up to 340 feet high , often “form chains or rows,” and have “stony” till. (La Forge, 1932 ). When swarms of bolides impact earth, they’re known to hit in a linear placement generally sorted by weight with the heavier hitting first trailed by the lighter rocks. This leaves a signature of ejecta mounds that presents as a straight or curved line rather than one single crater or mound. These swarms may also results in two or more bolides hitting a small area which can create layered ejecta mounds.

This appears to be exactly what we see with Beacon Hill on the Shawmut Peninsula. Beacon Hill is the only drumlin noted to have two distinct layers of “glacial till” without any explanation how that could have occurred. (P. J. Barosh 2011). The theories have required speculation that Beacon Hill was the only location in Boston able to preserve till from a prior glacial cycle and no other location was able to preserve till from that same cycle. A related theory argues central Shawmut Peninsula has a unique layer of deformed upper till – which would be located directly above the extensive kaolinization and decomposition of argillite below it, which sounds more like an impact then a deposition.

Alternatively to the current theory of “we’ll never know,” the elongated hill shape of the Beacon Hill drumlin occurred due to multiple bolides impacting a small area and stacking their ejecta mounds and leaving a messy, ambiguous landform. That also aligns with the extensive amount of altered rock and clay, and depressed landform, in that specific area. Barosh also directly documented that “the majority of drumlins around Boston rest on bedrock highs or have a core of bedrock.” (P. K. Barosh 1989). That sounds like at least three bolides.

Analysis of the "Trimountain," which included Mount Vernon Hill, Beacon Hill, and Pemberton Hill, found it was “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.” (Aldrich 1970), (Oldale, R.N., et al., 1994).. That sounds like at least three bolides.



*Boston Harbor (Fitzgerald, 1974).*

Boston also has a perplexing number of boulders. In 1905, the Army Corps reported they had already removed least “184,299 cubic yards of boulders and 156 cubic yards of “ledge” were dredged from Presidents Roads to Broad Sound” and “7,755 cubic yards of boulders were also dredged from [other] areas” (Boston Evening Transcript, 1905).

Boulders always seem to show up in boring reports for deeper borings at the Site, generally around some sort of breccia, decomposition, and/or alteration. Currently the only explanation is “glaciers.” This includes chunks of broken bedrock which are then labeled “boulders” without explanation for what broke the bedrock into large chunks and slabs *in situ*. A bolide could and that is an expected result of a bolide impact.

Geologists have also reported placement of the same clay, boulders, and drumlins at issue at heights and depths that they will openly refer to as “confounding.” There’s no explanation for how glaciers and sea water could deposit such things with heights varying over 300ft but occurring simultaneously. These erratic placements are easily explained by bolide impacts with vapor events and tsunamis, where placement occurred from above rather than parallel to ground level.

In the MDT there were a few “scattered boulders” less than two feet in diameter. There are igneous rock intrusions in the argillite with fresh or altered diabase, including olivine, chlorite, kaolinite, pyrite, and magnetite and including

“discordant bodies of irregular shape.” (Rahm 1962).

Stony bolides are literally defined by being “rocky” including frequent “boulder fields” and near earth asteroids are documented to have boulder fields. One could imagine a boulder encrusted bolide hurtling towards Boston would foreseeably litter Boston with said boulders. (Lucchetti 2024).



*“Boulder stalls Silver Line work,” The Boston Globe, April 19 2003, CB9702023A02*

A very large erratic boulder is incorporated into its base in the Fort Point Channel at the MBTA Silver Line crossing. (Leifer 2006). During dredging for the immersed tube placement, a 6 by 6 by 2.4 meter (20 by 20 by 8 foot) glacial erratic boulder was found at the clay-till contact and had to be broken up in place before dredging could be completed. (Woodhouse, D. & Barosh, P.J. 2011).

In 2003 the press reported on it as an “ancient piece of gabbro-diorite, with an estimated size of 8 feet by 12 feet, sits in the middle of 60-foot wide work area and escaped detection despite numerous test borings... Attempts to lift the boulder in a dredging bucket were useless. A diamond-headed chisel broke apart on the rock, which is four times stronger than granite. Drill bits snapped off while taking a core sample. (Associated Press, 2003).

‘The deepest we got was 54 inches,’ said David Ryan, the MBTA’s assistant general manager in charge of construction. ‘We were hoping we were going to pass through the other side, but we didn’t.’ ... Some progress has

been made, Mulhern said. Divers are using hydraulic splitters and an eight-ton chisel to whittle it away. A chunk the size of a conference table has already been knocked loose, he said.” When MBTA was building tunnel tubes for the Silver Line bus service, the test borings did not reveal the “monster rock.” Tons of clay and sediment removed above it and the “rock poked its head out of the earth like a rudely awakened giant.” It was there since 12,000 years ago. Believed to be “glacial erratic” deposited in “Boston’s sea.” Identified as a Salem gabbro-diorite. “Exhibiting what seemed like understandable outrage at trespassers, it snapped off drill bits and cracked a diamond chisel as workers tried to measure its girth.” (Associated Press, 2003).

MBTA said “will never know how deep the thing goes” just focused on part they had to remove to finish the job and removed 8×12 ft mass 4 ft thick. Required coring machine, hydraulic rock splitter, and pounding off pieces with 8-ton chisel – but still took nearly three months. (Associated Press, 2003).



*Casting Basin Excavation: Boulder found imbedded in the clay layer. (February 2, 1997), copyright Don Eyles.*

Another article noted that “the plan called for placing tunnel sections underneath the Fort Point Channel. An unexpected problem was the discovery of a 33-ton boulder directly in the tunnel alignment underneath the Channel. An eight-ton chisel was ineffective to break up the rock; a hydraulic rock splitter was used instead. This problem delayed the project by about a year.” (Schimek 2007).

About eight years after removing a large portion of the boulder, a large sinkhole developed at the surface around where the boulder is located in Fort Point Channel and near South Station. The ground settled “eight feet over eight years” (Boston Globe, 2011).

Glacial transport also does not produce shock-hardened boulders. Glaciers transport erratic boulders, but glacial transport does not quadruple the hardness of igneous rock. The extreme hardness of the Fort Point Channel gabbro-diorite boulder is consistent with shock metamorphism from impact, not with glacial deposition.

### **RAPID BURIAL IN FRESH, FOSSIL-LESS, VARVE-LESS CLAY (IMPACT)**

There is extensive marine clay around the Town of Boston reaching depths of ~125 ft around Back Bay and the waterfront, ~200 feet around Cambridge and Mass. Ave, and ~246 ft around the Charles River. It also descends ~200 ft MSL eastward from the Shawmut Peninsula. The clay is generally soft and greenish gray but can also be yellow where it is weathered and oxidized. The clay may also be blue as seen in areas of Boston where there is also deformation. Where the clay was overlaid by peat, iron reducing bacteria may alter weathered clay back into ~6.5 ft of soft blue clay. (P. J. Barosh 2011).

The clay is approximately 30–45 percent illite, 15–20 percent quartz, and 5 percent chlorite. (Ladd 1971). The water content is around 30% and has a high percentage of fine-grained “rock flour.” (P. J. Barosh 2011). Alterations of the clay generally include kaolinite and/or illite, other alumino-silicates. (Rahm 1962). The clay may contain gravel, pebbles, cobbles, and boulders (up to several tons in weight). A “very large” boulder was found in the clay under Fort Point Channel. The upper clay often has a “prismatic structure” and/or “cubical jointing and fissuring.” The clay is thought to conform to the shape of the basement rocks and may have “deep funnel-shaped downfolds” 330–660 feet across. (P. J. Barosh 2011).

The Shawmut Peninsula was essentially an island and was formed as a ridge of marine clay bordered by the Roxbury Tidal Flats, South Boston Bay, Roxbury, and the Boston Harbor. Most of the clay across Boston may have been formed/laid ~14,000–~12,200 years ago. Around the time of the Younger Dryas, there was a reported abrupt and dramatic lowering of the sea level around Boston, deep

penetration of the clay, and indication of a “rapid burial with marine regression” on the coast. The clay formed at this time often has higher water content, and can reach over 70 ft thick. (P. J. Barosh 2011).

Emerson’s 1817 USGS Bulletin report noted that the clay and slate “appears to have been deposited in a body of fresh water, possibly a lake at the margin of the ice” but that does not explain how such a thing could occur adjacent to the ocean, how the clay would be deposited without glaciers present, or explain the other unconformities. (Emerson, 1917).

Generally when clay is formed it may display “varves” and this occurs more often in freshwater than brackish or marine water. The clay around the Town of Boston and Cambridge “on the whole... seems to lack varves.” (Horner 1929). This has led to great debate as to whether the Boston Blue Clay was created in a freshwater, saltwater, or mixed environment.

Chondrite asteroids are the most common asteroids and they simply consist of clay and silicate rocks, just like Boston’s argillite mudstone and illite clay. Upon impact, the “Boston Blue Clay” would have either been created by obliterated argillite mudstone that was struck by the impact and saturated with immediately melted glacier waters, and/or the Boston Blue Clay is made of the obliterated bolide itself. In either case, there are no discernable fossils because the impact would have vaporized any organic matter.

This interpretation has a longer history than is generally acknowledged. Writing in 1883 — before chondrite mineralogy was understood, before radiometric dating existed, and before impact science was a discipline — Ignatius Donnelly made a specific compositional argument that anticipates the modern hypothesis. Donnelly argued that the fine blue clay of the drift was composed of ground granite from a destroyed cometary body, separated by particle size during its passage through space, with the feldspar-derived fraction producing the light-colored white and blue clays and the mica and hornblende fractions producing darker varieties. (Donnelly, 1883).

Donnelly noted that no grinding process on Earth’s surface — not glaciers, not rivers, not wave action — was adequate to produce the volume and fineness of the drift clays; and that the clay was distinguished from all other terrestrial

deposits by being entirely destitute of organic remains. (Donnelly, 1883).

These observations — the extraordinary volume and fineness of the clay, its fossil-lessness, its composition from ground silicate minerals — remain accurate descriptions of the Boston Blue Clay. What Donnelly could not know was that chondrite asteroids are themselves composed largely of clay and silicate rocks, and that a chondritic impactor obliterated on contact with the Laurentide ice sheet would produce exactly the material he was attempting to explain. The specific mechanism he proposed was wrong; the observation that drove it was not.

One outstanding mystery of Boston's argillite and clay is the historic difficulty in dating it — with some geologists vaguely complaining about an extreme range of results but not providing the public any further details. Chondrite asteroids are “among the most ancient objects in the solar system.” (NASA 2026). Yet, meteorite impacts also reset most of the U-Pb dates for impacted rocks. (Walton 2022), (C. Walton 2023).

If Boston's clay is partially from chondrite bolide deposits and some, but not all, of the rock dates were reset — then the dating results could assumably produce a range of results that are extremely old (billions of years), and also quite new (~12,900 years), and all of which scientists may assume had to be errors.

Scientists have been unable to explain how Boston's deep, thick, and extremely fine clay were formed in situ. In the Montagnais Crater, the impact vaporized the sea, fractured and melted the sea floor with the ejecta, and created glass at the point of impact. At the Mjølner Crater, the impact created a blanket of ejecta, but it was resuspended into sediment by the waves and rapidly transformed into gel. (Dypvik 1998), (Moore 2024). These formations also present as being created in oxygen-poor, extreme environments. This all fits the deep and mysterious clay and argillite in the Boston Basin around the Site.

The deep, thick, extremely fine, varve-less, and fossil-less marine clay around Boston was deposited approximately 14,000–12,200 years ago, with a “rapid burial with marine regression” coinciding with the onset of the Younger Dryas. (Barosh P. J., 2011). At the Mjølner Crater, the marine impact created a blanket of ejecta that was resuspended into sediment by waves and rapidly transformed into gel. (Moore

C. L., 2024), (Dypvik, 1998).

The absence of varves indicates the clay was not deposited through normal seasonal glacial processes. The absence of fossils indicates that organic material was vaporized or that the depositional environment was too extreme for preservation — both consistent with impact-generated sedimentation in an environment of extreme temperature and pressure.

Glaciers produce varved clay. Normal glaciolacustrine and glaciomarine processes produce varved (layered) sediments through seasonal variation in meltwater discharge. The absence of varves in the Boston Blue Clay has been a longstanding mystery. Impact-generated sedimentation (either from obliterated target rock or from bolide material deposited in a catastrophic marine environment) does not produce seasonal varves because it is created all at once rather than as part of a longer-term ongoing process.

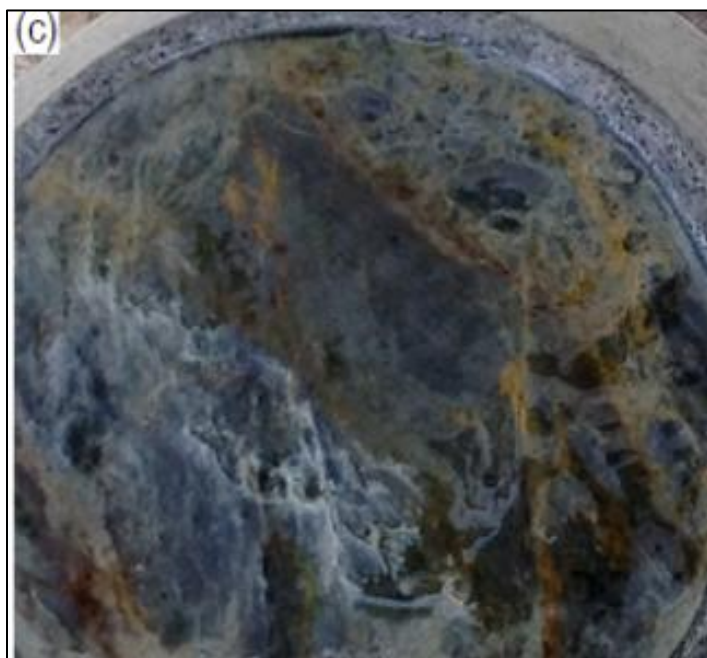
### **TUFFACEOUS ARGILLITE IS SUEVITE (IMPACT BRECCIA)**

The Cambridge Argillite is consistently described as “tuffaceous”—containing volcanic ash beds, accretionary lapilli, and fine-grained material interpreted as ash-fall deposits. (Thompson M. D., 2020), (Thompson M. , 2000). demonstrated that the immobile trace element ratios of the argillite “fall largely within the field of andesitic rocks on plots of Zr/TiO<sub>2</sub> and Nb/Y,” confirming what appeared to be a volcanic ash signature.

There are frequent reports of igneous altered rock (i.e., kaolinite) and fragile igneous formations (i.e., ash, tuff) created apparently in situ placed in young marine clay and silt (formed less than ~15,000 years ago). The argillite of the Boston Basin has “many zones of penecontemporaneous deformation” and “small depositional unconformities are common.” (Kaye 1984). All of these are indicators (“unusual “volcanic” breccias and other deformed rock,” “papers that describe strange breccias and unusual “volcanic” rocks” etc.) for “unrecognized impact structures” where shock effects may be identified well after the original documentation (French, 1998).

The accretionary lapilli documented by Thompson, was “inversely graded from silt-size crystals at the base to coarser accretionary lapilli or volcanic ash clusters at the top” (Thompson M. , 2000) —which forms in volcanic

eruption columns and in impact vapor plumes. They are morphologically identical from both processes. (“the suevite from the Ries Crater was considered to be a volcanic tuff for nearly two centuries” (French, 1998)).



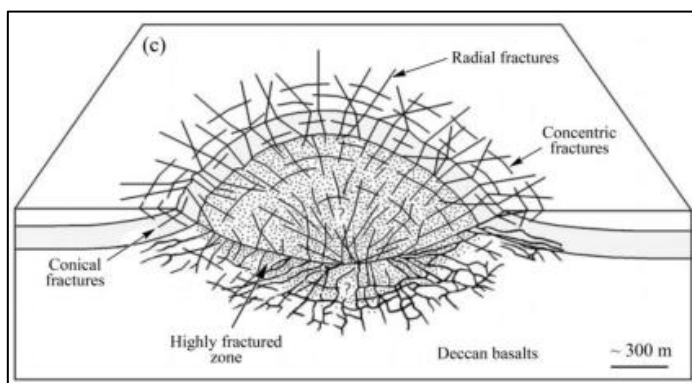
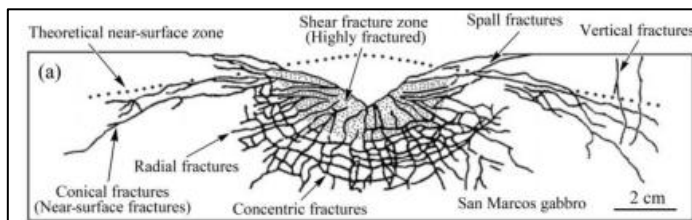
“*decomposed argillite*,” (US Army Corps of Engineers, 2015).

At the K-Pg boundary, accretionary lapilli are a primary impact indicator. In the calcareous argillite at Mystic River Quarry, calcite alteration was so extensive it “obliterated textures” while the beds “nevertheless retain the trace element signature of less altered ash.” (Thompson 2000). Complete textural destruction with trace element preservation documents total recrystallization—consistent with impact-generated carbonate flooding of the host rock.

Billings (1976) described the alteration products as “white, ashy, tuffaceous, glassy, and being extremely fragile.” These are the descriptors of suevite alteration: white from kaolinization, ashy from fine-grained matrix, tuffaceous from glass-bearing texture, glassy from preserved melt phases, fragile from pervasive fracturing. The “tuffaceous argillite” of the Boston Basin warrants re-examination as potential suevite—impact breccia that has been classified as volcanic because the methods used to characterize it cannot distinguish between the two origins, and no one has looked for the distinguishing features: shocked minerals, meteoritic signatures, or chondritic mineral chemistry.

The polymetallic sulfide assemblage deposits from 200–400°C fluids; it is distributed as accessories throughout the formation (Thompson 2020). Coarsely crystalline kaolinite

(0.3 mm—150 times larger than weathering kaolinite) forms from hydrothermal fluids above 175°C (Kaye 1967). Anderson (2008) estimated bulk recrystallization at 175–250°C. In the fracture networks, quartz-healed joints (precipitating above ~200°C) formed before calcite-healed joints (precipitating below ~200°C)—both are present at MW-808B, recording the cooling transition.



*Impact breccia fracture patterns* (Hossain, 2015).

This is a thermal decay curve: >700°C → 400–600°C → 200–400°C → 175–250°C → 100–200°C → ambient, recorded in six independent mineral systems. The spatial pattern matches: titanite (highest T) is basin-wide; alteration intensity increases toward the basin center (Ross 1990); Cape Ann dikes are “generally less altered” than Boston Basin dikes. A single heat source at the basin center, cooling outward and downward over time.

The temperature-dependent minerals documented across the basin record a single hydrothermal system cooling from extreme temperatures to ambient. Myrmekite formation requires 400–600°C; it is present in the argillite (Thompson 2020). Titanite forms at 400–700°C; it is universal across the basin (La Forge 1932). Epidote forms at 200–400°C; it occurs in altered dike zones (Ross 1990).

Ross (1990) documented that Boston dikes have anomalous chemistry relative to regional Eastern North American dikes: higher TiO<sub>2</sub>, higher K<sub>2</sub>O, lower SiO<sub>2</sub>, lower MgO. These anomalies are typically interpreted as evidence of a “different magma source.” But if the dike magma intruded through impact-altered host rock, it would have absorbed



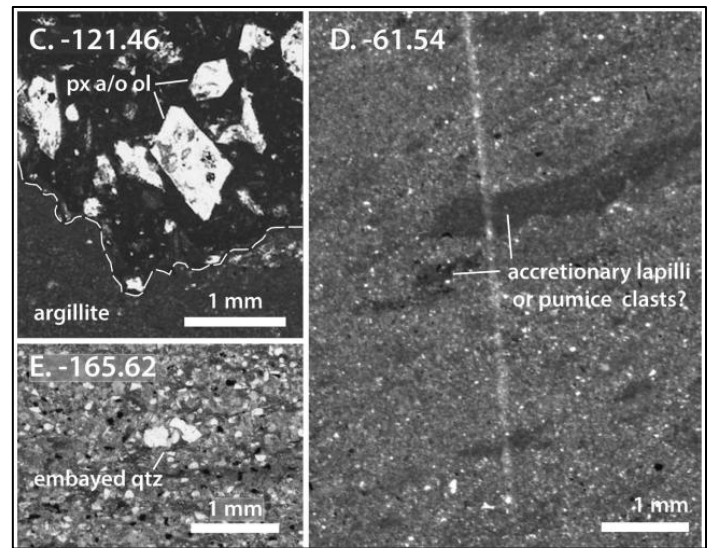
the chemistry of that host rock.

Yet, the most recent documented igneous intrusions would have been formed hundreds of millions of years ago. There are only a handful of geological processes which are capable of creating igneous intrusions. This includes: volcanoes (but there are no active volcanoes anywhere near the Site and these intrusions are limited/localized), hydrothermal activity (but the underlying argillite is ~15,000 feet thick and there is no known hydrothermal activity in or under it), and bolide impacts.

Rahm (1962) described the MDT igneous bodies not only by their anomalous mineral assemblage but by their physical form: "discordant bodies of irregular shape." Normal igneous intrusions are not irregular — dikes are tabular, sills are sheet-like, volcanic necks are roughly cylindrical. Discordant bodies of irregular shape carrying a chondritic mineral assemblage — fresh olivine, chlorite, kaolinite, pyrite, and magnetite — are the morphology of impactite fragments and bolide remnants embedded in target rock. At confirmed impact structures, irregular bodies of exotic composition embedded in target rock are used to map impactor material distribution through the crater and ejecta field. The MDT bodies have been classified as igneous intrusions because that was the only available framework. They are candidates for the same reinterpretation as the Kaye Locality 1 outcrop. (Rahm, 1962).

The conventional glacial interpretation of the Boston Basin's geology does not account for the convergent anomalies documented above. Specifically that glacial processes do not produce kaolinization. Glaciers erode and transport rock; they do not heat rock to 175–350°C along fault-controlled pathways to produce kaolinite at depths exceeding 300 feet. ("Intensive alteration has occurred in some areas to depths of 300 ft. or more" (Aldrich, 1970)).

The only geological processes capable of producing the kaolinization pattern documented in the Boston Basin are volcanism (for which there is no evidence in the last 400+ million years in this area), tectonic hydrothermal activity (for which there is no evidence in the 15,000+ feet of underlying argillite), or bolide impact-generated hydrothermal circulation.



*Boston argillite samples, (Thompson M. D., 2020)*

"Aphanitic" argillite was identified around A Street in South Boston in 2022. Boring GT-10 reported the bedrock at around 71 ft and that it was laminated, covered in clay, and "decomposed" and "weathered." At 75 ft it "crumbles easily with light finger pressure," at 80ft it is "fractured," and around 86ft it is "weathered, gray, aphanitic." (Haley & Aldrich, Inc, 2022).

Around 91ft the "very thin" bedding dips with "joints dipping at moderate to high angles," "planar," and "discolored to decomposed." At 96ft it is "very brittle," at 101-109 ft there was no recovery due to complete weathering. At 109ft it was again "aphanitic" with "indistinct" bedding and joints. From 100ft-110ft the RQD is marked "0." (Haley & Aldrich, Inc, 2022).

Nearby around Seaport Square and 391 Congress St., 2019 borings returned "tuffaceous" and "aphanitic" argillite. The bedrock was weathered down more than 30 ft and covered in "glacial till," with clay, cobbles, and various amounts of gravel that was "well bonded in situ" (HA19-A8 and HA19-D8). (Haley & Aldrich, Inc., 2019).

Boring HA19-D8 also noted the presence of a "boulder" at 101.-103 ft, below "marine deposits" and above the top of "decomposed bedrock" around 112ft, with a collapsed borehole around 109 ft. At 112ft was "severely weathered, decomposed tuffaceous" that "severely weathered, decomposed tuffaceous" (Haley & Aldrich, Inc., 2019).

Around Fan Pier, in 2008, "aphanitic" argillite was found around 120 ft, under "glacial till" and gravel and 125-130 ft as "aphanitic" and "severely" and "completely"

“weathered.” At 130 ft the rock is “extremely fractured.” At 160ft it is weathered, fractured, “steeply dipping” with “gray aphanitic argillaceous sandstone” and “presence of former fractures that have ‘healed.’” (B103, B118). (McPhail Associates, Inc., 2008).

Reports describe tuff things like: “lapilli tuff beds and reworked ash in turbidites.” (Carto & Eyles, 2012). What was called “tuffaceous argillite” may be suevite—impact breccia indistinguishable from tuff by the methods used to classify it. What Dana called “phosphorescent quartz” that is “very hard” and “exhales a peculiar odor” (Dana, J.F. & Dana, S.L., 1818), is shocked quartz exhibiting triboluminescence from lattice defects.

Dana (1818) also noted that argillite “is cut into rhomboidal tables. The rents are sometimes separated a few inches from each other, and the interstice is filled with a kind of breccia, formed of angular fragments of Argillite, cemented by ferruginous clay.” Angular argillite fragments cemented by iron-rich clay filling fractures in the rock is a hydrothermal/impact breccia feature — the same process described for suevite and impact breccia globally.

Suevite—impact breccia containing glass fragments, shocked minerals, and melt particles in a fine-grained matrix—is macroscopically indistinguishable from volcanic tuff. Both contain: glass fragments or their alteration products; fine-grained matrix; mixed-lithology clasts; and accretionary structures. Impact melting of average continental crust produces andesitic bulk composition because average continental crust is andesitic. The trace element method used to identify “volcanic” origin cannot distinguish between volcanic ash and impact-processed crust. The method identifies composition, not process.

High  $\text{TiO}_2$ : the magma picked up titanium mobilized by impact hydrothermal alteration. High  $\text{K}_2\text{O}$ : the magma picked up potassium redistributed by the hydrothermal system. Low  $\text{SiO}_2$ : silica had been removed from the host rock by prior hydrothermal leaching. Low  $\text{MgO}$ : magnesium had been stripped by alteration. The Boston dikes are not from a different magma source. They are from the same regional magma that was contaminated by passage through impact-processed rock. Their “hybridized” character and xenocrystic plagioclase and microcline (Ross 1990) are samples of the impact-altered substrate, preserved in the dike like insects in amber.

What was called “deep weathering” is hydrothermal destruction: kaolinite veins, coarsely crystalline kaolinite 150 times larger than weathering products, “aphanitic” mudstone, mineral-by-mineral replacement controlled by host rock chemistry, and alteration at 300 feet depth that no surface process can reach. Around the Sudbury meteorite impact structure, there are “in situ” “breccia bodies in the footwall” which “consists of subrounded fragments set in a dark, fine-grained to aphanitic matrix” with “irregular-shaped bodies or dikes that range in size from mm to km scale.” (Rousell, 2003).

### **FRAMBOIDS & LAMINAE ARE MICROSPHERES & PRESSURE-WAVE LIQUEFACTION**

Boston’s argillite is often reported as having a “dark laminae” which in one case had “abundant triturated organic matter in which no organic structures were recognizable.” (Rahm 1962). The laminae reported in Boston Harbor rocks was “millimeter scale” and “defined by horizons varying in grain size or crystal content.” (M. D. Thompson 2020).

In 1982, a potential fossil was reported in the Cambridge argillite and theorized to be an acritarch of the cyanobacteria *Bavlinella cf. faveolata* found near Harvard Square and Mass. Ave. in Cambridge. This assumed fossil was referenced to provide the first estimate for the timeline of formation of Boston argillite prior to U-Pb dating. (P. J. Thompson 2014).

Kaye (1984) examined it and reported “abundant minute, opaque spheres” with “very thin coating of pyrite” in Cambridge argillite. These were tentatively interpreted as possible microfossils but were never confirmed organic. Their subspherical morphology, size range, and iron-rich composition are consistent with microspherules—cooled metallic droplets documented at 50+ YDB sites worldwide. Additional pyrite-coated subspherical bodies are documented throughout the formation.

In 2008, three argillite rock samples with ring-like structures were obtained around Boston Harbor and examined with a petrography microscope and a Scanning Electron Microscope. The ring-like structure cross sections had “thin, dark... laminations” but no sulfur or carbon was found, making it unlikely to be a pyritized layer. The dark laminae was found in “varying thicknesses” that

“interbraid with one another,” and the laminae sometimes appeared to be weakly reflective. (Anderson 2008).

One of the three rocks had small (20–30  $\mu\text{m}$ ) spherical pyrite framboids with iron and sulfur. The pyrite grains were subhedral cubes or semi-spherical, with a width of no more than 1–2  $\mu\text{m}$ . In one slide the crystals had dark centers rich in iron and poor in sulfur, the grains that were triangular or rhombohedral, and appeared to be secondary hematite (Anderson, 2008).

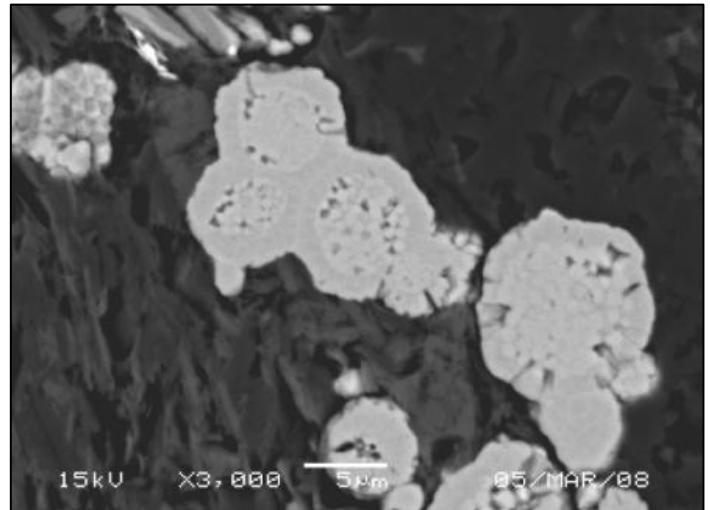
Alterations include quartz altered to chert, and feldspar altered to sericite or unknown clay. One sample had dark laminae from a slightly reflective pale yellow mineral rich in titanium (Ti) and silica (Si) which may be titanite/sphene ( $\text{CaTiSiO}_5$ ). No framboids were found in the ring-like structures or dark laminae, but were located just above or below dark layers. The siltstone and slates had “clearly undergone considerable recrystallization” likely heated between 175°C–250°C. (Anderson 2008).

Supposed fossilized tree trunks were also reported, but which were found to be more likely inorganic sandstone “pipes” formed by “rapid deposition and high energy” (possibly from “upward flowing sand and water mixtures”... “injected rather quickly”) and with a matrix covered in “laminae composed of sparse grains of magnetite” (0.15 to 0.20 mm). (Bailey R.H, 1978).

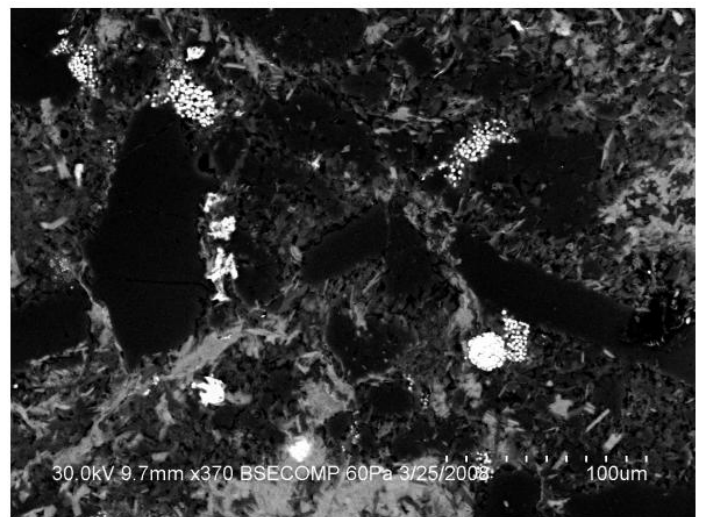
The “fossil” presented as “abundant minute, opaque spheres” with a “very thin coating of pyrite” around what is thought to be “spherical cells,” “multicellular filaments of cylindrical form,” and “dense colonies of minute spherical cells.” (Kaye 1984). The subspherical bodies were “interspersed” with “laminae.” The colonies were theorized to represent *Bavlinella*, however these were smaller. (Lenk, 1982). No organic material was confirmed, and the subspherical bodies were smaller than typical *Bavlinella*.

What were called *Bavlinella* microfossils (Kaye 1984) are pyrite-coated spherules with no confirmed organic content at sizes smaller than the proposed organism—matching the morphological description of impact microspherules documented at fifty sites worldwide. What were called *Aspidella* fossils are structures that “superficially resemble a small crater” forced into a “junkyard taxon” (Persons, 2008). What were called fossilized tree trunks are injection pipes with magnetite-bearing matrices formed by pressure-

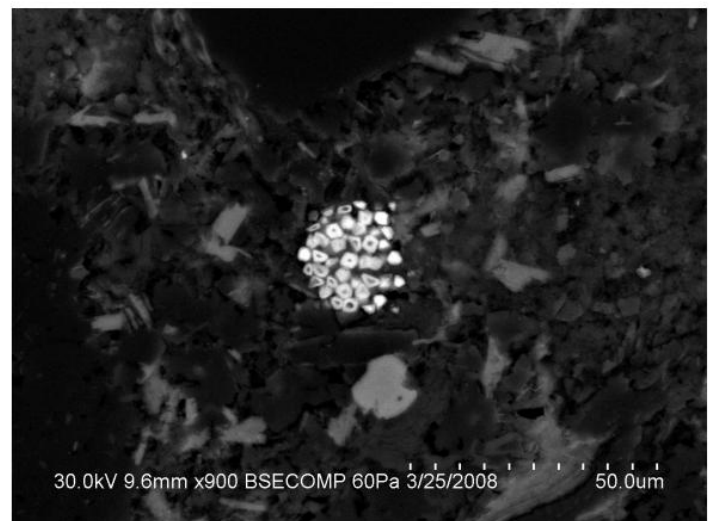
wave liquefaction.



“fused pyrite framboids,” Hewitt’s Cove Argillite, Boston Basin (O’Donnell, 2008).



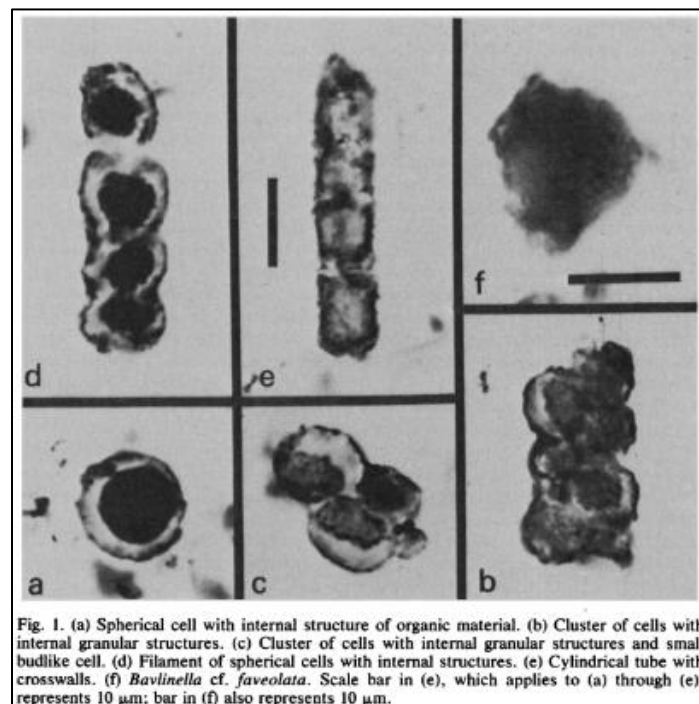
“cluster of pyrite framboids,” Hewitt’s Cove Argillite, Boston Basin, (Anderson, 2008).



“rhombohedral” framboid of secondary hematite, Hewitt’s Cove Argillite, Boston Basin, (Anderson, 2008).

These pyrite-coated subspherical bodies are morphologically consistent with iron-rich microspherules – cooled metallic droplets – which are among the most widely confirmed YDB impact proxies, found at over 50 sites worldwide. The interpretation of these structures as microfossils was never formally confirmed, and no follow-up investigation was conducted.

Kaye reported finding “magnetic spherules” “heavy beach sand,” and “tektite” at Martha’s Vineyard in 1961-1965. The spherules were found to contain heavy metals primarily of “monazite,” “biotite,” “garnet, staurolite, magnetite, and ilmenite” and rare earth elements “rutile,” “cerium, yttrium, vanadium, zirconium, and titanium” (Kaye, C. & Morse, M.E., 1965). Tektites are distal ejecta and would be beyond the crater rim –making their appearance reasonable in Martha’s Vineyard if the impacts were around Boston Harbor, Boston, and Cambridge.



“spherical cells” (Lenk, 1982)

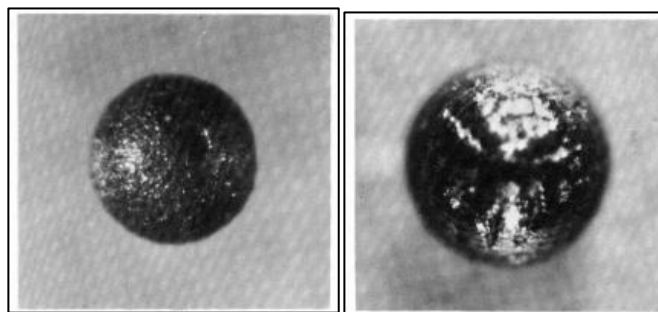
Kaye’s spherules were “strongly magnetic,” with “striking sphericity and polish,” and 22 were found with “nearperfect sphericity of the grains” with “the appearance of minute steel ball bearings.” Kaye noted they resemble other spherules with “probable meteoric origin” and “represent cosmic dust and ablation droplets that have been stripped from meteoroids falling through the earth’s atmosphere.” (Kaye, C. & Morse, M.E., 1965).

Kaye noted: “the beach-sand spherules resemble those

described as being of extraterrestrial origin, except that the beach-sand spherules are exceptionally large. The largest found measured 660u diameter.” These were found to consist of maghemite and magnetite (Kaye, C. & Morse, M.E., 1965).

The 1961 tektite was noted to be “fresh” and of “recent origin” (Kaye, C. & Schnetzler, C., 1961). Tektites “are thought to be frozen splashes of material ejected from a crater as a meteorite or asteroid collides with earth” (Hawkins, 1962).

Kaye also identified bauxite in Martha’s Vineyard which he thought was deposited by glaciers in the last ice age and at which time the kaolin deposits were also laid. Bauxite is only formed in tropical climates “where humus is destroyed before humic acids can be produced” and there was not an explanation for its presence in eastern Massachusetts, especially alongside a glacier. (Frederiksen, 1984).



Martha’s Vineyard spherules (Kaye, C. & Morse, M.E., 1965).



Argillite (Thompson P. J., 2014)

Impact “features such as shatter cones, tektites, spherules and Ni-spinels, shocked quartz, isotropication, and partial melts, are common to both submarine and subaerial impacts.” (Dypvik, H. & Jansa, L.F., 2003). Tektites may include terrestrial sediment mineral inclusion, most commonly: quartz, zircon, rutile, chromite, and monazite.

(French, 1998). All of these minerals are abundant around Boston.

Samples of argillite from Hewitt's Cove showed oversized clasts with downwarped laminae with distortion above the next layer indicating "they were dropped." A "single granitoid lonestone" was also identified in the area. Thin section of a granitic dropstone with deformed laminae both above and below. quartz is present (blue crystal) as well as albite twinning in the plagioclase. Other feldspars appear chemically weathered. (Williams, 2008).

Thompson photographed a "Laminated mudstone and sandstone" in 2014 with a black-colored opaque streak strongly resembling the black streams identified after bolide impacts (Thompson P. J., 2014)

Siliceous sediments, like those in Boston, have been found to provide exceptional preservation of Ediacaran fossils. (Newman, 2019). Silica, iron, and aluminum are all ideal minerals for preserving organic material – so it would be highly probable that Boston's clay and mudstones could contain preserved microfossils and invertebrates and Boston's marine environment would have likely been well suited for these types of Avalon biota. Yet, Boston's clay and argillite is generally claimed to be fossil-less, with only a few exceptions.

The Younger Dryas impact is also thought to have triggered massive fires which would have then been washed across the Site in the glacial outwash and could have laid some of the deeper ash, charcoal, soot, and cinders currently found all over Boston. (Sweatman M. , 2021). (Wolbach 2018).



*Tunguska event, Leonid Kulik expedition, May 1929*  
(Historical Geology, 2026).

Additionally, it appears there are no other public records of investigations into potential fossils or ancient microbial organisms in the Boston rocks or clay. (Bailey R.H, 1978). Further, in modern literature the prior mentioned fossils are rarely discussed and instead the Boston area is often deemed "fossil-less" – raising questions about the basis for modern interpretations.

## **REVISION OF THE ROLE OF GLACIERS IN BOSTON'S GEOLOGY**

### **SUBMARINE/AQUATIC BOLIDE IMPACTS**

Most of the unconformities and anomalies in the Boston Basin are clearly explained by submarine/water bolide impacts – and almost none of them are explained by glacial movement.

"In submarine impacts, the targets are mostly unconsolidated or poorly lithified sediments, or sedimentary rocks, with high volumes of pore water. Such differences result in variability in crater morphology and in sedimentary processes inside and outside the impact area. (Dypvik, H. & Jansa, L.F., 2003).

Impacts in shallow-water marine environments "produced craters with low or absent rims and wide and shallow brims, as characterize by both the Montagnais (on the Scotian shelf), the Mjølner (in the Barents Sea), 45 and 40 km in diameter, respectively, and the Chesapeake Bay (90 km in diameter). Lack of elevated rims is thought to be the result of current reworking and resurgence of the water back into the excavated cavity, as the water in the crater is vaporized." (Dypvik, H. & Jansa, L.F., 2003).

"Submarine impacts can be inferred from the presence of sedimentary features resulting from processes not occurring at subaerial impacts: e.g. formation of megatsunamis, high waves, strong currents, and features resulting from collapse of the central high and crater rim and the rush of returning water into excavating crater." "Impacts of large bolides into marine environments will also generate tremor-like earthquakes, which could lead to fluidization of sediments, slope instability, slides, slumping, generation of turbidites, mass- and debris-flows, and avalanches." (Dypvik, H. & Jansa, L.F., 2003).



“Some of the gravity and debris flows generated by margin collapse may be channelized, with final deposits up to several hundred meters thick, extending for hundreds of kilometers from the impact site.” “No simple, bowl shaped submarine crater has been found.” (Dypvik, H. & Jansa, L.F., 2003).

Boston Basin can be explained by impact science based on the existence evidence by simply reclassifying that evidence under impact science rather than glacial theory. So why does glacial theory persist?

### **AGASSIZ’S LEGACY OF DEFUNCT GLACIAL THEORIES**

For over a century, geologists relied on “glacial theories” to explain most of Boston’s geology. However, even by 2003, researchers recognized there were “profound differences in the distribution and character of landforms, such as moraines, drumlins, and tunnel channels” and “the extent of... Wisconsin ice is now thought to have been less extensive than previously interpreted.” (Mickelson, 2003).

The geological framework used to describe the Boston Basin (the bedrock, soil, and landscape underlying one of America’s oldest and most densely populated cities) has never been independently validated using modern science. It is based on terminology and concepts introduced in the mid-19th century by Louis Agassiz, a Harvard professor who was also one of the most prominent scientific racists in American history and also a creationist who called his scientific framework “The Plan of Creation.” (Irmscher, 2013), (Smith, 2014).

Agassiz’s framework says the Boston landscape was shaped by glaciers: the drumlins are glacial hills, the till is glacial sediment, the clay is glacial marine clay, the boulders are glacial erratics carried by ice, and the fractured bedrock is the result of natural weathering. Agassiz’s reasoning was that God used glaciers to kill non-white humans (who he claimed were a separate species) in order to prepare the land for the white *Homo sapiens* to settle and build their own civilization. Further complicating this theory: there are no glacial deposits or sediments in Boston from prior to the end of the last glacial period. (Wolfe, 2013), (Menand, 2001), (Wallis, 1995).

This timeline where glaciers supposedly established Boston’s geology is a time where concurrently there were no glaciers present in Boston. This includes the timing of

the creation of the 200+ drumlins. While there is evidence of additional glacial activity surrounding Boston during Younger Dryas, there is no evidence glaciers in Boston itself at that time. (P. J. Barosh 2011), (M. D. Thompson 2020). During Younger Dryas, it seems probable that the glacier ice sheet over Boston was vaporized when the bolide swarm made contact with the ice sheet.

Louis Agassiz was hired by Harvard University in 1847 to establish a school of science built around his glacial framework. (Gibson, 2022). Agassiz’s recruitment, arrival and institutionalization at Harvard was part of a coordinated effort by the Lazzaroni, a small network of American scientists organized around Alexander Dallas Bache, Superintendent of the U.S. Coast Survey, whose explicit goal was to consolidate control of American scientific institutions. (Chaitkin, 1989).

In 1846, under pressure from Lazzaroni members including mathematician Benjamin Peirce, Harvard moved to establish a separate school of science. That same year Agassiz arrived in Boston. In 1847, Bache ordered Lieutenant Charles Henry Davis to take Agassiz out on the government vessel U.S.S. Bibb for research off Cape Cod (where Kaye has reported extensive evidence of impact debris) to report back on glacial origins. Davis subsequently moved in near Agassiz and, in the words of Mrs. Agassiz, became the professor’s “prime minister.” (Chaitkin, 1989).

In 1848, Harvard’s appointment of Agassiz under Lazzaroni pressure was the result of organized institutional capture of American science, in which Agassiz’s glacial framework was installed as doctrine and alternative hypotheses were structurally excluded from the institutions that would have evaluated them. (Chaitkin, 1989).

Agassiz founded Harvard University’s new Lawrence Scientific School and used that position to displace an existing hypothesis (documented by Edward Hitchcock in the first Commonwealth geological survey of 1833–1841) that a catastrophic event, possibly a comet impact, had devastated the New England landscape. (Hitchcock, 1833).

Hitchcock initially rejected the comet hypothesis only because 19th century science incorrectly believed comets were made of matter “thinner and lighter than air.” That has been known to be wrong for over a century, but nobody reopened the question. Hitchcock also fervently rejected glacial action as a default explanation for Boston geology but



his argument was forgotten. (Hitchcock, 1841).

Agassiz's glacial theories were directly connected to his racist pseudo-science, with him arguing that a "recent ice age" had caused the extinction of prior species of man who were completely separate from existing species. He argued this theory in Brazil, which has no evidence of glaciers in 300 million years (roughly 297 million years prior to the oldest evidence of *Homo sp.* on earth). Agassiz found evidence of glaciers wherever he needed to in order to justify his racism. (Haag, 2010), (Drake, 2021).

Agassiz's racist pseudoscience replaced indigenous knowledge (the oral traditions of Native peoples who had maintained accounts of fire from the sky and mass destruction for approximately 12,900 years) with a religious, white-supremacist European theoretical framework that had no observational basis, no testable mechanism, and found glaciers in order to justify ethnic cleansing narratives.

*"In the legends of the North American Indians we read that the earth was covered with great heaps of ashes..."*

*In the legend of the Indians of Lake Tahoe we are told that the stars were melted by the great conflagration, and they rained down molten metal upon the earth...*

*In the legend of the Tupi Indians we are told that God "swept about the fire in such way that in some places he raised mountains and in others dug valleys..."*  
(Donnelly, 1883).

In 2021, The Crimson wrote "To Agassiz, the natural world was a window into the mind of God. He was so focused on the philosophical and the divine that he often overlooked the material implications of his research." (Iqbal, 2021).

It's time to reset and re-evaluate the geology of the Boston Basin without Agassiz's influence – in order to understand Boston's geology, to advance research on bolides and the Younger Dryas event, and as part of an ongoing reckoning with geologic theories based on 19<sup>th</sup> Century false assumptions and political beliefs (Frankel, 2025).

### **IMPACT ON THE LAURENTIDE ICE SHEET: A HYDROTHERMAL EVENT**

The original comet responsible for the bolides triggering the Younger Dryas event is estimated to have been approximately 100 kilometers wide (an erstwhile giant comet), and it is theorized to have fragmented into

thousands of pieces as it entered the inner solar system around 20,000 years ago and well before impacting 12,900 years ago. (Hardrien, 2021), (Firestone et al. 2007), (Napier, 2010).

The bolide swarm that hit the Laurentide ice sheet 12,900 years ago is thought to have descended from the Taurid meteor complex, with meteors that "are the remnants of an erstwhile exceptional body in a short-period, Earth-crossing orbit." Comet Encke is a descendent of this group, as are fragments that have hit the earth in more recent times (Sweatman M. , 2024), (Napier, 2010).

Analysis of meteorites from the Taurid complex showed "resemblance to the most primitive carbonaceous chondrite types, the CI and CM chondrites," but are "nevertheless quite distinct from either of them." Overall, the complex "incorporates an ancient, dispersed system of related meteor streams" (Napier, 2010).

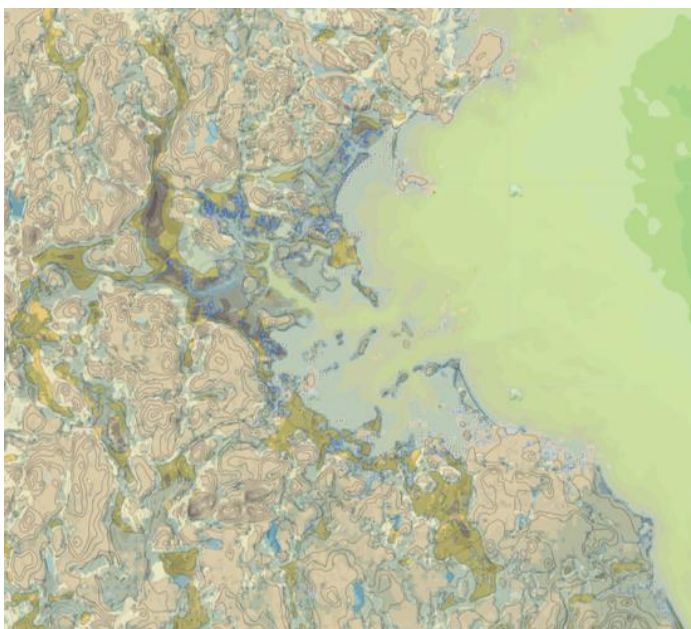
The fragmented YD bolide is hypothesized to have struck or exploded over the Laurentide ice sheet in northeastern North America, with individual fragments creating "touchdown" airbursts – explosions at low altitude that generate devastating shockwaves, extreme overpressure, and temperatures exceeding 2,000°C at ground level without necessarily leaving identifiable craters in the surface geology. (Moore et al. 2024). ("We propose that one or more large, low-density ET objects exploded over northern North America, partially destabilizing the Laurentide Ice Sheet and triggering YD cooling"), (Firestone et al. 2007).

Computer simulations have confirmed that cometary fragments can explode before reaching the ground while generating shockwaves capable of widespread surface impacts. (Moore 2024). The 2–3 km thick Laurentide ice sheet would have absorbed the initial energy of the impacts, changing the typical dynamics of meteorite impact events and explaining the apparent absence of traditional crater morphology. The shockwave from such an event would have created "intense winds traveling across North America at hundreds of kilometers per hour, accompanied by powerful, impact-generated vortices." (Firestone 2007). The impact would have destabilized the glacial ice sheet, triggering the collapse of massive glacial meltwater lakes and subsequently disrupting the Atlantic Meridional Overturning Circulation, which initiated the Younger Dryas cooling. (Wu 2013).

If fragments of the hypothesized comet struck the ice sheet over what is now the Boston Basin, the resulting thermal and collision reactions would have simultaneously (1) rapidly melted overlying ice, (2) vaporized and obliterated surface rock into fine particles, (3) driven ejecta and meltwater into the fractured substrate, (4) created high-pressure shockwaves that compacted and deformed subsurface materials, and (5) initiated hydrothermal circulation through the newly fractured and heated rock.

Boston's argillite bedrock exhibits extensive kaolinization at multiple documented locations including the South Station Postal Annex, the former Stone & Webster Building, Washington Street, Atlantic Avenue, Boston Common, Castle Square, Gillette Safety Razor plant, and Pier 2. (Kaye & Reed, Haley & Aldrich).

At the Ames Building, kaolinite clay reaches 27.11 wt.% in argillite that also contains 59.18 wt.% SiO<sub>2</sub>. This kaolinization penetrates to over 300 feet depth, is fault-controlled rather than stratigraphic, and transitions abruptly from sound rock to fully altered material – a pattern diagnostic of impact-generated hydrothermal circulation rather than surface weathering. At confirmed impact sites including Chicxulub, Ries, and Vargão Dome, kaolinite and related clay minerals form through identical mechanisms: hot, impact-generated fluids circulating through fractured rock along zones of high permeability.



MassMapper, Jan. 17 2026 (Combined Overlays of state maps for: Transmissivity and Aquifer Yield, Bedrock Altitude, Surficial Geology Depth in Feet, 30ft Contours, USGS Water Bodies, and Gulf of ME Bathymetry).

Anderson (2008) reported that Boston's argillite siltstone and slates have "clearly undergone considerable recrystallization" at temperatures estimated between 175°C and 250°C. This temperature range falls squarely within the documented range of impact-generated hydrothermal systems (generally peaking at ~350°C per Chicxulub data, and persisting below 100°C for millions of years for larger craters). There is no documented source of 175–250°C heating in the Boston Basin since the end of Avalonian volcanism over 400 million years ago.

What about the Boston Basin's mysterious lack of basin features? Chelyabinsk is an apt comparison where "energy deposition that led to the explosion took place in stages and was spread out over a long distance because of the shallow entry angle" and "slug of energetic material carried much of the original momentum of the asteroid and continued to push its way downrange as it exploded—still moving much faster than a fighter jet. Because of the long distance over which energy was deposited, the geographic pattern of the shock intensity, inferred from observed damage, looked more like an inclined cylindrical bow shock than a spherical explosion." (Physics Today 2014).

"For nearly a century, the origin and the age of the Boston Bay Group of sedimentary rocks have been a matter of dispute." (Caldwell, 1981). Geologists have historically reported difficulty in dating Boston's argillite and clay, with "an extreme range of results" that has never been publicly explained. (Kaye 1984). Meteorite impacts reset U-Pb dates for impacted rocks. (Walton C. , 2023), (Walton C. S., 2022). If chondrite material – "among the most ancient objects in the solar system" (NASA, 2026) – is mixed with impact-reset target rock, the resulting dates would produce an irreconcilable spread from billions of years (chondrite ages) to approximately 12,900 years (impact-reset ages), which would appear as laboratory errors to researchers unaware of the impact context.

## **THE CONCEPTUAL SITE MODEL FOR THE BOSTON BASIN IS FUNDAMENTALLY INCORRECT BURIED RIVER VALLEYS, FAULTS, & FOLDS**

This area was also mapped with faults and folds by Kaye. (Kaye, 1980). The "bedrock valley" is supposedly -244 msl

deep and “so extensively filled, or buried, that most of them have no surface expression.” (Upson, 1964). Judson explain that other than a couple specific locations, no portion of the surface of Boston represent conditions prior to the Lexington Substage & Younger Dryas event – otherwise, everything is all gone. (Judson, 1949)

Its theorized there is a “buried river valley” running parallel with Fort Point Channel, and also perpendicular around the base of Roxbury Canal. (Barosh P. J., 2011). The rivers supposedly. “followed fault zones, across Dorchester Heights, and a southwest flowing one below Fort Point Channel.” “A separate river channel is seen at the north end of the Shawmut Peninsula in the detailed topography of the buried surface around North Station” (Barosh P. J., 2011).

The Boston Basin’s internal fault network is characterized by average lateral spacing of approximately 490 feet, “surprisingly little unconsolidated fault breccia or gouge,” and some silicified cataclastic material. This is an unusual combination: closely spaced faulting typically produces abundant gouge. The absence of gouge, combined with the presence of silicified (heat-sealed) cataclastic material along fault planes, is consistent with impact-generated fracturing subsequently sealed by hydrothermal fluids—a process well-documented in confirmed impact structures.

The geometry of Boston’s dike and fault swarms has not been examined as an impact structural diagnostic. Barosh (2011) documents “multiple, parallel, radial, or conjugative sets of intrusions” across the basin. At confirmed impact structures, radial and conjugate fracture patterns centered on the impact point are a primary diagnostic — they form because the shockwave radiates outward from the energy release point, fracturing target rock along lines of maximum stress.

Random tectonic faulting does not produce radial patterns. If the fracture orientations documented by Barosh were mapped systematically and their radial lines extended, they would converge on the impact center — standard methodology at confirmed impact structures that has never been applied to the Boston Basin because no one has been looking for an impact. (Barosh P. J., 2011), (Kenkmann, T., et al., 2014).

“The Boston area has undergone deep erosion at various times in its history that has produced a number of unconformities.” Most alteration dies out at relatively

moderate depths. Barosh – most common “under the Shawmut Peninsula and adjoining Cambridge.” (Barosh P. J., 2011). There are many faults which are sometimes designated dikes and the presentation labeled a “swarm” where there are multiple, parallel, radial, or conjugative sets of intrusions. (Barosh P. J., 2011).

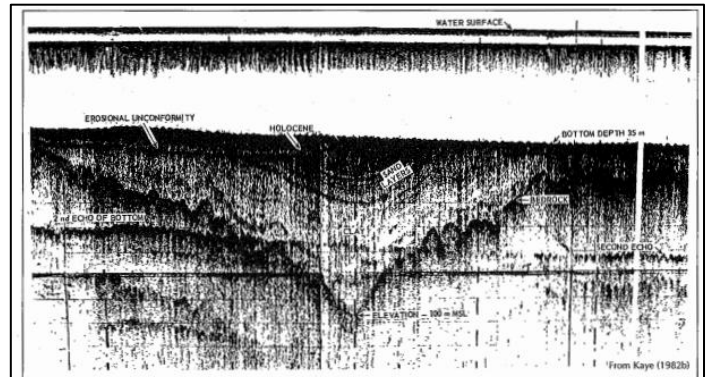
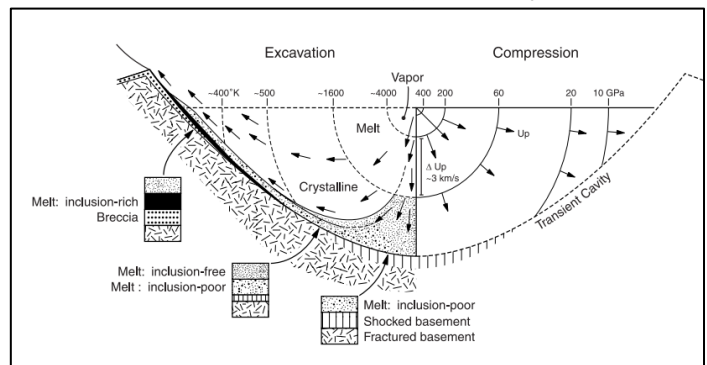


FIGURE 3-71. Sub-bottom seismic profile in western Massachusetts Bay, off Boston, showing V-shaped trough in bedrock filled with marine clay and, in upper part, interbedded sand (upper outwash). Note conformable bedding, erosional unconformity and overlying post-glacial sand. The bottom of trough is at about -95 meters (-312 feet) MSL.

*Boston Harbor & Mass. Bay, (Barosh P. J., 2011)*



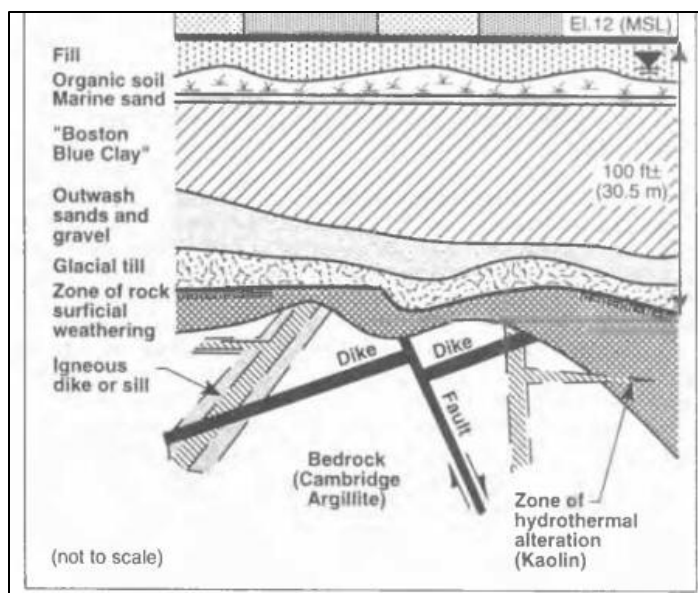
*Impact melt formation and movement through transient crater, (French, 1998)*

A deep well on Spectacle Island penetrated 360 feet of unconsolidated material, of which Clapp (1907) noted “only part could be drift.” The remainder could not be assigned to any recognized stratigraphic unit. Under the glacial framework, all unconsolidated Boston Basin material is expected to be till, glaciomarine clay, or outwash. Material that cannot be classified as any of these has no conventional explanation.

Under the impact framework, impact ejecta, bolide-generated sediment, impact-obiterated target rock, and impact melt products resuspended by the impact-generated tsunami would all appear as unconsolidated material that does not fit standard stratigraphic categories — because it was not produced by any standard stratigraphic process.

Spectacle Island sits in the area Hitchcock (1833) described as "obviously the wrecks of one continuous diluvial formation" — the impact ejecta field. The 360 feet of unidentified material beneath it is consistent with impact-generated deposition depth within the crater field. (Clapp, 1907), (Hitchcock, 1841).

Reports document examples of a "v-shaped channel in bedrock filled with- marine clay" including in Boston Harbor at a depth of around 312 feet. The Harbor topography is also covered with a "series of north- to northwest-trending enclosed basins and highs with aligned east northeast-trending irregularities" (Oldale & Bick, 1987). (Barosh P. J., 2011).



"typical geologic conditions," Boston, MA (Brown, 1997).

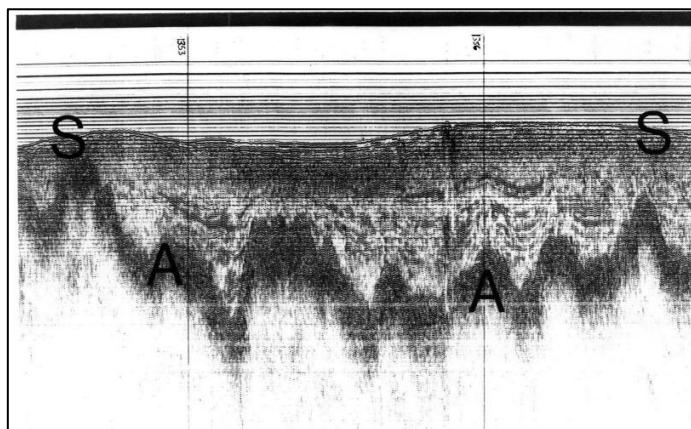
Acoustic basement reflectors define "cut-and-fill and slump structures" but in other areas without reflectors the record is "mottled." Boston Harbor generally "has a flat upper surface, and partly or completely fills topographic lows in the basement unit." (Fitzgerald, 1974).

There is "scattered small deposits of sand and gravel found beneath the lower till, up to 1.8 meters (6 feet) thick" around Tech Square Cambridge, Davis Square Somerville, under John Hancock and New England Mutual buildings in Copley Square, South Station, under Deer Island. There is also a deposit around Deer Island with a layer of dense brown/gray/orange-brown sand with shell fragments under till, 20-60ft thick to the north and thinning, above argillite, with a narrower lens of boulders and sand underneath it, "draping over shoulder of diabase

dike dropping off to south" — which Barosh says is "hard to explain" and "not described elsewhere in the inter-island tunnel alignment to the south." (Barosh P. J., 2011).

These are all areas where there is also kaolinization, drumlins, boulders, gravel, and altered rock.

No natural process produces all the anomalies simultaneously. The statistical co-occurrence of fault-controlled kaolinization to 200+ ft depth, 175–250°C recrystallization, framboidal pyrite with secondary hematite, pyrite-coated subspherical bodies, injection structures and magnetite-bearing rapid deposition, extreme silica-alumina enrichment, elevated Zr, Ti, K<sub>2</sub>O, LREE enrichment with negative Eu anomaly, 24–64% mineral alteration in surficial sediments, shock-hardened megaclasts, boulders embedded in kaolinized rock beneath drumlins, varve-less fossil-less clay with funnel-shaped downfolds, and anomalous dating results – all within a single basin with radiocarbon dates of 12,200–14,400 years BP – has no known explanation other than bolide impact and its consequent effects.



Mass. Bay, (Fitzgerald, 1974)

"Complex terrestrial impact craters up to 10e20 km formed in sedimentary targets show common features in the central uplift structure: anticlines and synclines with radial fold axes are typical for the periphery of central uplifts and the inner part of the ring syncline. They result from constriction caused by the convergent mass flow. Radial fold axes usually plunge outward and cause the serrated appearance of central uplifts in geological maps" (Kenkmann, T., et al., 2014).

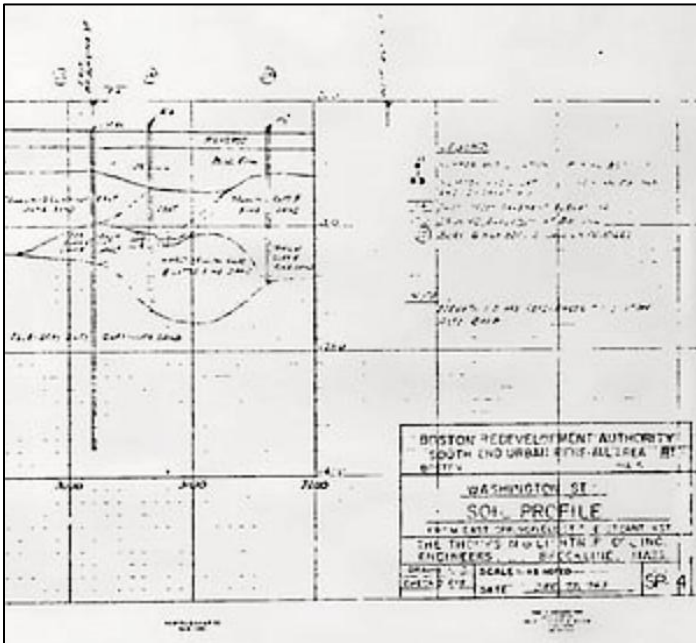
"Geological observations show that the target underneath the crater floor is disintegrated into blocks, in particular in the central uplift. These blocks are commonly internally



deformed (bent or folded).” (Kenkmann, T., et al., 2014).

What was called a “bedrock trough” channeling contamination at Fort Point Channel is the damage crater from a 33-ton ballistically emplaced megaclast and/or bolide fragment. What were called “glacial pot holes” 100 feet deep are collapse structures in shattered bedrock. What were called “funnel-shaped downfolds” 100–200 meters across in the clay are the clay draping into individual fragment craters.

What was called “prismatic or cubical jointing” in the clay, attributed to freezing, may be cooling joints from hot deposition—the same process that creates columnar joints in basalt, occurring in thermally deposited impact-derived sediment. What was called “Cretaceous or Tertiary strata” beneath Dorchester (Pearsall, 1937), was kaolinized argillite misidentified as younger sediment because no one could explain why 570-million-year-old rock was soft and white.



Washington St. soil profile, (Boston Redev. Auth., 1960s).

What Hitchcock (1833) described as harbor islands that “seem obviously the wrecks of one continuous diluvial formation” is an ejecta field. What Clapp (1907) could not explain—boulders in white clay, “unlike general clay found in Boston,” with the well driller reporting “peculiar soft white deposits” across the city—is impact regolith with ballistic clasts.

Glacial erosion produces recognizable landforms: roches moutonnées, and smooth bedrock surfaces with striations. It does not produce bedrock at 360 feet below sea level at

Spectacle Island. The “extremely irregular” bedrock surface documented by Kaye and Hughes is morphologically consistent with impact cratering and associated structural disruption, not with glacial scour.

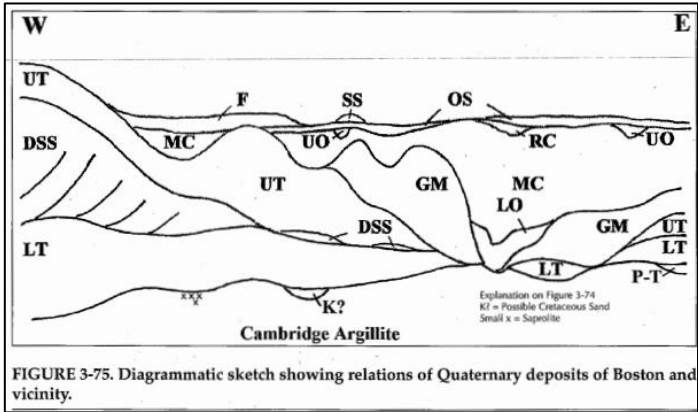


FIGURE 3-75. Diagrammatic sketch showing relations of Quaternary deposits of Boston and vicinity.

*Argillite & deposits diagram* (Barosh P. J., 2011)

As Moore and colleagues observed regarding the YDB proxy layer: “No critic has identified any other non-impact layer that coincidentally contains the broad suite of these proxies. It is statistically improbable that these dozen proxies are unrelated and only coincidentally found in the same layer.” (Moore C. L., 2024). The same reasoning applies to the Boston Basin. No critic has offered any non-impact geological process that produces kaolinization along faults to 200+ feet, 175–250°C recrystallization, pyrite framboids, extreme silica-alumina enrichment, shock-hardened megaclasts and bolide fragments, varve-less clay, and anomalous dating results – all in the same basin, all at the same time, and all atop 15,000 feet of otherwise undisturbed argillite mudstone.

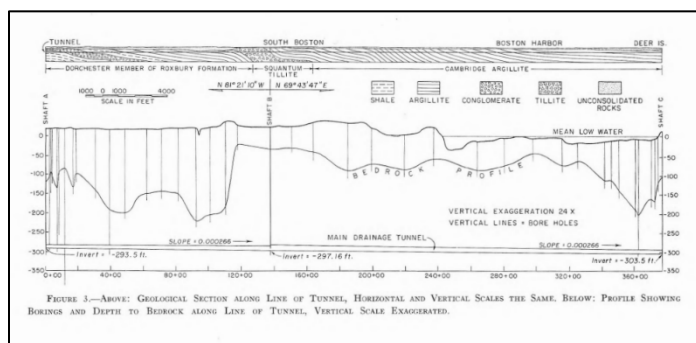
A bolide impact event could be why there’s giant erratic boulders in the Fort Point Channel, why the Channel’s path is lined with drumlins, and why Shawmut looks like a drowning person’s hand reaching up for help with only three fingers breaching the water. It could be why the Dorchester Neck looks like it was peeled away from the Shawmut Peninsula and twisted hard to the right; and why the Boston Neck is a strange narrow wedge of clay acting as a reluctant, part-time isthmus while concurrently remaining part of the sea. It could also be why the Shawmut Peninsula’s strange, deformed landform inexplicably lays in nearly perfect obstruction of the Charles river’s outflow. A bolide impact could be why there is a “bewildering assortment of sediments” across Boston. (Barosh P. J., 2011).



## BOLIDES, IMPACT, & ENVIRONMENTAL SITE ASSESSMENTS

The geological evidence presented in the preceding sections is not of purely academic interest. If the Boston Basin is a Younger Dryas impact site, then the foundational assumptions underlying every environmental site characterization, every remediation plan, every cleanup target, and every contaminant transport model in the basin are incorrect. The consequences cascade from geology through hydrology through chemistry through regulatory compliance through environmental justice.

Every environmental site assessment in the Boston Basin operates from the same conceptual site model (CSM): artificial fill overlying organic deposits overlying marine clay (the Boston Blue Clay, treated as a confining layer) overlying glacial till overlying bedrock (treated as an impermeable base). Contamination is assumed to migrate downward through these layers according to their permeability. Remediation plans are designed to intercept contamination within this layered framework. Monitoring wells are placed at depths consistent with this model. If the basin is an impact site, this model is wrong in every layer.



*Geological section from Dorchester Member to Deer Island, (Rahm, 1962).*

The Clay is treated as the primary confining unit preventing downward contaminant migration. However, the clay contains “many lenses of fine sand, local strata and pockets of granular soils and occasional boulders” (Aldrich 1970). It has “deep funnel-shaped downfolds on the order of 100 to 200 meters across” (Barosh 2011) that may connect directly to the damaged bedrock surface below. It is composed substantially of “rock flour” (Barosh 2011)—impact-pulverized bedrock, not pure marine clay. It drapes over irregular impact topography rather than forming a uniform seal. Sand lenses, boulder inclusions, and funnel-shaped penetrations create preferential pathways through which

contamination can bypass the “confining” layer and reach the underlying damaged bedrock.

The material classified as glacial till consists of “broken pieces of the underlying bedrock material” (Barosh 2011) with cubic cooling joints up to 50 feet, hydrothermally altered clasts containing siderite crystals, and a composition that varies with the underlying bedrock because it IS the underlying bedrock, shattered and redeposited. Its hydraulic properties—permeability, porosity, geochemistry—are those of pulverized, hydrothermally altered argillite, not glacial sediment. Site assessments that model the till as a glacially deposited unit with assumed hydraulic conductivity values from glacial till literature are using the wrong parameters.

Kaolinized zones are more permeable than intact argillite, creating preferential flow paths that follow the alteration pattern. The Gillette Phase II CSA (1998) documented dissolved VOCs traveling through bedrock groundwater in a trough that corresponds to the location of the 33-ton “boulder” (GEI Consultants, Inc., 1998).

No environmental site assessment in the Boston Basin has evaluated contamination below approximately 50 to 100 feet in bedrock, because the model assumes bedrock is the base of the system. Contamination that has migrated into the impact-generated fracture network—through kaolinized zones, along healed joint surfaces, into the deep aquifer systems—is invisible to the current monitoring infrastructure. It is not being detected because no one is looking for it at those depths.

The impact-generated mineralogy of the Boston Basin is itself generating contamination through ongoing geochemical processes that have been active for 12,900 years and will continue indefinitely.

There are several deep wells drilled around Shawmut Peninsula. Two 1500 ft “geothermal” wells were built on East Berkely street in 2006. They reported clay between 13 ft and 130ft, and medium grey bedrock between 130ft and 1500ft, with a water zone between 150 ft and 560 ft. (MassDEP well reports 101183 & 139741). Multiple deep geothermal and monitoring wells were built around 450 Harrison Ave ranging from -1,440. The reports noted clay from 10ft – 55ft, and bedrock starting around 55 ft-60ft, and going down to at least 1140 ft. Water zones were identified around 865 – 1060 ft. (MassDEP well reports 101181,

101183, 101184, 101185, 101186, 101187).

Deep borings for environmental assessments returned deep bedrock around Boston including: 150 Seaport Blvd (sand and gravel to 148 ft, MassDEP 659484), 5 Necco St (silt/peat, clay, till, then argillite bedrock to 106 ft), 700 Albany St (clay to 105 ft, silty sand, till, then more clay to 135 ft), and MBTA East First Street.

A geothermal well on Dorchester Ave. reported clay from 20ft to 107ft and bedrock at 107ft through at least 500ft, with a water zone around 240-260ft and 420-421 ft. (MassDEP well report 304848). Its unclear what these aquifers are or what they contain, and there's no public reports of any hydrothermal activity in Boston, but this does confirm deep argillite bedrock under the Shawmut Peninsula and in South Boston.

Pyrite oxidation in the Argillite is actively producing sulfuric acid. The acid dissolves metals from the surrounding hydrothermal ore assemblage: copper and zinc from chalcopyrite and sphalerite, arsenic from arsenopyrite, lead from galena, chromium from chondritic chromite residues in the substrate. These dissolved metals enter groundwater, are transported through the fracture network, and discharge into surface water and harbor sediments from below. This is functionally identical to acid mine drainage from mining operations—but no regulatory framework has ever classified the Boston Basin as an acid-generating substrate, because the impact origin of the sulfide mineralogy has never been recognized.

No environmental site assessment in the Boston Basin has evaluated  $H_2S$  as a vapor intrusion pathway from natural sources. Vapor intrusion assessments focus on volatile organic compounds from anthropogenic contamination. But  $H_2S$  generated from impact-emplaced pyrite decomposition is a natural vapor intrusion source that operates independently of any anthropogenic contamination and cannot be remediated by removing an industrial source. Every building in the basin with a foundation penetrating the organic deposits or contacting the bedrock surface is potentially exposed to  $H_2S$  from this uncharacterized natural source.

Groundwater circulates through the impact-fractured bedrock, contacts pyrite and ore minerals, mobilizes dissolved metals through acid dissolution, and discharges into the harbor from below. The most severely damaged

zones—which Barosh (2011) showed correspond to the topographic lows where groundwater discharge is concentrated—deliver the highest natural metal flux.

(Tuit, 2000) found that platinum and palladium in harbor sediments “may not be decreasing with cessation of sludge input as rapidly as other metals.” The Pt and Pd are not decreasing because their source is not the sludge pipe. Their source is the bedrock, continuously leaching meteoritic platinum group elements through the fracture network. The sludge pipe was shut off; the bedrock cannot be.

Environmental site assessments compare measured contamination against “background” concentrations that represent assumed pre-industrial natural conditions. In the Boston Basin, background samples collected from “uncontaminated” locations are drawn from soils and sediments overlying impact-processed bedrock that has been leaching meteoritic and hydrothermal metals for 12,900 years. The “background” already contains elevated chromium (from chondritic chromite), nickel (from meteoritic Fe-Ni metal), platinum group elements (from the impactor), arsenic (from arsenopyrite), lead (from galena), copper (from chalcopyrite), and zinc (from sphalerite)—none of which has ever been separated from the anthropogenic component.

Every contaminant fate and transport model in the Boston Basin assumes contamination migrates primarily downward through a layered stratigraphy, with lateral movement controlled by layer geometry and hydraulic gradients. In an impact-damaged substrate, contamination moves differently. Lateral migration through fracture networks:

The impact-generated fracture network connects sites laterally at depths that no surface investigation would predict. Contamination from one property can migrate to another through impact fractures in bedrock, bypassing the overlying clay “confining layer” entirely. The fracture network does not respect property boundaries, disposal site boundaries, or municipal boundaries.

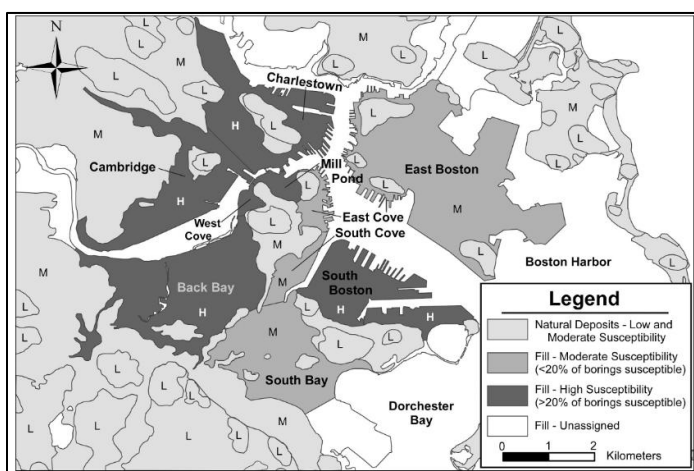
Deep fracture systems under artesian conditions can drive contamination upward into shallower zones. The multiple aquifer zones documented at different depths (150–560 ft, 240–260 ft, 420–421 ft, 865–1,060 ft) in the geothermal wells may have different hydraulic heads, creating vertical gradients that move contamination up as well as down.

Preferential flow along impact damage: Kaolinized zones, bedrock troughs (megaclast damage craters), and healed fractures with soluble calcite or quartz fill create preferential flow paths that concentrate contamination along impact features. Every mapped “bedrock valley” or “fault” in the basin is a potential preferential flow path of this type.

Contamination that enters the impact-generated fracture network can migrate to depths of 1,000 feet or more, far below any existing monitoring well. No assessment framework currently in use contemplates contamination at these depths because the conventional model treats bedrock as impermeable at tens of feet below its surface. The actual depth of the contamination problem in the Boston Basin may be an order of magnitude greater than any existing assessment has characterized.

### THE “FILL” AROUND BOSTON IS EJECTA, BOLIDE, & IMPACT-ALTERED ROCK

If the drumlins are impact ejecta mounds containing shattered, hydrothermally altered bedrock with meteoritic and hydrothermal metals, then drumlin material used as fill contains those metals. If harbor dredge spoils are impact ejecta and shattered bedrock from the harbor floor, then dredge-derived fill contains impact-processed substrate. If excavated “bedrock” was kaolinized, sulfide-bearing impact-altered rock, then that material was placed as fill with its associated acid-generating pyrite and dissolved metal load.



(Brankman, 2008)

Approximately one-third of modern Boston is built on artificial fill. This fill was sourced from harbor dredging (removing boulders and sediment from the harbor floor),

drumlin removal (leveling hills to fill tidal flats), and excavation of construction sites across the city. (Seasholes, 2003), (Aldrich, 1970).

The neighborhoods built on this fill—Back Bay, the South End, the Seaport, East Boston, South Boston, portions of Charlestown and Roxbury—are built on material that has never been characterized for naturally elevated metals from impact processing. The fill is assessed for anthropogenic contamination (lead paint, petroleum, industrial solvents) but the “clean fill” designation assumes that the rock and soil used as fill was geochemically normal. If it was impact-processed rock containing chondritic metals and hydrothermal sulfides, then the fill itself is a source of metals and acid that has been placed directly beneath communities.

Multiple borings report hydrogen sulfide at the bedrock contact: “PEAT; strong rotten egg odor” (B-452), “strong hydrogen sulfide odor” (MW-811B). (Gillette boring logs 1996–1997). Hydrogen sulfide ( $H_2S$ ) is toxic at low concentrations and is generated by the anaerobic decomposition of the same pyrite that generates sulfuric acid under aerobic conditions.

The communities most affected by contamination in the Boston Basin—Roxbury, Dorchester, East Boston, South Boston, Chelsea, Charlestown—are disproportionately low-income and communities of color. These communities are concentrated in the low-lying areas of the basin that were created by filling tidal flats and marshes.

These low-lying filled areas correspond precisely to the zones of maximum impact damage. Barosh (2011) documented that the “cause-and-effect relationship of low topography and deep bedrock with altered rock is notable.” The areas that are low—that required filling to become buildable—are low because the underlying bedrock was most thoroughly destroyed by the impact and its hydrothermal aftermath.

The communities built on these filled lowlands are therefore situated over the most severely impact-damaged bedrock, receiving the highest flux of naturally leached metals through groundwater discharge, sitting on fill that may itself be composed of impact-processed material, and exposed to  $H_2S$  vapor intrusion from the most sulfide-rich substrate.

These communities bear the double burden of well-documented anthropogenic contamination from decades of industrial activity, combined with uncharacterized natural impact-derived contamination that no regulatory framework has ever identified. Because the impact component has never been recognized, remediation plans for sites in these communities do not address it. The environmental injustice is compounded: the most vulnerable communities are exposed to a contamination source that does not officially exist.

## CONCLUSION

In conclusion, the geological framework underlying all environmental site characterization in the Boston Basin is incorrect. Further action is required to bring site characterization, remediation, and environmental protection into alignment with the actual geology. The geological evidence exists. The boring logs exist. The geochemical data exist. The petrographic descriptions exist. They have been in the published literature and in engineering files for decades, in some cases for two centuries. What has been missing is the framework to connect them.

If the Boston Basin is an impact site, it is also an irreplaceable scientific resource: potentially the first identified ground-zero location for a Younger Dryas impact that contributed to the extinction of North American megafauna, the collapse of the Clovis culture, and a 1,300-year climate disruption. Building luxury condominiums on top of it without even knowing what it is would be a loss for all of humanity and put workers and residents at risk of unknown hazards.

If Indigenous peoples were right all along (if Native folks maintained an accurate account of this event for 12,900 years while Western science dismissed it as myth while creating their own glacial myths) then the least we can do is listen now and apologize. The evidence exists and has been in the published literature and in engineering files for decades, sometimes for centuries. What has been missing is the willingness to look at them without Agassiz's glacial framework as a filter.

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## APPENDIX: MAPS, DIAGRAMS, & FIGURES

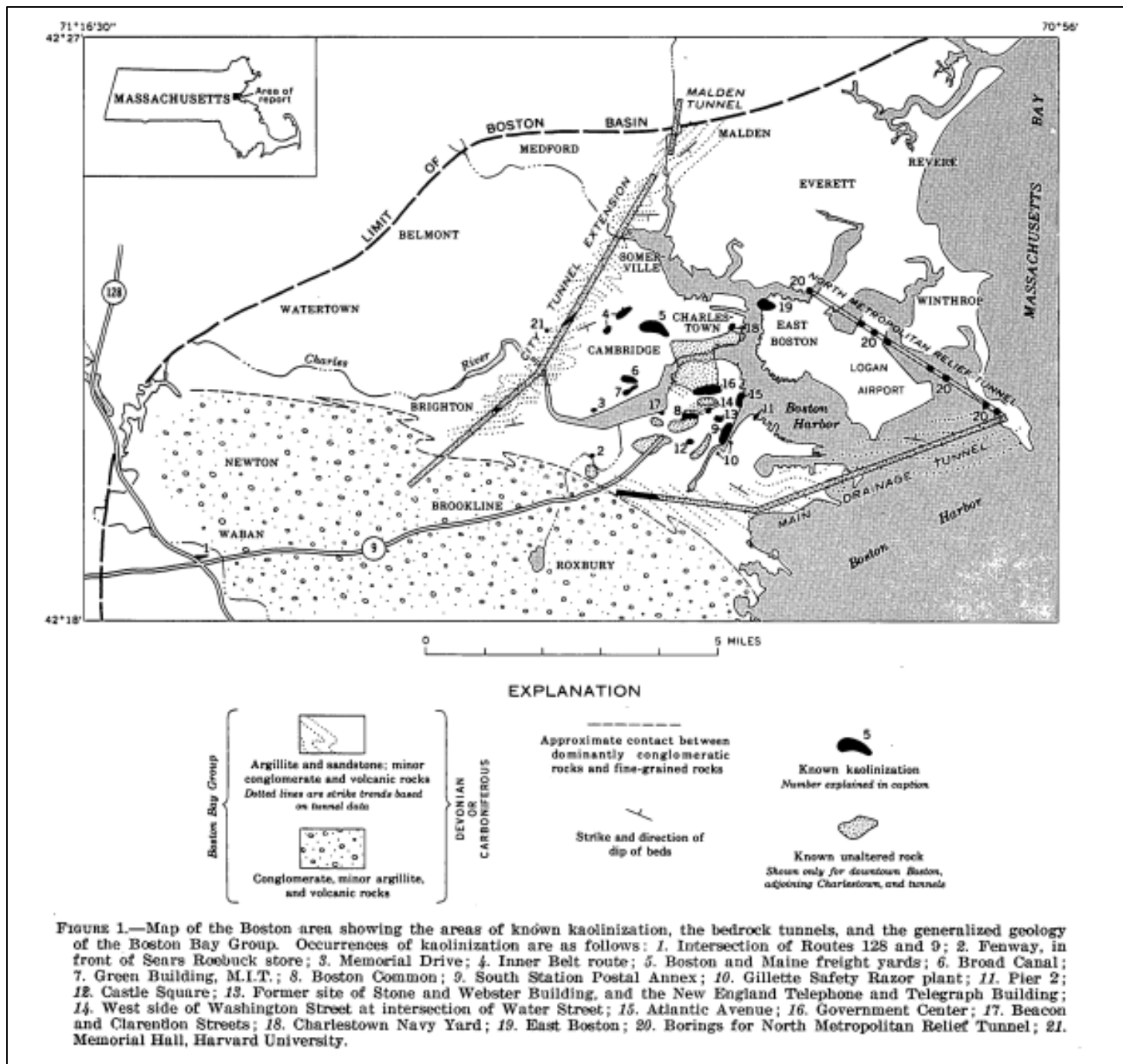


Kaye, Boston, USGS MF 1241 (1980).

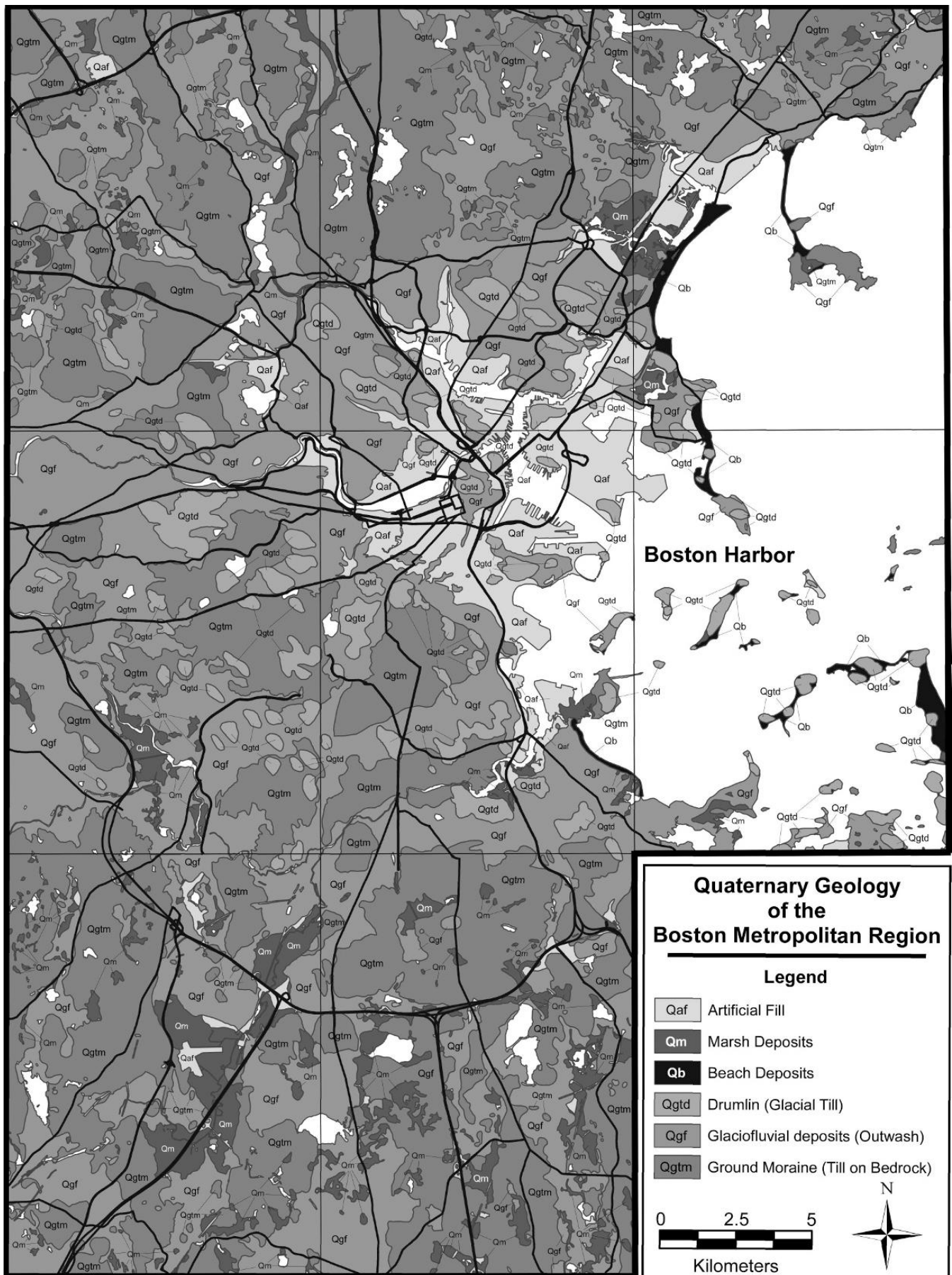




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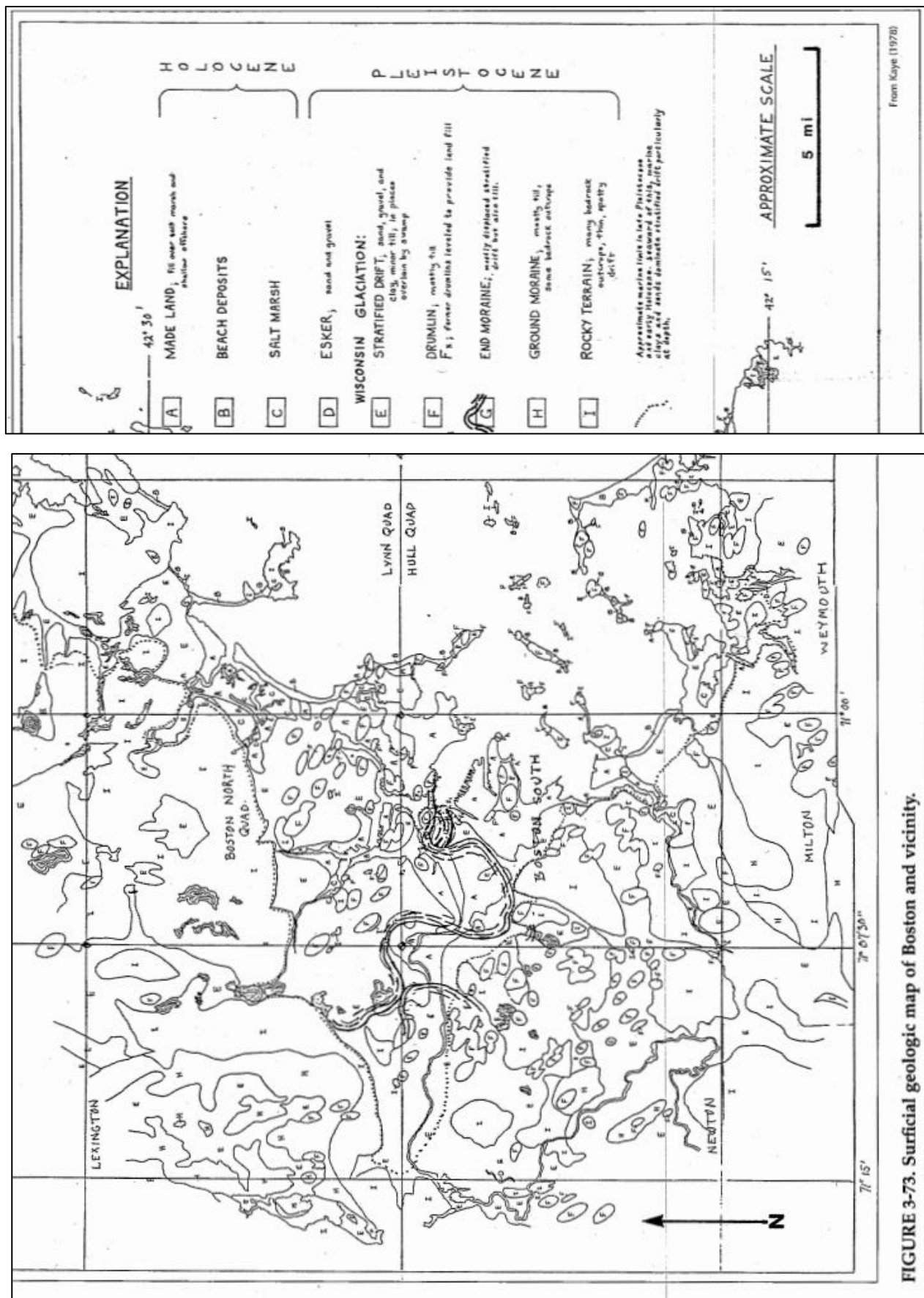


(Barosh P. J., 2011)

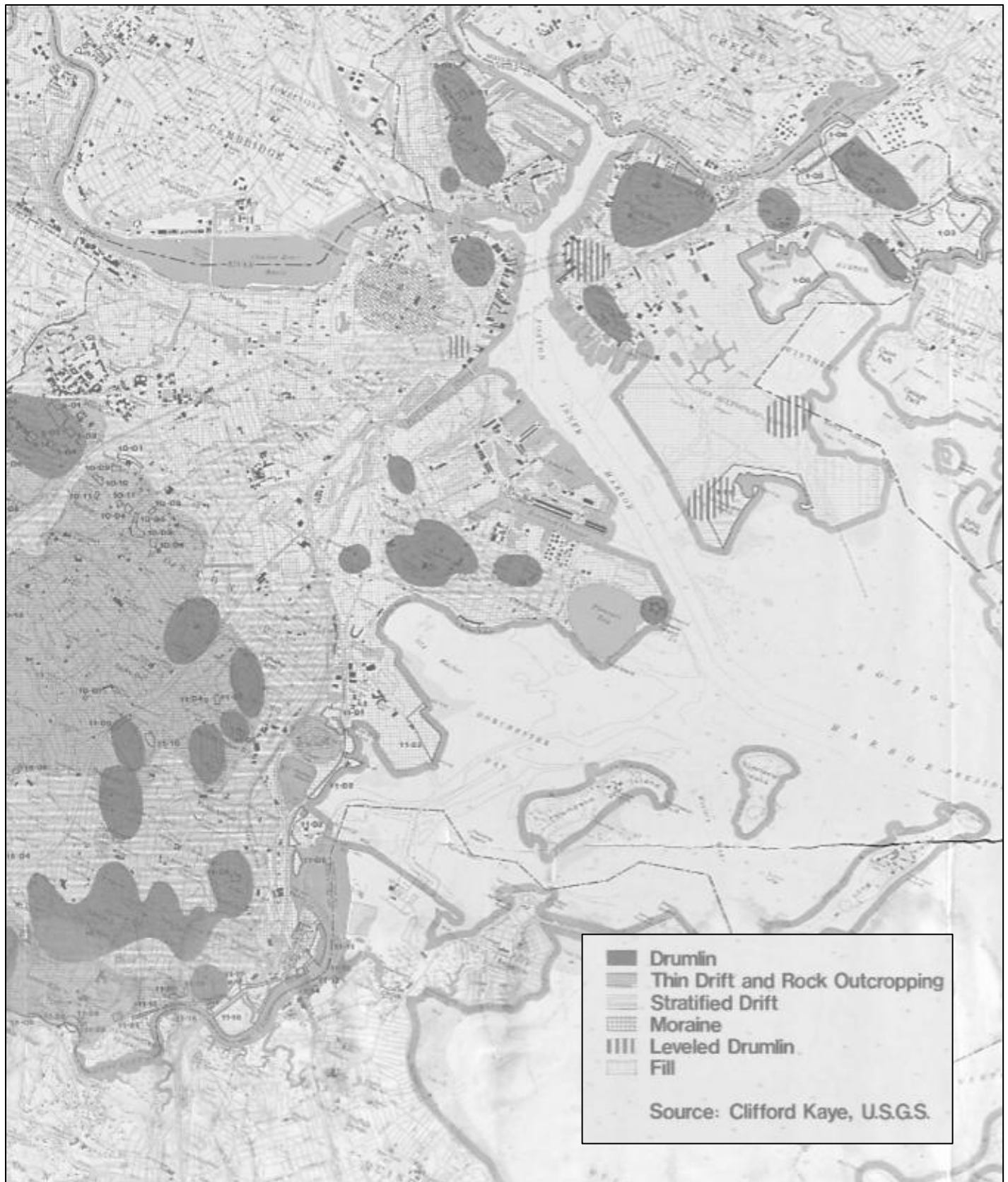


(Brankman, 2008)





(Kaye, 1978), adapted by (Barosh P. J., 2011)



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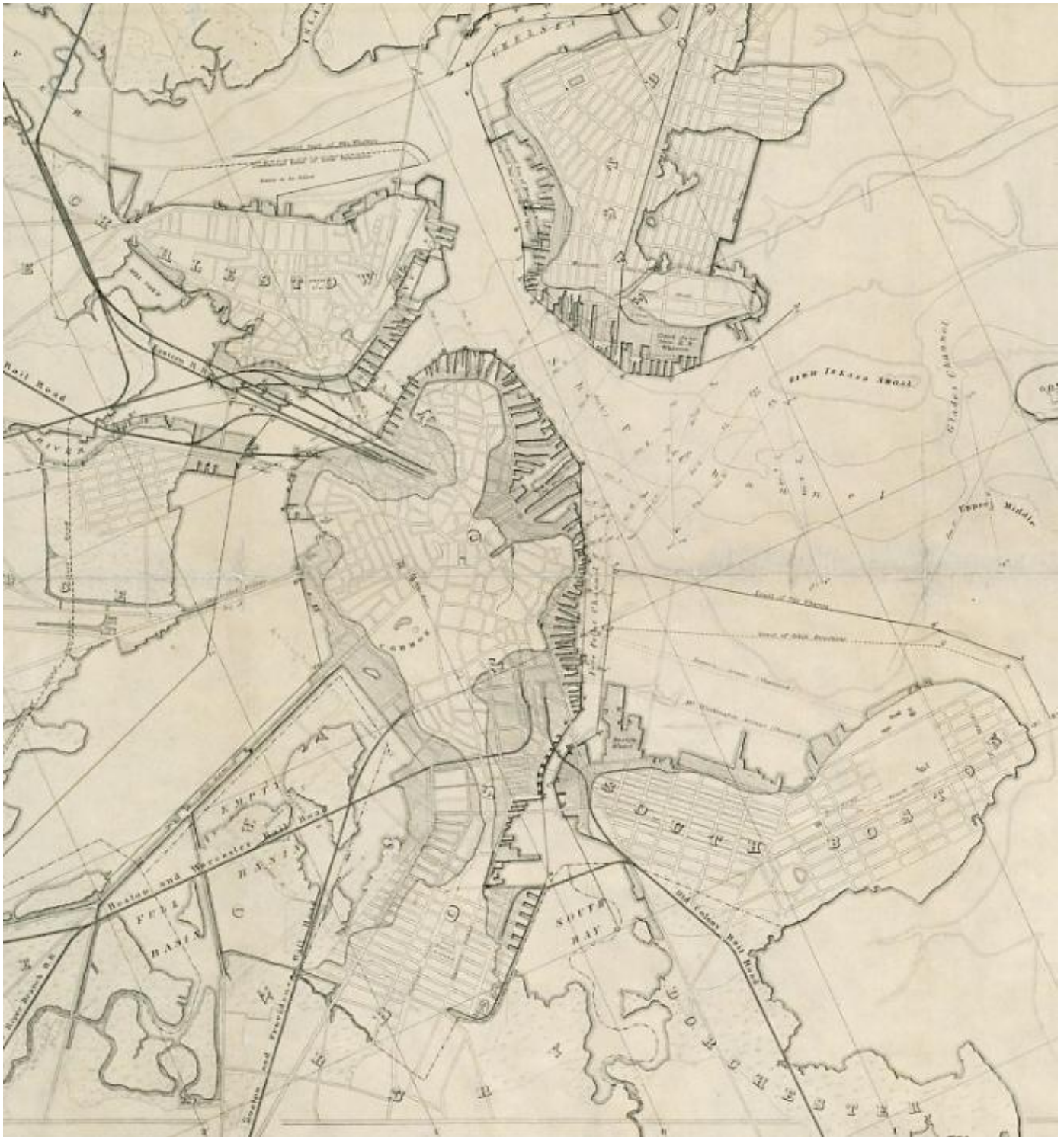
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Stone, B.D., and DiGiacomo-Cohen, M.L., comps., 2018, Surficial materials map of the Boston South quadrangle, Massachusetts, quadrangle, Surficial materials of Massachusetts—A 1:24,000-scale geologic map database: U.S. Geological Survey Scientific Investigations Map 3402, 1 sheet, scale 1:24,000. [Blue is Glaciomarine fine deposits/Clay; Orange is Coarse deposits/Gravel; Mint Green is Till/Drumlins; Brown is Fill].



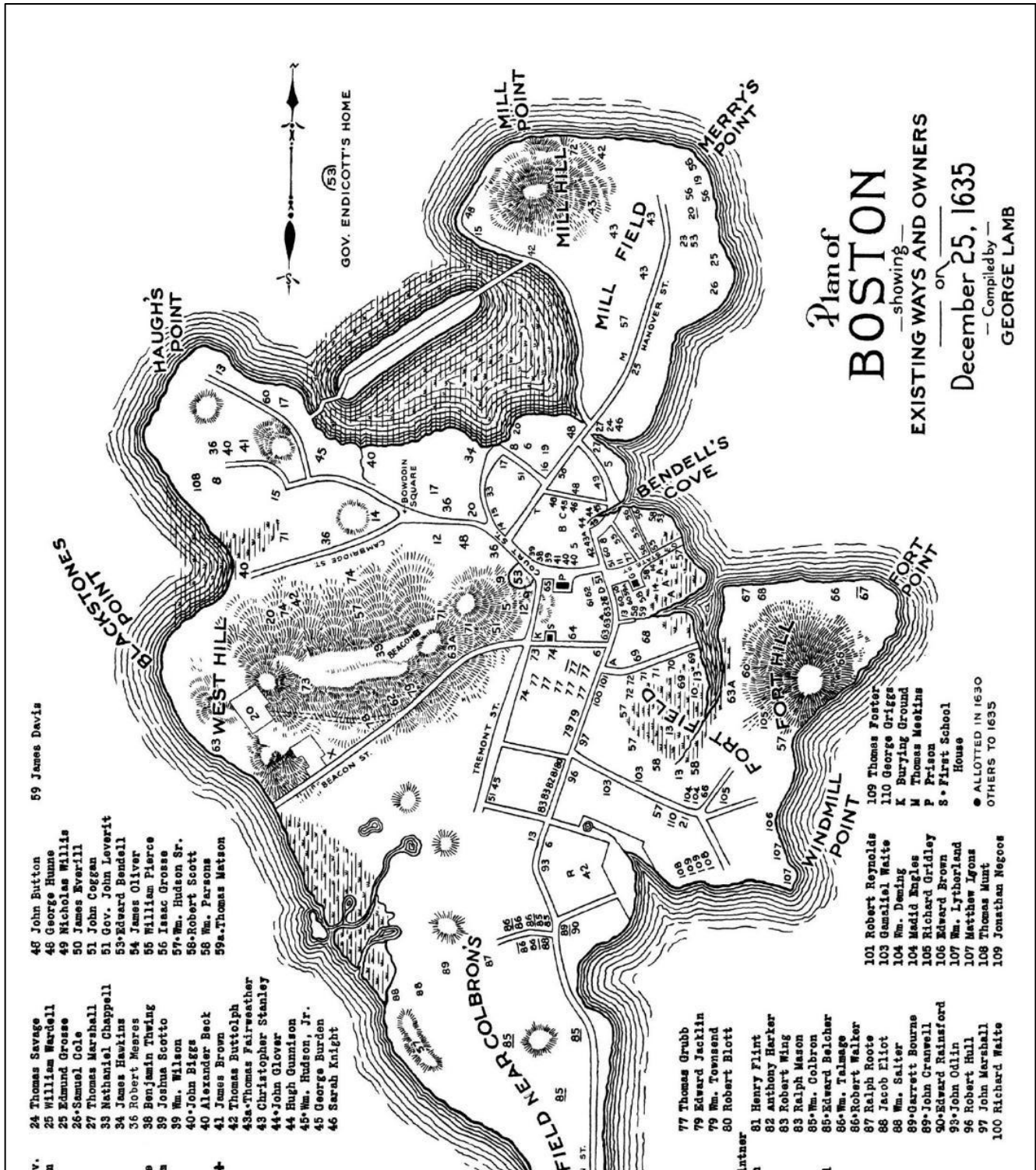


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MapJunction overlay 1770 Boston John Hills & ERSI Imagery





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