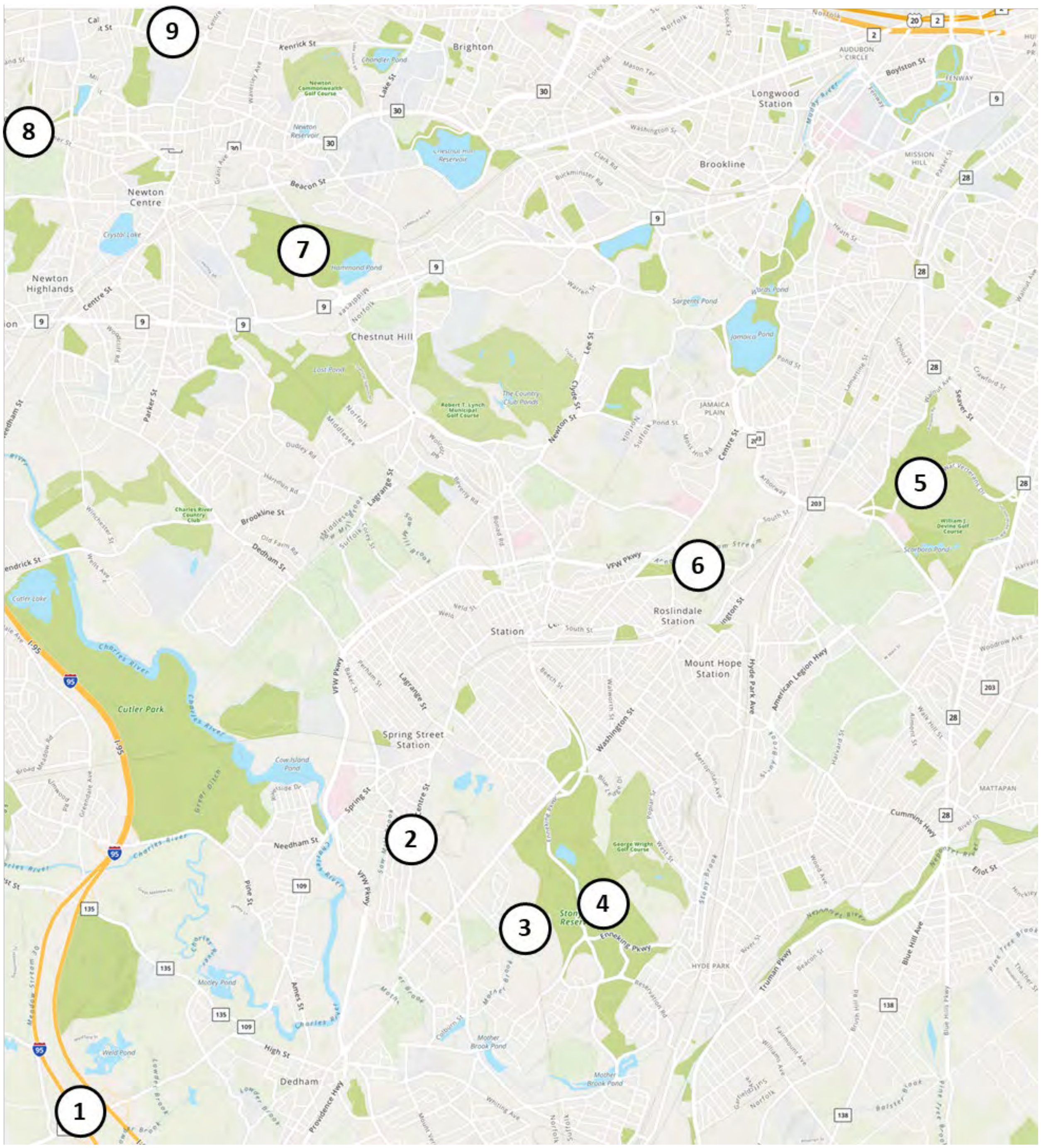
A Tour of the Boston Basin Rocks

Brookline Rocks! Web Site
March 24, 2021

This tour is designed to introduce you to the major types of rocks that make up the Boston Basin in a one-day trip. With the exception of the first stop, this tour presents a series of stops to see these rocks in the order in which they formed. Locations are provided for the use of GPS. The map below shows the location of all these stops.



The opportunity to see this range of rocks within a geographically compact area is due to the extensive changes these rocks underwent after deposition. Tectonic stresses on the basin resulted in the development of faults in the rocks, with movement occurring between the different blocks of the fault. Some of this movement may have been horizontal, but fault blocks were also displaced vertically with respect to each other. After displacement, subsequent erosion exposes rocks of different kinds that were formed at different dates next to one another.

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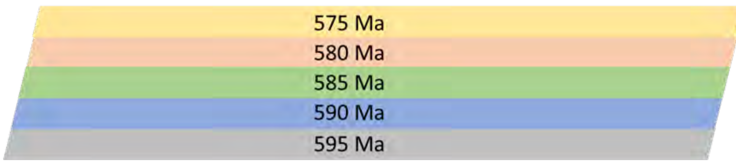
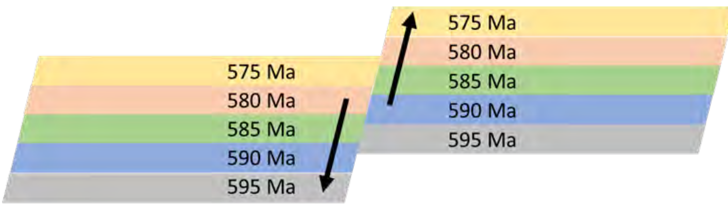
<tr><td>
</td><td>Over time, a number of different rock layers are deposited.</td></tr>
<tr><td>
</td><td>Stress on the rock layers causes faulting, with some of the layers displaced vertically relative to the others.</td></tr>
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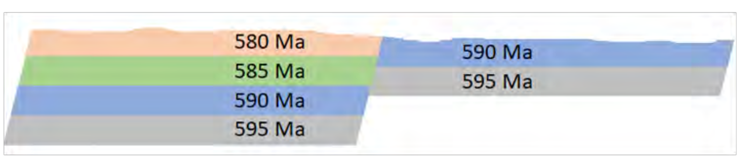
</td><td>Subsequent layers of rock are deposited on top of the faulted units.</td></tr>
<tr><td>
</td><td>Over a long period, the overlying rock is eroded. This erosion eventually exposes rocks of different ages next to each other.</td></tr>
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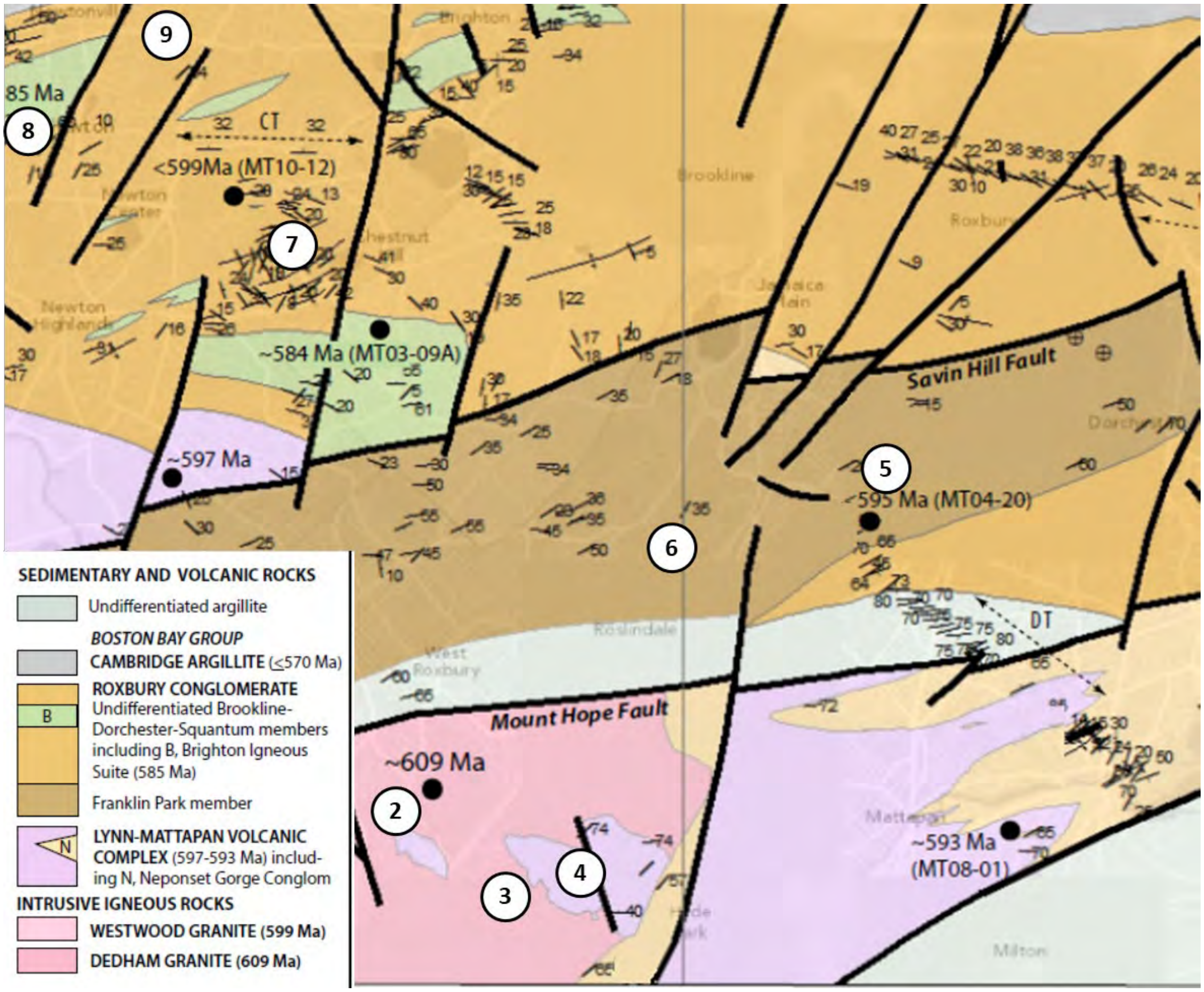
The figure below shows the tour stops from above laid on top of a map of the basement geology of the area (Thompson *et al.* 2014). While in general, rocks in the southern part of the map are older than rocks in the northern part, rock displaced by faulting (black lines) often changes where outcrops of specific rocks appear. Radioisotopic dating of these rocks (some sampling sites with attendant dates are shown with large black dots), accomplished over a 20-year period by Dr. Margaret Thompson's group (Wellesley College) in collaboration with the MIT Radiogenic Isotope Laboratory, has helped provide a context for interpretation of the geological history of the area. Nevertheless, a number of questions still remain to be answered about the development of the Boston Basin.



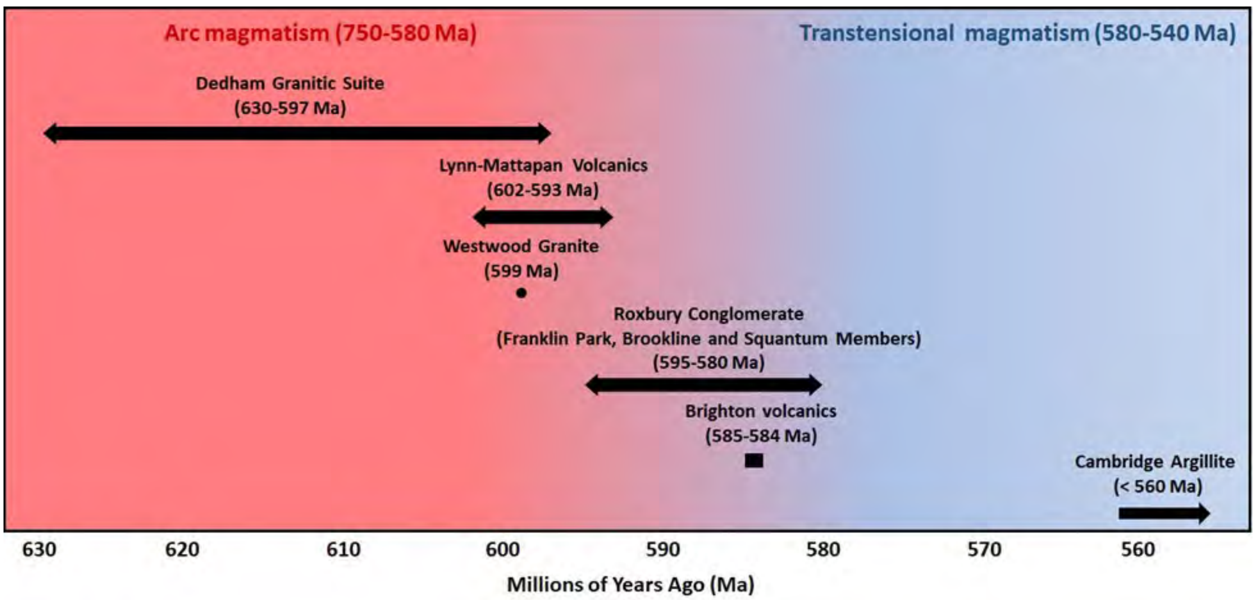
The tour stops shown atop a map of the basement geology of the area. Map is from Thompson *et al.* 2014 (used by permission from American Journal of Science). Thick black lines mark major faults within the area. Small lines with numbers denote strike and dip of sedimentary deposits. Longer lines with arrows show the axis for folds. Dotted lines show location of underground drainage tunnels.

This tour does not include a visit to the Squantum Member of the Roxbury Conglomerate. The best-published example of this deposit is the so-called Squantum tillite exposure at Land's End in Quincy. This site is worth a tour on its own, and there are several published studies that can be used to enrich such a visit. In-depth discussions are found, for example, in Shannon Carto's 2011 Ph.D. thesis (with lots of great pictures!) and in Galli and Bailey's field trip guide (2018).

Please note that many of these stops are in parks and wooded areas. In parks and reservations, please do not use hammers on samples or take anything with you but memories and pictures. In the wooded areas, watch out for poison ivy and use insect repellant to avoid tick bites! Finally, if you are following directions in your car, keep your eyes on the road. Pull off to check directions, use GPS, or have someone help guide you.

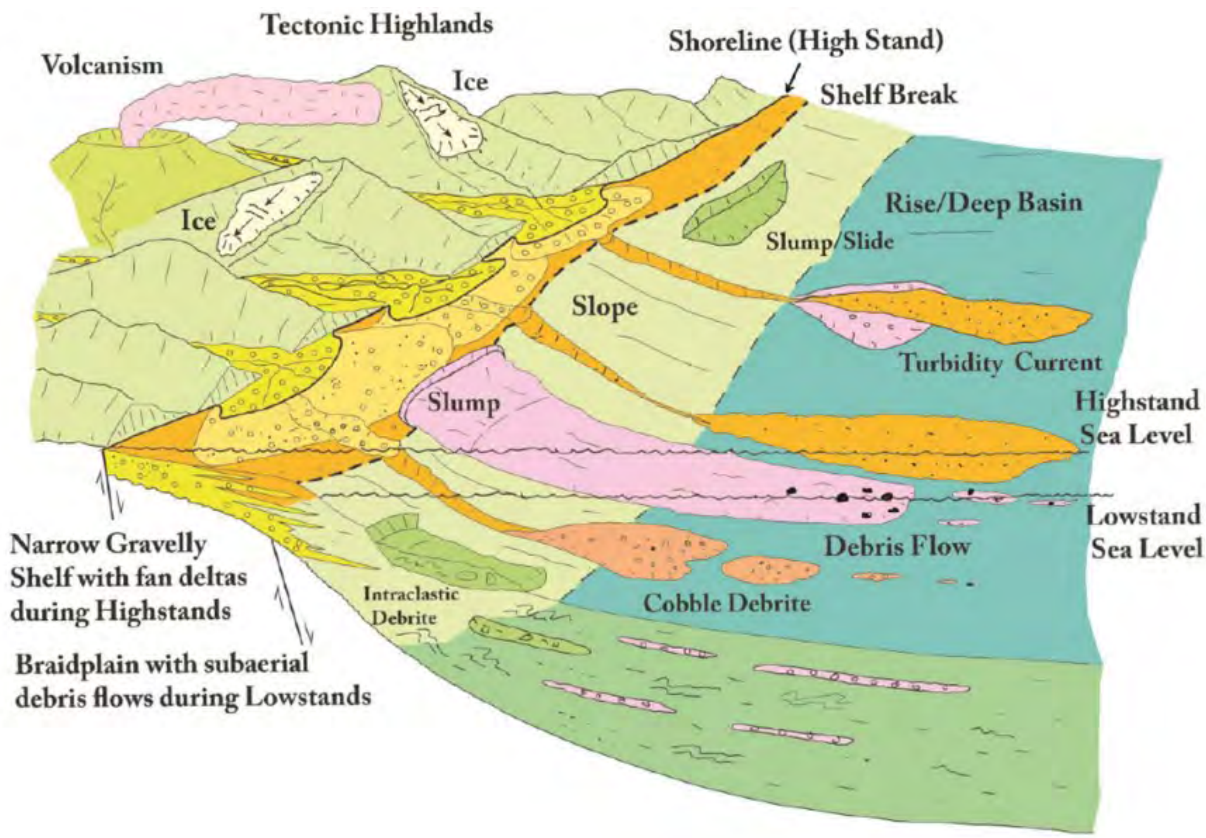
Geological Summary

The rocks to be viewed on this field trip cover a 25-million-year stretch of time from about 610 Ma to about 585 Ma. This time period marks the latter part of the main magmatic arc phase for the microcontinent of West Avalonia, which at that time lay offshore the supercontinent of Gondwana (near what is now the northern coast of South America). Some time after the last of these rocks were deposited, the edge of the island arc collided with the oceanic ridge that had been supplying crust for subduction, and the environment transition from being an active magmatic arc over a subduction zone to becoming a relatively quiescent geological environment. The rocks on this tour chronicle this transition.



The earliest igneous rocks from the area—the Dedham granite and Westwood granite (stops 1 and 2)—are products of the active magmatism fed by the subduction zone beneath the microcontinent of Avalonia. They were likely deposited before the Boston Basin was formed. Its formation was most likely a result of back arc or intra-arc faulting that is common to such environments. This faulting event was accompanied by the intrusion of basalts into the older granites (stops 1 and 2) as well as the production of the extrusive Mattapan volcanics (stop 3). As the basin formed, rock eroding from the surrounding area washed down into the basin, leaving sedimentary deposits that are known as the Roxbury Conglomerate (stops 4-6). For the most part, the clasts contained within the Roxbury Conglomerates are derived from these previously deposited granites and volcanics. Toward the end of the period of subduction, an additional period of volcanic activity led to eruptive deposition of lavas and ash flows on top of these conglomerates or the intrusion of igneous rocks within them (stops 6-8). After the deposition of the Brighton Igneous suite about 584-585 Ma, there is no further evidence of local volcanism until the time when Avalonia began to come in contact with other microcontinents and continental masses—more than 140 million years after basin formation. These more recent intrusive rocks are not definitively found at any of the stops of this tour.

In its current orientation, the basin generally opens to the east-northeast. The meta-sedimentary rocks of the basin are bordered on both the south and north by older intrusive and extrusive igneous rocks. The sedimentary rocks of the basin generally grade from older, coarser conglomerates in the south to mudstones in the north. There is evidence that a major portion of the Boston Basin was under water during its formation (e.g., the presence of turbidites—a distinctive marine deposit—and fine mudstones), perhaps opening into a shallow sea. These deposits are typical for this kind of island arc basin. Some of the volcanics in the area also show evidence of being deposited underwater. In the northern part of the basin, the sediments are dominated by massive mudstones, which eventually formed the rock of the Cambridge Formation (previously called Cambridge argillite, stop 9). The figure below provides an illustration for the possible environment of deposition for most of the rocks on the tour.



Source: Galli KG, Bailey RH. Field guide to sedimentology of the Ediacaran Roxbury conglomerate, Boston Bay Group of eastern Massachusetts. 2018.

It is likely that the shoreline of the basin area changed with the progress of erosion, the development of new volcanoes or basaltic eruptions, and the rise or drop in sea level, in part due to regional or more global ice age periods. There was a time when many geologists attributed the deposition of sedimentary rocks in the Boston Basin to glacial activity. That is in part because much of the Roxbury conglomerates are poorly sorted conglomerates in a fine matrix, the original location of Avalonia during this deposition was near the south pole and, during the period of Avalonia's formation—a time called the

Neoproterozoic Era, there is evidence of regional and global glaciation. Nevertheless, the current consensus is that clear evidence of direct glacial influence on the formation of these sedimentary deposits is lacking. However, glaciation may have occurred even locally and would have contributed to erosion of the source rock and feeding the streams that carried sediments into the sea. This nuance is captured in the diagram of deposition above.

Over the intervening 580 million years, the Boston Basin rocks have been subject to stresses that fractured, folded and transformed the rock into metamorphic versions of the original rocks. The many major faults that cut through the area can be seen in the area geological map above. The evidence of fracturing, folding, faulting, and metamorphic alteration of the rocks can be seen at many of the stops. Some of these are fingerprints of the collisions between Avalonia and other microcontinents and with Laurentia during its initial amalgamation to the North American continent, and finally its being crushed between Laurentia and Gondwana as the supercontinent of Pangea formed and then buried beneath miles of rock eroded from the mountains formed by these collisions. After all this time, erosion has finally re-exposed the basin to the surface, providing us an “outdoor museum” of ancient Avalonia to explore.

Field Trip

Stop 1: Westwood Granite

Interchange of 109W and Route 95; Westwood/Dedham

This tour starts with the Westwood Granite, as it is the most geographically separated outcrop from the others, to minimize driving time on the tour. If you do want to visit each stop in order, do stop 1 first and then stop 2. There are two quick stops in the Westwood area to see these outcrops.

Stop 1a: Meditech Executive Center, 200 Lowder Brook Drive, Westwood, MA (42°14'21.4"N, 71°12'32.7"W)

<u>Directions</u>
Lowder Brook Road is located off of 109 (High Street) just west of Route 95, on the south side of the road. It can be accessed from either direction.
Enter by the main road and turn left to go to the Meditech Executive Center.
At the stop sign turn right to 200 Lowder Brook Drive.
You will see outcroppings of Westwood Granite on the left side of the road.
At the first left, turn into the parking lot and park in the visitor area.

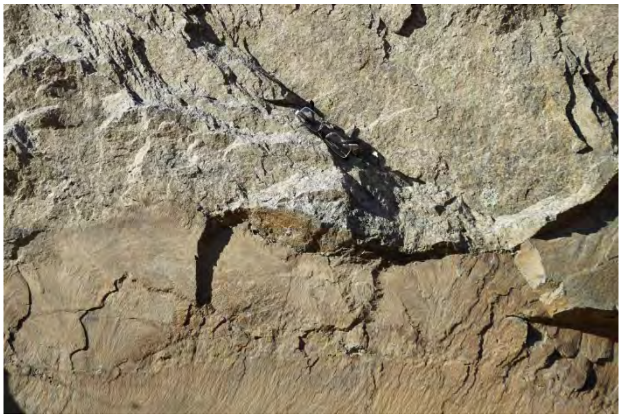
Westwood Granite forms small lenses of light-colored (light-gray to pinkish-gray), fine- to medium-grained granite intruding Dedham Granite and older rocks. No reports of cobbles of Westwood Granite have been found within Roxbury Conglomerate, suggesting that Westwood was not exposed to erosion at time of deposition of Roxbury Conglomerate. Originally, Westwood granite was dated at 579 +/-28 Ma (Fairbairn *et al.* 1967). More recent uranium-lead isotope dating by Thompson *et al.* (1996) evaluating zircons from four samples obtained at the interchange between Route 128S and Route 109W (near where this stop is located) yielded an upper age of 599 ± 1 Ma. At this stop a relatively pristine outcrop of Westwood Granite can be seen (likely shaped as part of the landscaping of the commercial park), making it possible to see the pinkish-gray color and the relatively fine-grained texture. The granite here, and at the second stop, is full of fracturing representative of the stress visited on the rock over time, as well as the effects of surface weathering.


Stop 1b: Deerpath Road, Dedham, MA (42°14'45.5", N 71°11'51.7"W)

<u>Directions</u>
Depart the Meditech Executive Center and return to Route 109 (High Street). Turn right. Go about 0.7 miles, crossing over Route 95/128. You will see additional granite outcrops at the ramp areas on the left.
Look for Deerpath Road, just past the interchange and turn left.
The outcrop of interest is at the entrance of the street. Park on the right side of the road.

The granite at this location is highly weathered and the color of the rock is hard to discern due to the weathered patina. Here it tends to be a more grayish color compared to the Lowder Brook outcrop. This outcrop is of interest because it contains a later inclusion of dikes (vertically intruded igneous rock) and sills (horizontally intruded igneous rock). This darker, denser, basaltic rock appears to have intruded into the granite with little mixing with surrounding rock. The intrusions seen here are similar to those in the Dedham Granite (stop 2). Those intrusives have been identified as part of the Mattapan volcanics suite, so if these are related, they may have been emplaced at the time when extensive back arc or intra-arc rifting was occurring, when cracks in the crust would have allowed basaltic magma to intrude into the existing rock. These basalt intrusions may have occurred during the formation of the Boston Basin.

The outcrop on Deerfield Road contains a large basalt sill intruded into the granite. Note in part of the basalt a very large chunk of Westwood granite was broken off and "floats" in the sill matrix. If you go out to High Street and follows the sidewalk toward the interchange at 95 (after the sidewalk ends stay well off the road!) a large, weathered mafic dike can be seen splitting the outcrop.



Two views of the contact between Westwood granite (above) and intruded basalt (below). On right, one can see fractures within the basalt where quartz has crystallized. Glasses are 5.5 inches.

Two views of Intruded basalt cutting through Westwood granite. The fracturing of the granite is obvious. At left, a basalt dike.

Stop 2: Dedham Granite, Mattapan Igneous Rock

West Roxbury Crushed Stone Quarry, 10 Grove Street, West Roxbury (42°16'07.2"N 71°09'42.0"W)

Directions

Depart Deerpath Road, turning left on High Street.

Follow 109E (High Street) for 1.9 miles into West Roxbury. High Street changes to Bridge Street in Dedham. After the intersection of Bridge Street and VFW Parkway, it is called Spring Street.

At the intersection of Spring Street and Cypress Street, turn right.

Cypress immediately ends at Baker Street, turn right.

Follow Baker street 0.4 miles until it intersects with Centre Street, turn right.

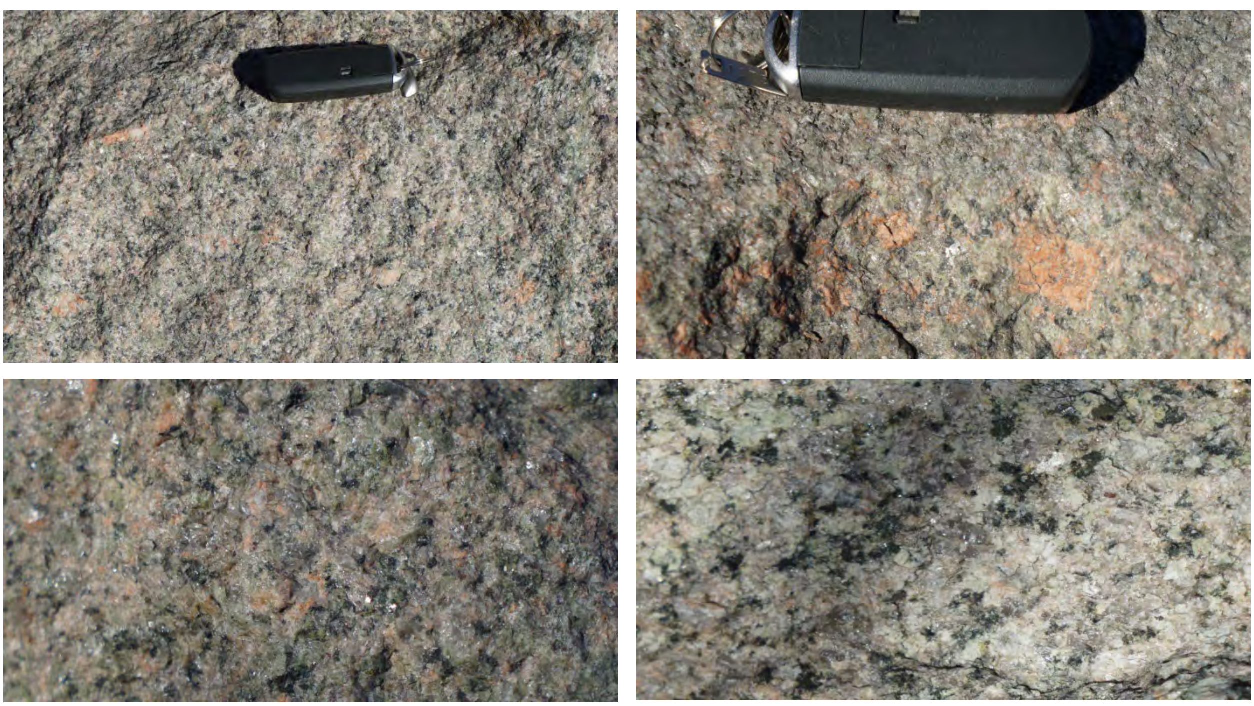
After 0.2 miles, continue straight onto Grove Street. You will see the quarry entrance on the left. Park in the parking lot across the street on the corner of Centre and Grove Streets, or on either side of the road further down the street.

The West Roxbury Crushed Stone Quarry has been active since 1887. It is private property, and for site access you must contact the office. However, parts of the quarry can be seen from the road and there are numerous examples of stone from the quarry presented along the side of the road. The quarry penetrates Dedham granite that borders the southern and western margins of the Boston Basin. Thompson and her colleagues (2014) performed uranium-lead isotope dating on samples from the quarry and determined a formation date of about 609 Ma.

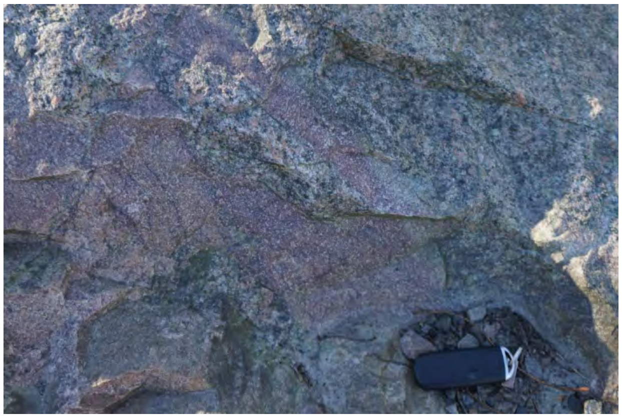
This rock was intruded under the surface of the ground, in a large formation called a pluton. This pluton was formed when crust subducted under Avalonian island arc melted in the presence of seawater and began to ascend through the rock above. In modern island arc environments, such melting tends to occur between 100-150 miles down. As this mass of magma ascended, it melted surrounding rock, changing the composition of the magma. In this case the magma cooled before it reached the surface, forming a large igneous intrusion.

Plutons may not be formed in one step at one time but may also accumulate through ongoing melting that occurs deep within the earth, that incrementally contributes new magma and rock to the growing pluton. Each of these melts can have a slightly different composition, and re-melt the previous plutonic rock, or mix with the existing magma. Within the magma body, circulation of magma can cause crystallized minerals to be separated from the remaining melt, which may solidify at a later time. The process of selective crystallization results in changes in the remaining magma, a process called fractionation. All these factors can result in variations of rock type within the same pluton. You will be able to see some of these variations in the rock samples at the quarry. There are also differences in mineral size in the rock, reflecting the rate at which different parts of the granite cooled. Some of the pluton eroded into the Boston basin after it was formed and can be found as clasts in the Roxbury conglomerate.

Along the edge of the quarry on Grove Street, and further down the street, Mattapan igneous rock can be seen. These are darker, mafic (rich in magnesium and iron) magmas. In some cases these magmas intruded into the Dedham granite while under the ground; in other cases they were deposited on top as lava. The contact edges between the basalt and the granite that can be seen at the quarry and down the street suggest these local deposits were intrusive. The intrusions may be contemporaneous with the intrusions seen in the Westwood granite.



Variations in the mineral composition and size in the Dedham granite. For size reference for feldspar crystals, key fob is 3 inches.




Left: variations of granite composition within the rock. Right: Metamorphic modification of granite to chlorite (greenish bands).


Left: basalt outcrop showing glacial rounding.

Right: contact between the basalt (bottom) and granite (top). Note greenish zone of alteration at the contact point between the two rocks.

Stop 3: Mattapan Volcanics

Stony Brook Reservation, West Boundary Road, Hyde Park (42°15'36.6"N, 71°08'42.6"W)

Directions
Head south down Grove Street 0.4 miles to Freeman Avenue, turn left.
Follow Freeman Avenue 0.1 miles to Washington Street, turn left.
Follow Washington Street 0.5 miles to West Boundary Road.
Follow West Boundary Road South. There are two places to stop, both on the left side of the street. One is at the gate for the Johnson Path, about 0.3 miles down the road, the other is the gate for the Overlook Path, located at a sharp bend about 0.6 miles down the road. At either location, Mattapan volcanics can be seen from the road.

Taking the Overlook Path, the rock outcroppings will be seen running along the trail on both sides, but mainly on the left.

The outcrops at this location are igneous rocks formed by eruptive processes. While we often think of lava flows being the main type of eruptive igneous rocks, the Mattapan volcanics were formed in a variety of ways: as lava flows and domes, ash deposits and flows (tuffs), eruption of broken, angular fragments welded together (breccias). The Mattapan volcanics are similar to the eruptive rocks of the Lynn volcanics to the north of the Boston basin and were deposited during the same time frame. Both lie unconformably on Dedham Granite and other unnamed plutonic-volcanic complexes in eastern MA. This means that parts of the Dedham granite were exposed to the surface and eroded before Mattapan deposition (conformable deposition means one layer is deposited on top of the other without a noticeable gap and erosion). The Mattapan volcanic are conformably and fairly continuously overlain by Roxbury Conglomerate of Boston Bay Group. The difference between the transition of Dedham granite to Mattapan volcanics and Mattapan volcanics to Roxbury conglomerate suggests that the Boston Basin had formed after the formation of the Dedham granite and before or during the time when the Mattapan volcanics were deposited. The Mattapan volcanics have been given a Proterozoic age of 602 ± 3 Ma based on U-Th-Pb zircon dating (Kaye and Zartman 1980). More recently, the work of Thompson *et al.* (2014) established a date of 593.2 ± 0.7 Ma for the Mattapan rocks.

Top Left: Volcanic outcrops line the Overlook Path in the Stony Brook Reservation. Top Right: Glacially eroded tops of Mattapan Volcanics outcrop. Bottom Left: rhyolite outcrop on Outlook Path. Bottom Right: close-up of rhyolite showing reddish color (directly under key fob, which is 3 inches in length).


Ash flow tuffs showing different size volcanic fragments.


Left: Tuffs with small rounded glass inclusion and larger fragments. Right: Tuff with flattened glass inclusions.

Stop 4: Neponset Gorge Conglomerates

Stony Brook Reservation, Rooney Rock, Turtle Pond Parkway, Hyde Park (42°15' 7.3"N, 71°8'15.0"W)

Directions

Departing either stop along West Boundary Road, head south until you reach the intersection with Georgetown Road, turn left.
Follow Georgetown Road 0.3 miles to Dedham Parkway, turn right.
Follow Dedham Road just 300 feet to Alwin Street, turn left.
Follow Alwin Street 0.2 miles to Turtle Pond Parkway, turn right.
Follow Turtle Pond Parkway 0.4 miles. You will see a sports complex and parking for the Stony Brook Reservation on the left.
Turn into the entrance, head to the main parking area north of the Bajko Rink and south of the Olsen Pool.
Park in the very northeast part of the lot. You will see a trail entrance heading northeast from there.
Follow the trail on the east side of the pool to trail marker 104; continue about 500 feet. You will see Rooney Rock ahead.

In this part of the reservation can be seen a variety of granitoid rocks (granites and quartz porphyrys). The lower part of Rooney Rock is made up of these kinds of rock. There is no definitive identification of the granite; it may be a part of the Dedham pluton (Kaye and Zartman 1980). The interesting aspect of this outcrop is that conglomerate lies unconformably atop the granite. An unconformity is when one type of rock is exposed to erosion before the deposition of the other rock. The uncomformity layer is typically not even. The clasts within the conglomerate overlying the granite are composed of different type of igneous rock than the granite underneath. These have been identified as deriving from the Mattapan Volcanics (Thompson 2014)—the type of rocks seen in the last stop. They are therefore not part of the Roxbury conglomerates, but evidence of local erosion of the Mattapan igneous rocks.

A view of the top of Rooney Rock from the south side showing the unconformity between the granitoid rock, which had been eroded, leaving an uneven surface, before the deposition of the conglomerate. The broken line traces the contact between the two types of rocks.

Stop 5: Roxbury Conglomerates, Franklin Park Member

Franklin Park, Roxbury

Stop 5a: The Wilderness, Franklin Park (42°18' 17.9"N, 71°5'43.3"W)

<u>Directions</u>

Head back to Turtle Pond Parkway and turn right, heading north.
Stay on Turtle Pond Parkway about 0.7 miles until at the intersection of Turtle Pond Parkway, Dedham Parkway, and Enneking Drive, continue straight on Enneking Drive.
Follow Enneking Drive 1.4 miles until the intersection with Washington Street.
At the light continue straight, where the road turns into West Roxbury Parkway.
Follow the West Roxbury Boulevard for 0.9 miles until the rotary, turn right to Centre Street (first right in the rotary).
Follow Centre Street for 2.1 miles, past the Arnold Arboretum.
At the rotary, take the first right to Arborway heading south with the Arboretum on the left.
Follow the Arboretum 1.2 miles through the intersections at Forest Hills T Station.
Stay in the left lanes to make a left at Circuit Drive/North Jewish War Veteran's Drive.
Drive past the Shattuck Hospital and follow the road about a half mile.

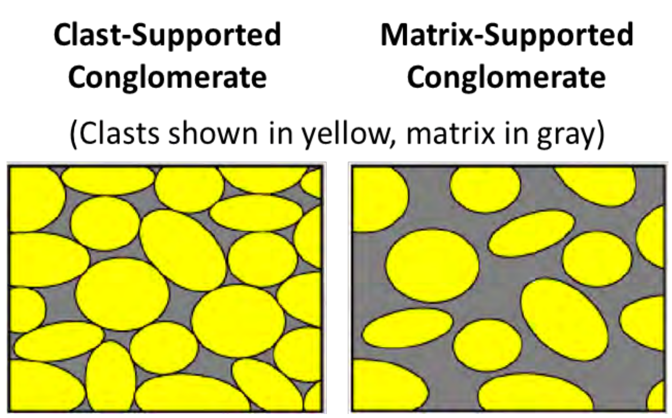
You will see a parking lot on the left side of the road. You can turn around at the triangle intersection ahead. The lot is currently locked but you can park along the road by the parking lot. Alternatively, you can park along the south side of the road in a designated parking area.
Walk northwest across grass to Gate 7.
Follow paved path into the park area. This part of Franklin Park is called the Wilderness. There are numerous outcrops of Franklin Park Member throughout this area. Feel free to wander along the paths in this area that follow numerous conglomerate outcrops.

To find the sandstone outcrop discussed below:

Follow the paved path ~400 feet north from Gate 7 past sign on left to Wilderness Picnic Grove.
At the sign, follow the gravel road to the right about ~100 feet. You will come to an intersection with an old carriage road (with stone fences) that head back toward the road. Instead, follow the gravel road to the left (westward).
The gravel road will give way to a dirt path. Ahead you will see the remains of several picnic tables. You will pass these to the right.
Immediately after the tables, a dirt path goes off the the left (Westerly). Follow the dirt path about 400 feet up and over top of a small hillock with Franklin Park outcrops. You will start to head down the hill with outcrops on both sides of the trail. Look for an outcrop running down the hill to the right side of the path. The sandstone outcrop is toward the end of the bed.

Compared to other members of the Roxbury conglomerate, the Franklin Park Member is highly variable and poorly sorted. The conglomerate in the Wilderness area is consistent with this characterization. Clasts within the matrix can reach almost a foot in length. The orientation of the clasts in most of the beds appear relatively random, with no clear suggestion of a bedding orientation. In most cases larger structures that might show bedding are also absent. The exception may be at large outcrop along one of the paths that suggest a south-sloping direction for the join between two distinct bed members (see image below).

In many outcrops, the matrix is clast-supported. This suggests that either large clasts predominate in the deposit or that the large clasts settled out first, with the matrix filtering in later. Thompson (2014) reported that the clasts in this area are predominantly composed of Mattapan igneous rocks, although granite and quartzite appear to be common among the largest clasts.



At one specific outcrop in the northwestern part of the Wilderness (see directions above), there is about a 4-5 inch section of layered sandstone that Thompson (2014) had concluded to be dipping in a southerly direction at about 10°. This bedding orientation accords with the general dip of a larger conglomerate bed the lines one of the major paths in the area

Examples of Franklin Park Member conglomerates in the Wilderness at Franklin Park. In these images, glove length is 10.5”. The largest clast in top right picture has a maximum length of 10 inches. The rock in this area appears to have a clast-supported structure.

Left: close-up of sandstone layer showing the gentle southward dip. Sunglasses are 6 inches for scale. Right: Large nearby outcrop shows same southerly dip in an apparent bedding surface between top and underlying layer.

Stop 5b: Scarborough Hill and Pond, Franklin Park (42°17'50.5"N, 71°5'55.5"W)

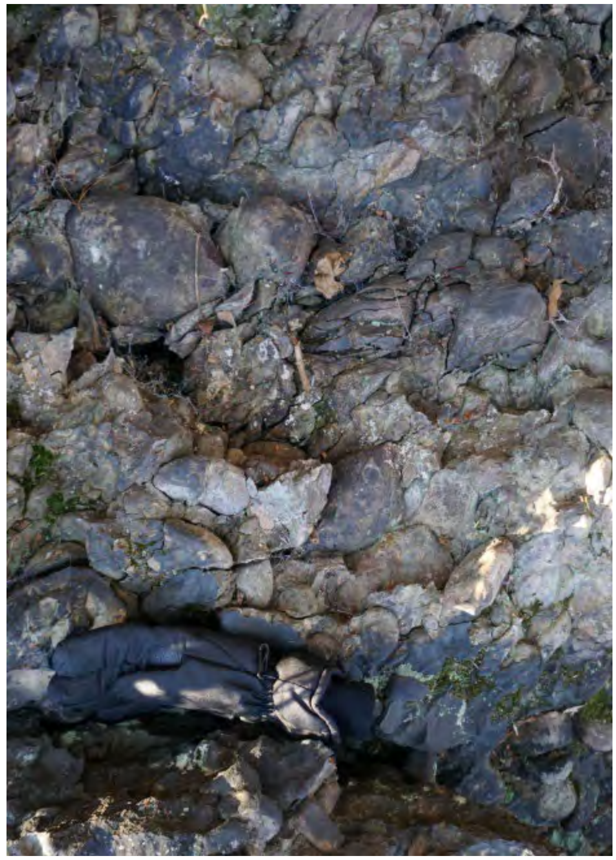
Directions
Return to the parking lot on Circuit Drive and head back toward the entrance of Franklin Park.
About 0.4 miles ahead is an intersection off the left that runs past Shattuck Hospital. Turn left.
Follow this road past the hospital.
Currently, there are one or more locked gates ahead (the second gate is at a turnaround). There will be signs pointing toward Scarborough Pond.
Park one either side of the street in one of the designated spots.

Trails here travel toward the Franklin Park golf course along the slope from the top of Scarborough Hill on the left side down to Scarborough Pond on the right. Take any of these paths to see outcrops of the Franklin Park Member. The largest exposure in this area is just to the north of Scarborough Pond.

The conglomerate here is smaller grained here than in the Wilderness, with the largest clasts less than 6 inches in maximum diameter. The clast assemblage here is also more diverse, featuring quartzite, felsite, a few mafic volcanic rocks and a stratified argillite (Thompson *et al.* 2014). Again, there is very little suggestion of bedding in any of the outcrops with the exception of an outcrop of coarse, dark red, pebbly sandstone within the deposit just north of Scarborough Pond that has a maximum thickness of about 40 inches. The sandstone has a steep southerly dip (60-65°, Thompson 2014).


Left: the large outcrop north of Scarborough Pond. Right: close-up of Scarborough Hill conglomerate showing the clast-supported structure.



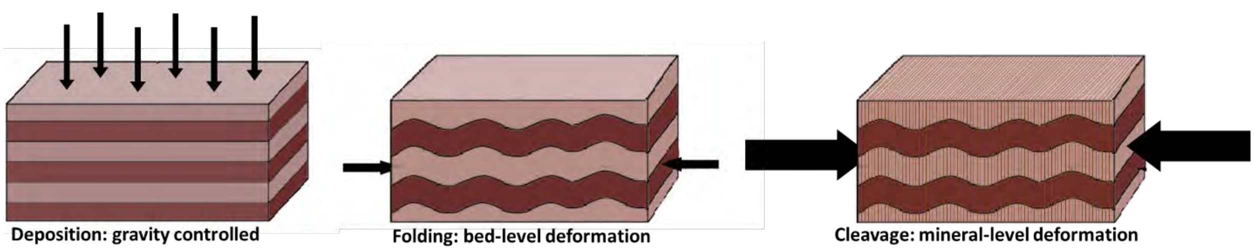


More examples of Franklin Park Member conglomerate in the Scarborough Hill area. For scale in some images, glove is 10.5 inches in length.

Some of the conglomerate outcrops in the area also show a distinct cleavage that is almost vertical (see image left). Compared to the bedding plane, which shows the orientation at which sediments were originally laid down, cleavage is a reflection of stress that was exerted on the rocks after their formation. The rocks of the Boston Basin have been subject not only to alteration by igneous intrusions, but also by multiple metamorphic events, including the collision between Avalonia and Laurentia, the impact of the microcontinent Meguma with Avalonia, and the collision between Gondwana with Laurentia that caught Avalonia in the middle. These collisions happen at a geological scale, involving the impact between trillions of tons of crustal material moving toward each other at about an inch per year and lasting tens of millions of years. Such impacts provide prolonged stresses of temperature and pressure sufficient to cause crystals and other materials inside the rock begin to re-orient, and cleavage layers form orthogonally (at right angles) to the pressure (see image). The near-vertical cleavage in the conglomerate suggests that the main stress was imposed almost horizontally (maybe from the impact of Gondwana during the formation of Pangea). We will see this same, nearly-vertical cleavage more extensively at the next stop, but look for it in the conglomerates at many of the following stops.

In the image shown above, the cleavage layers in the rock can be seen. It is also evident that the clasts themselves have flattened so that they have a more vertical orientation as well. This metamorphic alteration has not destroyed the original structure of the conglomerate, which can happen if the pressure and temperature is high enough for long enough. For this reason these kinds of rocks are sometimes referred to as “metasedimentary.” Although typically conglomerates are structurally weak, the metamorphism that has occurred in the Boston Basin elped make “Boston Puddingstone” an incredibly strong and resilient stone sufficient for use in building. As a result, it found its way into literally hundreds of buildings in the Boston area.

Apart from the formation of cleavage, there is also a change of bedding angles between 10° in the Wilderness and 65° here, suggesting that the Franklin Park Member has also been subject to folding. Indeed, there is extensive large-scale folding throughout the Boston Basin. Folding is another response to stress imposed by tectonic collisions. The fact that the angle of folding and the angle of cleavage are dissimilar suggests two separate incidents of metamorphism. It is possible that more gentle, early collisions earlier in its history (perhaps collisions between Avalonia and surrounding microcontinents or its initial contact with Laurentia) produced the crumpled folding of the beds of the Boston Basin, while the cleavage was the result of more intense stress at a greater depth, which would be appropriate to the formation of Pangea, where Avalonia would have been trapped between two massive continental blocks and then buried beneath miles of sedimentation shed from the mountains that resulted from the collision.



Stop 6: Roxbury Conglomerates, Franklin Member: Faulted Rock and Metamorphic Cleavage

Arnold Arboretum, Roslindale (42°17'46.4"N, 71°07'37.1"W)

<u>Directions</u>
Return to Circuit Drive and turn left to go back to Forest Hills Drive
Turn right at the light to head north on Forest Hills Drive.
Follow Forest Hills drive about 0.3 miles past the Forest Hills T stop on the left to the intersection of Forest Hills Avenue and Washington Street. At the light turn left.

Take the next right onto South Street.
Follow South Street for 0.6 miles until Bussey Street, turn right.
Follow Bussey about 0.4 miles over the hill and down toward Walter Street.
On the left you will see a fenced-in storage area on the left where mulch and branches from trimmed trees are stored. You can also see a tall vertical exposure of Roxbury Conglomerate.
Park along the side of the road (you can park on either side), cross into the storage area and approach the outcrop. If the storage entrance is locked, proceed west down the street to the south side Bussey Street gate into the Arboretum, and then enter the area through the side access road.

This part of the Arboretum is currently used for storage of trees and branches cut from the trees in the Arboretum and turned into mulch. In the past this was a working quarry the yielded stone used in construction of local buildings. As a result, there is a clean vertical rock face here.

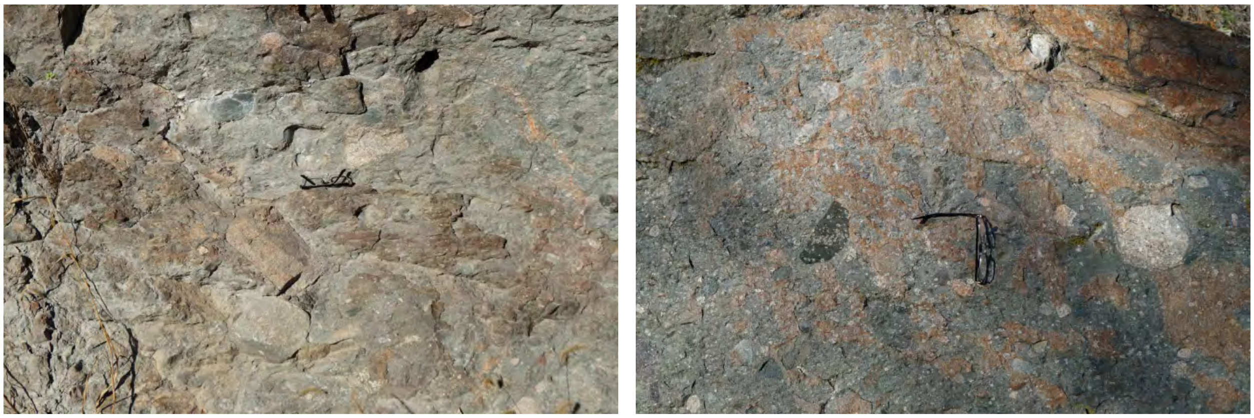
This exposure of the Franklin Member of Roxbury Conglomerate is notable for two things. First, there is a distinct, visible fault running through the exposure. Second, the difference between the bedding plane of the sedimentation and the cleavage plane from metamorphism are obvious. While a bedding plane is not obvious in the vertical rock cut, it can be seen in the low outcrop to the southern side of the west access road leading up into the Arboretum. Here, the bedding plane dips toward the north at approximately 25-40° depending on what part of the outcrop is measured. Depositional lenses can be seen in the cross section of the wall. In contrast, the cleavage plane here is almost vertical, similar to the cleavage at Scarborough Pond stop.

Left: View of the wall of the old quarry looking south from Bussey Street showing the angular fault in the rock cut face. Rock in the interface of the fault has been altered and the vertical offset is apparent by comparing the darkened area to each side of the right-most fault line.

Different views of the cleavage in the quarry face. Angle of the cleavage is about 75° and strikes roughly east-west.

The north facing rock wall bordering the western path out of the quarry area shows lenses of conglomerate. Bedding dips 25-40 degrees in a north-northwestern direction.

Outcrops on both sides of Bussey Street containing well-rounded to angular clasts of felsite, granite and quartzite, but also including a few mafic volcanic types. Unlike many of the outcrops in the Franklin Park Member, clasts here are generally “matrix supported,” suspended in an olive gray matrix. The larger clasts at this outcrop are about 10 inches, but the more typically size is about an inch.



Structure of the conglomerate at Bussey Street quarry. In image at left, the large clast in a middle measures about 8 inches along longest axis (glasses are 5.5 inches). Right figure show matrix-supported structure of the conglomerate.

Stop 7: Roxbury Conglomerates, Brookline Member and Brighton Igneous Suite (Extrusive)

Chestnut Hill Mall and Webster Conservation Area, Newton

For this part of the tour, we make three stops along the way to see some interesting aspects of both rock types. Examples of the Brookline Member of the Roxbury Conglomerate can, obviously, be seen all around Brookline. We chose this area because it features some unusual and interesting geological features and the Webster Conservation Area is a beautiful walk and a popular site for geological field trips.

Stop 7a: Chestnut Hill Mall, Newton (42°19'24.2"N 71°10'38.6"W)

Directions

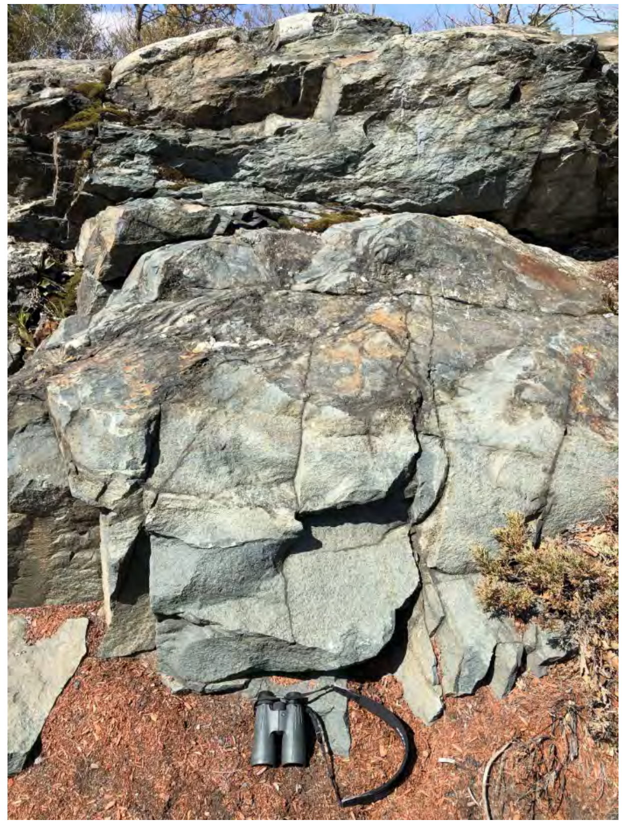
At the intersection, turn right on Walter Street.
Proceed 0.1 miles until the intersection with Center Street, turn left.
Follow Centre Street for 0.2 miles and turn slightly right onto VFW Parkway.
Follow VFW Parkway for 0.4 miles until the rotary, take the first right onto West Roxbury Parkway.
Follow West Roxbury Parkway 0.4 miles until it merges into Newton Street, continue another 0.5 miles until the traffic circle.
Take the second exit off the circle onto Hammond Pond Parkway.
Continue on Hammond Pond Parkway until you cross Route 9 and travel up the hill.
Look for the mall entrance at the first light at the top of the hill, turn left, and follow the entrance around into the parking lot.
Travel to the left of the parking garage toward the mall. You will see a rock outcrop on the northeastern border of the parking lot.
Park in a convenient area near the outcrop.

This outcrop runs for hundreds of feet along the edge of the upper-level parking lot. It transitions from entirely Roxbury Conglomerate on the north end to the appearance of intrusive basalt about half-way down. At the north end, the conglomerate has been shaped by glacial flow. At about the half-way point, a layer of sandstone appears at the top of the outcrop. The interface between the sandstone and the conglomerate here is undulating and shows how the moving sand scoured the surface of the conglomerate as it was deposited. As one moves southeast along this road cut, the sandstone shows more of appearance of small lenses of deposition, which may be from sand bar deposition. The dips of the beds trends north and vary between almost horizontal to about 40°.

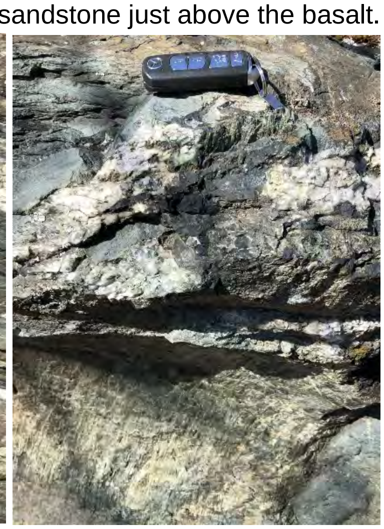
The Roxbury Member conglomerate at the northern end of the outcrop. Top left image shows rounded tops of outcrop from glacial scouring. Top right shows conglomerate in a rock cut.

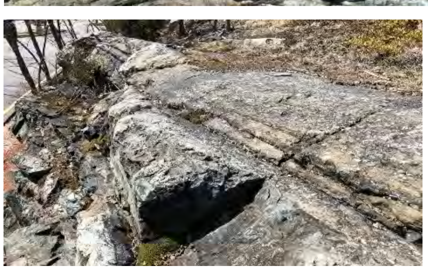
Left bottom: sandstone layer capping conglomerate about mid-way down the road cut. Layer shows angular bedding that may be suggestive of sand bar deposition. This feature is largely absent at the north end of where the sandstone appears.

Further southeast along the outcrop, an intrusive basalt appears below an upper portion of the conglomerate. At many points, the contact between the basalt and conglomerate is not clear because of the landscaping. Further down as the road begins to descend toward the lower level of the mall, the contact point can be seen, but is not clean. Rather, in the area near the top of the basalt sill, metamorphic modifications have been made to the basalt. There are lenses of dark green chlorite, which represent metamorphic modifications of the basalt, as well as fibrous asbestos. Above the basalt, the sandstone layer closest to the basalt layer has been baked into a hard, altered rock called hornfels. The top of the outcrop is capped by a conglomerate with relatively small clasts.



Top left: view of the basalt outcrop half-way down the rock cut. The blocky fracture cleavage in the rock is visible. On right, a view of the stack with conglomerate at the top (the more yellowish-orange rock is the Brookline Member. Middle left, a close up of the basalt shows the graininess of the rock. Lower left: top layer of conglomerate above the basalt intrusion. The layer has been rounded by glacial erosion. The top-most layer is composed of small conglomerate pebbles, which grade into sandstone just above the basalt.





Detail of alterations at the contact zone between basalt and conglomerate. Left: the contact zone shows the layer of heat-hardened hornfels just above the basalt. Right: modifications to the basalt below include alteration of basalt to chlorite and asbestos (see linear and fibrous rock at bottom of image). Near top of image under the key fob, quartz crystallization probably occurred after basalt intrusion, possibly from percolation of water through the deposit.

Stop 7b: Boston College Building, Hammond Pond Parkway (42°19'28.8"N 71°10'37.7"W)

Directions
Depart from the mall the same way you came in. At the light, turn left going north on Hammond Pond Parkway.
Continue on Hammond Pond Parkway about 250 feet. You will see a Boston College building on the left. Turn into the entrance and then turn to the left into the parking lot.
You will see an outcrop of Roxbury conglomerate just beyond the south edge of the parking lot nearest the road.
Park the car near that outcrop.

The Brookline Member of the Roxbury Conglomerate is considered to have been deposited after the Franklin Park Member and is distinguished by a greater variety of sedimentary rocks compared to the Franklin Park Member. It includes conglomerates, sandstones and siltstones (also called argillites). In the conglomerates, the clast sizes are smaller than those found in the Franklin Park Member. In contrast to the massively bedded appearance of the Franklin Member of the Roxbury Conglomerate, conglomerates of the Brookline Member often show clear bedding structures; in some deposits, clasts are more well-sorted and show flow alignment (with clasts lining up along their long axis in the direction of the bedding). The sandstones cover a range of grain size from coarse to very fine grained, and the siltstones (or argillites) are similar to those found in the Cambridge Formation. Different types of sedimentary rock may alternate in the same deposit, with coarser conglomerates sometimes grading to sandstones and then mudstones, or wild alternations between the types.

These differences suggest deposition in an environment where more sorting of sediments have occurred. This may be in part because Brookline Member deposits occurred further from their source rocks and the depositional slope may have been more gradual. Together these factors would result in smaller clast sizes and the opportunity for more working and sorting of the sediments. In many locations, these are interpreted as resulting from turbidite deposition, a kind of marine deposit formed where sediments flow down an underwater slope due to gravity slumping or earthquakes.

Some deposits in the Brookline Member have characteristics pointing to deposition in a marine environment. The deposits to be viewed here have characteristics suggesting either land-based (stream or river) or near-shore (e.g., tidal) deposition.

The outcrop to the south of the parking lot nearest the road contains sandstone layers alternating with the conglomerates. Near the bottom, one can see a layer about 9 inches thick featuring a continuous S-shaped (sigmoidal) cross-bedding that is an indication of either sand bar or tidal deposition. An animation of how these deposits are formed can be found here: https://www.youtube.com/watch?v=KYvWwbEi0A0. East of this area (e.g., Chestnut Hill reservoir and the Cleveland Circle neighborhood), there is clear evidence of marine turbidite deposits. The close proximity of turbidite structures and sand bar structures suggests that the environment of deposition for this part of the Boston Basin was on or near shore at this time.

Stop 7c: Webster Conservation Area (42°19'42.3"N, 71°10'40.4"W)

<u>Directions</u>
Return to Hammond Pond Parkway, and turn north.
Follow Hammond Pond Parkway another half mile. You will pass over a bridge running over the Green Line T.
Look for a sign indicating the Webster Conservation Area on the left side of the road. When you see it, turn around and park on the off-road parking.
Follow the trail about 300 feet almost past the rock outcrops on the right, then follow up to the overhanging ledges.
The basaltic flows described below can be found by descending to the trail leading along the base of the two large conglomerate outcrops. The basalt juts out from the base of the sedimentary deposits toward the west, forming a cliff area beneath the second, more northern, sedimentary outcrop.

The sequence here captures the diversity of Roxbury Member deposits found across the northern half of the Boston Basin. The smaller clast size and distinct interbedding of conglomerate, sandstones and siltstone can be seen here. While this location is a popular field trip stop and is well-described in a number of publications and field guides, the environment of its formation is still a matter of debate. There are characteristics here of both terrestrial and marine deposition. The large sandstone wedge found here has been attributed to deposition in a sand bar.In the northernmost outcrop, channel deposits of conglomerate can be found, which may have occurred in either a stream/river environment or in a marine turbidite flow. In some areas, ripple marks can be seen on sandstone surfaces.

Many of the clasts in Brookline Member conglomerates are composed of Dedham granite as well as quartzite (metamorphized sandstone) that may have eroded from the Westboro quartzite. Thompson et al. (2014) dated the youngest zircons in a sandstone layer above the basalt at around 599 Ma, providing an upper date for deposition of this rock. However, it is likely that this rock was originally deposited much later. If the basalt flow found at this location has a similar date to other Brighton Igneous deposits from the area, much of this outcrop was likely deposited after 584 Ma. In this scenario, these outcrops were laid down at the end of the very end of the magmatic arc period of Avalonia.

Top left: view of one of the outcrops at the stop from below. Top right: Alternation of conglomerates and sandstones, both with bedding structure. Bottom left: another view of alternating layers and bedding. Middle: Clasts are smaller than the Frankling Park Member (for scale, binoculars are 8 inches). Lower right: sandstone bedding showing large scale and diverse bed sets.

Image left shows trough bedding that is typically found in sand bars. Image right: Planar cross beds. For size comparison, key fob in both images is 3 inches.

The conglomerate here is also interrupted by Brighton Igneous Suite rocks in the form of a basaltic flow. Compared to the basaltic sill seen at the Chestnut Hill Mall, this deposit appears to be an extrusive lava flow. The upper part of the flow contains vesicles formed from gas release. Eroded clasts from the basalt can be found in the overlying sedimentary rock (Thompson 2014 and Galli and Bailey 2018). The basalt suggests land rather than water deposition, as basalt forms distinct pillow structures when extruded under water.

Top: a view toward the east showing the basalt flow at bottom, with the Brookline Member sedimentary stack appearing at the top. Bottom left: flow structures in the basalt. Bottom right: gas vesicles in the basalt. For scale, pen is 6 inches.

Stop 8: Brighton Igneous Suite

Valentine Street off Commonwealth Avenue, Brighton

<u>Directions</u>
Return to Hammond Pond Parkway and drive north until the intersection.
Turn left on Beacon Street, follow for 0.6 miles until Summer Street.
Turn right on Summer Street and follow as it turns into Willow Street, 0.2 miles.
Turn right on Centre Street and go for 0.2 miles until Commonwealth Avenue.
Turn left on Commonwealth Avenue, follow for 1.1 miles until Valentine Street.
After turning right on Valentine Street, you will see outcrops of rock on both sides of the street. Find a place to park on the street near some of these outcrops.

At this stop more extensive deposits of the Brighton Igneous Suite can be found. This is an andesite, which has more silica (SiO_2) than the basalt from the previous stop. It is a dark greenish gray and generally massive in character. Thompson et al. (2014) dated this sample to about 585 Ma. This date agrees with a number of other samples of the Brighton Igneous rock. While andesite is an extrusive igneous rock, there is some possibility that this rock was intruded in a shallow sill within the conglomerate (Tierney *et al.* 1968). On our own visit here, we saw some outcrops that appeared to have the characteristics of flow structure with much more layering, suggesting that some of the andesite may have been extrusive.

Left: example of the andesite outcrops on Valentine Street. Right: the upper part of an outcrop off Valentine Street shows what appear to be flow features on the surface.

Stop 9: Cambridge Formation(?)

Newton Country Day School of The Sacred Heart (TBD)

<u>Directions</u>
Return to Commonwealth Avenue and turn right.
Follow Commonwealth Avenue for 0.8 miles until Cedar Street. Turn left.
Follow for 0.2 miles until Mill Street. Turn right.
Follow Mill Street for 0.3 miles until Centre Street. Turn left.
Follow Centre Street for 0.3 miles until Colby Road. Turn left.
Proceed about 500 feet down the road, past a white mansion. You will see a lawn area between that building and a Boston College athletic field. In the middle is the outcrop. Park the car next to the lawn area.

In the Boston Basin, the sedimentary rock in the southern portion is largely metamorphosed conglomerates. In the north, it is mainly altered mudstones and fine-grained sandstones. These are the kind of deposits that would typically form in the outer (deeper) part of a basin. Normally, there would be an interfingering of these deposits. However, in the Boston Basin the Cambridge Formation appears to be thrust over the Roxbury Conglomerate or rests unconformably on earlier igneous rocks. Based on updated radioisotopic dating and a review of the geology of the Cambridge Formation, a recent study by Thompson and Crowley (2020) posits a much younger age for the Formation—with the earliest deposits around 260 Ma—representing a 20-million-year pause between the final deposition of the Roxbury Conglomerates (around 580 Ma) and the earliest deposits of the Cambridge Formation. This pause probably marks the ending of the magmatic arc period of this region of West Avalonia. Within this interpretive framework, the Cambridge Formation represents off-shore deposits in a tectonically-quiescent environment.

the most part, outcrops of Cambridge Formation are not visible at ground level in the Boston area, but are largely buried under glacial till. The mudstones at this stop were identified as being part of the Cambridge Argillite by Skehan (1979). However, in the latest bedrock map of the Newton Quadrangle (Thompson 2017), the border of Cambridge Formation is located somewhat to the north of this location. My suspicion is that this outcrop represents a relatively late deposit of the Brookline Member of the Roxbury Conglomerate that was formed in an offshore environment where mud was preferentially deposited. Nevertheless, it makes a decent stand-in for outcrops to the north and we include it here.

This is a small, isolated outcrop of finely laminated mudstone. The bed strikes in a north-northeastern area with a dip northwest at about 35°. There is also a very small fault which can be seen in the northeast edge of the outcrop, offsetting layers formerly continuous.

Top left: Possible Cambridge Formation argillite. Top right: view of argillite down the strike direction. Bottom left: close up of layering. Pen length is 6 inches.

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