A ROXBURY REVIEW

by
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INTRODUCTION

Conglomerate throughout the Boston Basin in eastern Massachusetts (Fig. 1) has long been called after the Roxbury district of Boston (early references in Holmes, 1859 and Shaler, 1869) and subdivided into three members typified by strata in the encircling communities of Brookline, Dorchester and the Squantum section of Quincy, MA (Emerson, 1917). NEIGC field trips, beginning with one led by W.O. Crosby in 1905, and also GSA-related field trips have provided regular opportunities for generations of geologists to debate the depositional settings of all of these rocks, particularly the possible glacial origin of the Squantum "Tillite". It appears, however, that none of these outings has ever included a stop in Roxbury itself (Table I and lettered localities in Fig. 1). A main purpose of this trip will be to visit the nominal Roxbury type locality in a section of the historic quarries where recent re-development includes the newly opened Puddingstone Park. Other stops will permit comparison of type Roxbury Conglomerate with other rocks traditionally assigned to this formation and highlight geochronological and paleomagnetic data bearing on the ages of these units.

Table I. Forty Years of Field Trips in the Roxbury Conglomerate

Trip leader(s)/year	Title	Stop locations (listed alphabetically; (abbreviations below)
Caldwell (1964)	*The Squantum Formation: Paleozoic Tillite or Tilloid?*	AR, CH, FP. SQ
Rehmer & Roy (1976)	*The Boston Bay Group: the Boulder Bed Problem*	AR, CH, RF
Bailey, Newman & Genes (1976)	*Geology of the Squantum "Tillite"*	AT, AR, CH, RO, SQ
Wolfe (1976)	*Geology of Squaw Head, Squantum, Massachusetts*	SQ
Cameron & Jeanne (1976)	*New Evidence for Glaciation during Deposition of the Boston Bay Group*	CH, NUF
Caldwell (1981)	*The Boston Bay Group, Quincy, Massachusetts*	AR, CH, FP, AT
Kaye (1984)	*Boston Basin Restudied*	SQ
Bailey (1986)	*Stratigraphy of the Boston Bay Group, Boston Area, Massachusetts*	CH, SQ
Hepburn,, Hon, Dunning, Bailey, and Galli (1993)	*The Avalon and Nashoba terranes (eastern margin of the Appalachian orogen in SE New England)*	NLF
Thompson & Bailey (1998)	*Ungrouping the Boston Bay Group*	HC, HN, SQ, WR
Hepburn & Bailey (1998)	*Avalon and Nashoba terranes*	CH
Bailey & Bland (2001)	*Recent developments in the study of the Boston Bay Group*	HC, HN, RN, SQ

AR, Arnold Arboretum (includes nearby Canterbury St. and Weld St. locations)
AT, Atlantic Avenue, Squantum section of Quincy, MA
CH, Chestnut Hill section of Newton, MA (includes Hammond Pond, Webster Conservation Area & Boston College)
FP, Franklin Park, Jamaica Plain section of Boston, MA
HC, Hewitts Cove, Hingham, MA*
HN, Houghs Neck, Quincy, MA*
NUF, Newton Upper Falls, Newton, MA (includes Wellesley Office Park at Rt. 9 and Rt. 128)
RN, Rocky Neck, Hingham, MA*
RO, Roslindale section of Boston, MA
RP, Ringer Park, Allston section of Brighton, MA
WR, West Roxbury, MA
SQ, Squantum Head, Squantum Section of Quincy, MA

* outside southeast edge of Figure 1.

LITHOLOGIC VARIABILITY OF ROXBURY CONGLOMERATE

Conglomerate in the Boston area falls into several geographic belts originally summarized by W.O. Crosby in his 1880 *Contributions to the Geology of Eastern Massachusetts* (detail of accompanying 1877 map as Fig. 1). Crosby's descriptions clearly establish considerable lithologic variability in conglomerate from belt to belt. The *Brookline and Roxbury Conglomerate Belt* covering approximately twenty square miles in the middle of the Boston Basin, for example, contains mainly large-pebbled conglomerate generally "wanting" in sandy or slaty beds that would permit attitude measurements (Crosby, 1880, p. 229). Maximum clast size varies from 4-9 cm in Roxbury (Stop 1) to14-33.5 cm (Stop 2) based on recent counts of the ten largest clasts within a representative square meter of outcrop surface. Whatever the size range, however, clast assemblages throughout the belt contain granite, volcanic rocks (felsic >> mafic), quartzite and other stratified varieties. The Dorchester Tunnel passes beneath this belt through more than 8,000 ft of similarly massive conglomerate before transecting a "white, kaolinitic layer of argillite" at the base of a sandier section that dips steeply to the south (Richardson, 1977, p. 254). The Brookline-Roxbury belt also stands out from neighboring belts described below because it contains no volcanic horizons.

In Crosby's *Hyde Park, Mattapan, and Squantum Belt* to the south, conglomerate "lies irregularly among and upon" volcanic rocks (dark gray domains in south central part of Fig. 1). Crosby (1880, p. 224) locally reports difficulty in distinguishing conglomerate from volcanic breccia in this belt, and much of this ambiguous rock has proven to be rhyolitic ash-flow tuff (Thompson, 1985; Thompson and Hermes, 1990). Conglomerate transected by the Dorchester Tunnel in this sector shows gradational contacts with neighboring volcanics, and is dominated by "reddish andesite pebbles and occasional large granitic cobbles" (Richardson, 1977, p. 268). This quartzite-free clast assemblage has lately been documented in surface outcrops in Hyde Park and east of Mattapan in Dorchester Lower Mills. On the Squantum end of this belt, and separated from the rest by a covered interval of approximately 2 miles, distinctive "slaty and sandy conglomerate" with "exceedingly coarse texture" (Crosby, 1880, p. 222-223) later came to be called the Squantum "Tillite" (Sayles,1914; diamictite of most recent workers). This rock stands out from other conglomerate in the belt because of its extremely poor sorting, because it contains quartzite clasts in addition to plutonic and volcanic varieties and because it is interbedded with purplish to brownish fine sandstones and mudstones.

North of the Brookline-Roxbury Conglomerate Belt, conglomerate is found bordering both sides of the mottled gray *Newton Lower Falls and Brighton Band of Amygdaloid* (west central portion of Fig. 1). These are "small pebble" conglomerates interbedded with thin bedded grayish, brownish and purplish, commonly ripple marked slate (Crosby, 1880). Recent studies document smaller maximum clast sizes than in the Brookline-Roxbury belt (4-6 cm in Newton's Webster Conservation Area for example; CH in Fig. 1). Quartzite, granite and volcanic rocks continue to be the most abundant clast types, however. The associated "amygdaloid" (Brighton Melaphyre of Zen, 1983) has been chemically analyzed to show generally basaltic compositions with SiO_2 around 50 Wt%, but some samples are andesitic with 61 Wt% SiO_2 (Cardoza et al., 1990 and unpublished data of Thompson). Crosby (1880) likens the structure of this belt (with generally dipping strata cut by numerous faults and dikes) to relations in the *South Shore District* stretching from Hingham to Nantasket Beach in Hull, MA (outside east edge of Fig. 1).

The eastern portion of the South Shore District appears in a later, exquisitely detailed map (scale 1" = 600 ft) of the Nantasket District (Crosby, 1893). The geology of the area consists of bedded sequences of conglomerate and mafic volcanic rocks disjointed by numerous high angle faults that bound topographic features with names like "conglomerate plateau" and "melaphyr (sic) plateau." The northernmost fault

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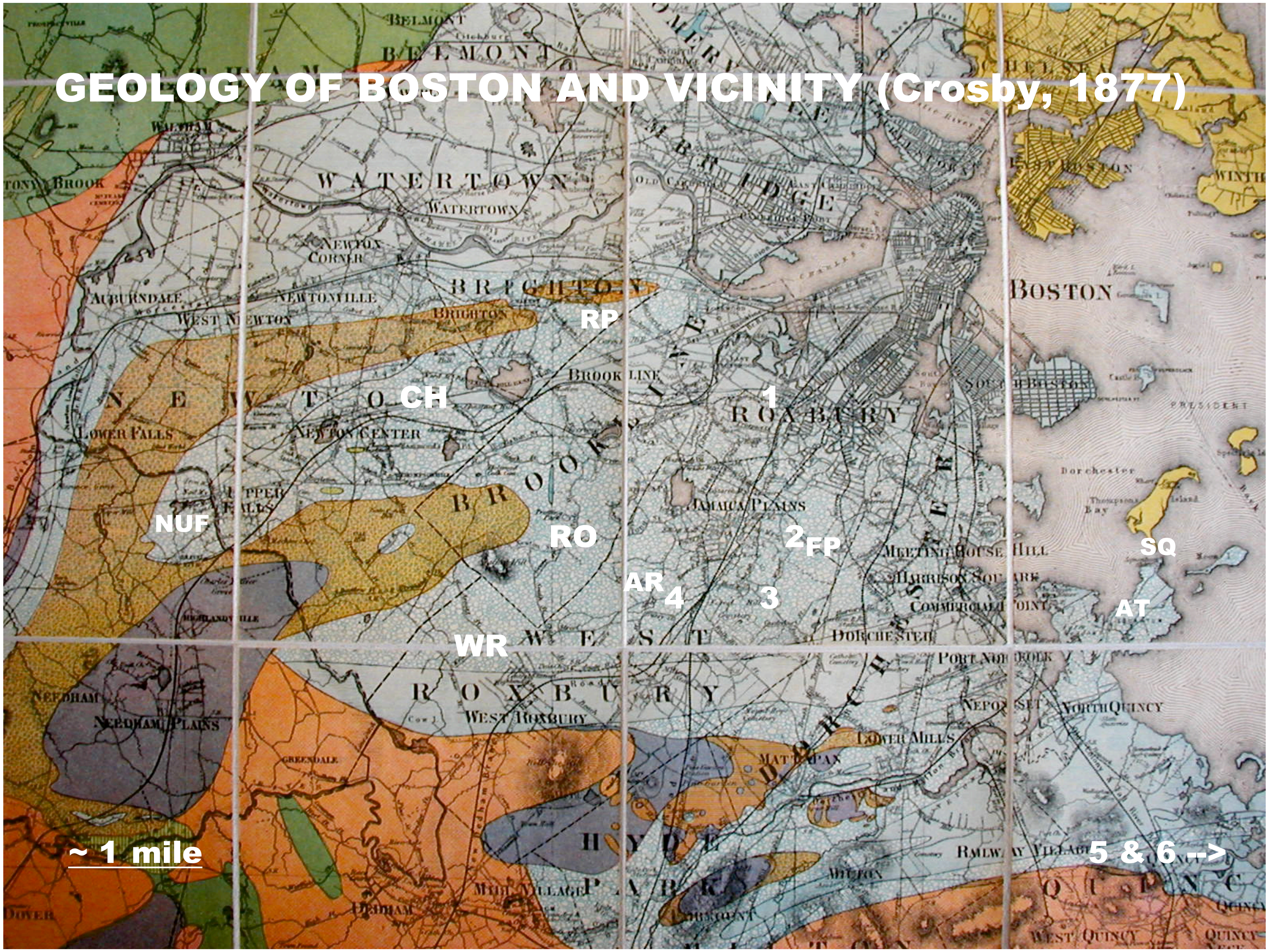
Figure 1 (facing page). Geologic map showing numbered locations where Roxbury Conglomerate (white stippled pattern) will be examined on this field trip. Letters mark locations of previous field trip stops listed in Table I. This map was prepared by W.O. Crosby for the Massachusetts Commission to the Centenniel Exposition and later explicated in his 1880 MIT doctoral dissertation entitled *Contributions to the Geology of Eastern Massachusetts*. This map provides a simple (and elegant) view of the regional distribution of Roxbury Conglomerate which was not yet subdivided into members. North parallel to right side of map.


GEOLOGY OF BOSTON AND VICINITY (Crosby, 1877)
RP
CH
NUF
RO
AR
4
1
2
FP
3
SQ
AT
WR
~ 1 mile
5 & 6 -->
BELMONT
WALTHAM
WATERTOWN
NEWTON CORNER
BRIGHTON
AUBURNDALE
NEWTONVILLE
WEST NEWTON
NEWTON
NEWTON CENTER
LOWER FALLS
UPPER FALLS
BROOKLINE
ROXBURY
BOSTON
SOUTH BOSTON
EAST BOSTON
JAMAICA PLAINS
MEETING HOUSE HILL
HARRISON SQUARE
COMMERCIAL POINT
DORCHESTER
PORT NORFOLK
WEST ROXBURY
NEPONSET
NORTH QUINCY
LOWER MILLS
MATTAPAN
HYDE PARK
MILTON
DEDHAM
NEEDHAM
NEEDHAM PLAINS
GREENDALE
MILL VILLAGE
DOVER
WEST QUINCY
QUINCY

block contains a south-dipping section beginning at Long Beach Rock with distinctive conglomerate composed of small pebbles of granite and siliceous volcanic rocks and many larger pebbles of different varieties of melaphyre. The section continues across Atlantic Hill and is cut off on the south by a fault (Crosby, 1893). Recent examination of conglomerate at Long Beach Rock and elsewhere around Hull, MA demonstrates the absence of quartzite in the clast assemblage. Several units of quartzite free conglomerate are also found interbedded with volcanic flows in the Rocky Neck section of Hingham in the western end of Crosby's map area (Ault, 2003). The flows in both sequences are basaltic with 44-54 Wt% SiO_2 (Cardoza and others, 1990 and unpublished data of Thompson). Volcanic ashes with are also present at Atlantic Hill and Rocky Neck, and both of these have yielded zircon for U-Pb dating discussed in a subsequent section.

HISTORICAL OVERVIEW OF BOSTON BAY GROUP STRATIGRAPHY

Crosby (1880) classed all of the conglomerate and finer grained strata described above as "Primordial" Paleozoic formations and concluded that most of the slate overlies most of the conglomerate. In the 1917 USGS Bulletin explicating the 1916 *Geologic Map of Massachusett and Rhode Island* (with eastern Massachusetts based on work by Laurence LaForge), B.K. Emerson summarized this sequence in formal stratigraphic terms of the Boston Bay Group composed of Roxbury Conglomerate overlain by Cambridge Slate (Argillite beginning with Billings, 1929). Emerson and LaForge both expressed reservations that the conglomerate could be consistently subdivided throughout the Boston Basin but nevertheless distinguished, in ascending order, the massive conglomerate of the Brookline Member, the red and purple slate-dominated Dorchester Member and the Squantum Member with its "peculiar breccia" (Emerson, 1917; LaForge, 1932, p. 40-41). In a later synthesis based on subsurface mapping in water supply and sewerage tunnels, Marland Billings (1976) restated the previous stratigraphic subdivisions in quantitative proportions of conglomerate, sandstone and argillite. Thus, the Brookline Member in the City Tunnel Extension (Fig. 1) contains 49% conglomerate, 27% sandstone and 24% argillite, while the Dorchester Member in the Main Drainage Tunnel contains 60% argillite, 22% sandstone and only 18% conglomerate. The Squantum Member which stands out lithologically because of its matrix supported character, alone is differentiated on Billings' 1976 sketch map which became the template for the current *Bedrock Geologic Map of Massachusetts* (Zen, 1983).

Tunnel mapping also gave rise to another lasting influence on stratigraphic thinking about the Boston Basin. Unfolded beds in the NS-trending City Tunnel Extension were interpreted to show Roxbury Conglomerate on the south and Cambridge Argillite on the north as interfingering lithofacies representing, respectively, proximal and distal deposits in a continuous depositional basin (Billings and Tieney, 1964; Billings, 1976). Billings' commonly reproduced palinspastic cross section (Fig. 2 after Billings, 1976) thus tied the age of the conglomerate to the age of the argillite, even though (as Billings emphasized in an introductory section entitled *Frustrations)* none of these rocks contains any fossils. Microfossils discovered shortly thereafter in Cambridge Argillite transected by the MBTA Red Line tunnel north of Harvard Square indicated Late Proterozoic Z age for the argillite (Lenk and others, 1982) which was applied to the Roxbury Conglomerate as well.

UGGS geologist Clifford Kaye had already backed away from the established stratigraphy of the Boston Bay Group by organizing his 1980 *Bedrock Geologic Maps of the Boston North, Boston South and Newton Quadrangle, Massachusetts* around units based on dominant lithology with stratigraphic divisions, if indicated at all, shown parenthetically. Sedimentary strata as schematized in a diagram accompanying the legend of this map (Fig. 3) are subdivided into eight packets that are numbered from oldest to youngest and lettered on the map itself to indicate rock type. Each packet is further correlated with plutonic and/or volcanic units in or around the Boston Basin. Conglomerates traditionally known as "Roxbury" appear on the map as units 3C, 4C and 5C, and "Cambridge" Argillite becomes units 5-6A, 6A and 7A. Kaye's sudden death in 1986 not only overtook his planned text outlining the case for these complicated lithologic subdivisions, but also cut short scrutiny of the established stratigraphic framework just as the first available U-Pb isototopic dates (Kaye and Zartman, 1980; Zartman and Naylor, 1984) were beginning to furnish age control around Boston.

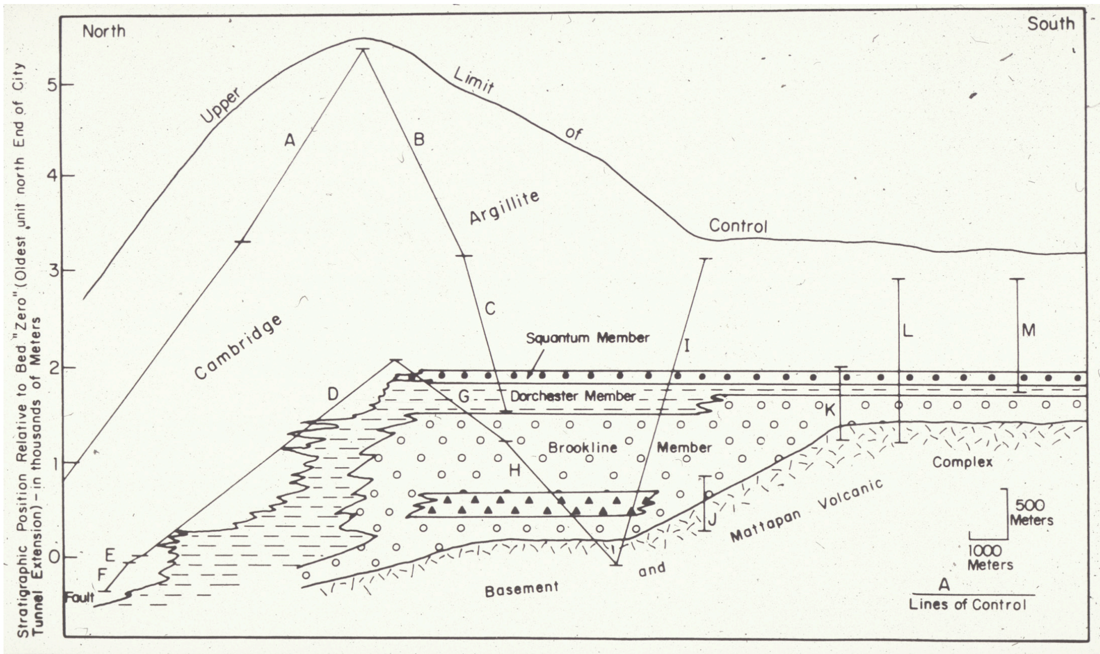


Figure. 2. Palinspastic cross section showing regional stratigraphy of the Boston Basin (from Billings, 1976). Lettered segments show control lines: A, north part of North Metropolitan Relief Tunnel; B, South part of North Metropolitan Relief Tunnel; C, Main Drainage Tunnel; D, North part of City Tunnel Extension; E, Surface geology in Malden; F, Malden Tunnel; G, south part of City Tunnel Extension; H, surface geology in Brookline; I, Surface geology from Brookline to Dorchester; J, surface geology, north limb of Mattapan anticline; K, surface geology, Hyde Park; L, surface geology, Dorchester Lower Mills; M, Furnace Brook at Adams St., Quincy.

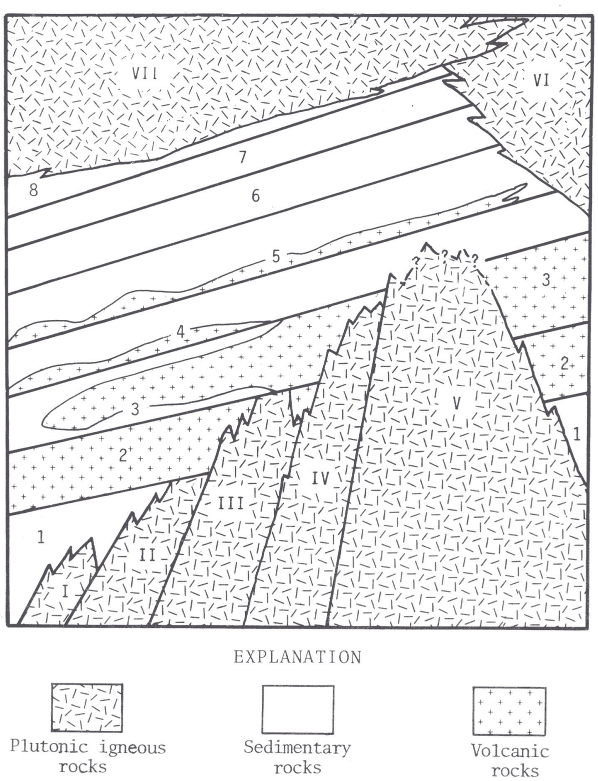


Figure 3. Inset in legend of geologic map by Clifford Kaye (1980) showing rock assemblages numbered from oldest to youngest. On map itself, letters are also added to indicate rock type (C for conglomerate and A for argillite, for example).

More pointed stratigraphic criticism soon emerged from sedimentological re-evaluation of conglomerate-sandstone-argillite associations of the Boston Bay Group. In this approach, sequences were described in terms of lithofacies assemblages and synthesized basin-wide in terms of glacially influenced sedimentation in a marine slope/fan setting (Socci and Smith, 1987 and 1990; Smith and Socci, 1990). This (or any other sedimentological synthesis) only works, however if all sedimentary lithofacies across the Boston Basin are essentially the same age, an assumption grounded in Billings' earlier structural interpretation. Here the argument breaks down because the structure is based on the same historically entrenched stratigraphy that the facies analysis seeks to undermine. Revisiting critical structural relations in the City Tunnel Extension, moreover, suggests that Cambridge Argillite may be thrust over Roxbury Conglomerate, in turn implying that these formations need not be the same age (Thompson, 1997). While the sedimentological details supporting the Socci-Smith critique effectively re-energized the glacial debate in the Boston area just as Neoproterozoic "Snowball Earth" glaciations were about to enter the spotlight (Kirschvink, 1992; Hoffman, 1998), only isotopic dating can establish age relationships needed to put the stratigraphy on a firm footing.

GEOCHRONOLOGICAL CHALLENGES OF THE BOSTON BAY GROUP

Determining U-Pb isotopic ages for sedimentary rocks around Boston is proving to be quite difficult. The most obvious limitation is that dates from detrital zircons can fix only a maximum depositional age, i.e. the sampled deposit must be younger than the youngest zircon it contains. Another limitation to maximum age determinations is that multiple generations of clastic sedimentary rocks, as envisioned by Kaye in Figure 3, may all contain detritus from the same sources. In other words, even if some conglomerate in the Boston Bay Group were deposited in Paleozoic time, it could still give a Neoproterozoic maximum age if there were no Paleozoic igneous rocks exposed to contribute younger zircon. Lava flows and volcanic ashes interbedded with conglomerate around Boston do mark unique age horizons in the sedimentary pile, but these commonly contain older, inherited zircons with such variable dates that results must sometimes also be stated in terms of maximum age. The paragraphs below summarize U-Pb zircon results obtained so far via isotope dilution-thermal ionization mass spectrometry (ID-TIMS) from various lava flows, volcanic ash, igneous clasts and single detrital zircons in rocks traditionally assigned to the Boston Bay Group. This work is very much in progress.

The most recently undertaken dating project has furnished age data from volcanic ash associated with basalt that is interbedded with conglomerate at Rocky Neck, Hingham, MA (Ault, 2003; Ault and others, 2004). This sequence rests unconformably on Dedham Granite and has generally been assigned to the Brookline Member of the Roxbury Conglomerate (LaForge, 1932). The granite has recently yielded an upper concordia intercept date of ca. 608 Ma based on four single-crystal zircon analyses, two of which are concordant (Thompson and others, 2004, in press). This result closely resembles published ages for Dedham Granite north of the Boston Basin (see Fig. 4). Volcanic ash near the top of the stratified section at Rocky Neck contains a population of ca. 597 Ma zircons (weighted mean $^{206}Pb/^{238}U$ age based on four single grain analyses), along with inherited zircons that yield older Neoproterozoic dates. This result together with Zr/TiO_2 and Nb/Y ratios link this ash with Avalonian arc volcanism that is recorded in the 602-593 Ma Lynn-Mattapan Volcanic Complex both north and south of the Boston Basin (exact dates and sources in Fig. 4).

Detailed results are also available for the Squantum Member of the Roxbury Conglomerate at Squantum Head, Quincy, MA (Thompson and Bowring, 2000). Nine single zircons from a poorly sorted, lithic-rich sandstone at the base of the section were analyzed to give generally concordant $^{206}Pb/^{207}P$ dates ranging from ca. 618 Ma to ca. 593 Ma. All of these results can be matched with published ages of plutonic and volcanic members of the Avalonian basement around Boston (Fig. 4). Three igneous clasts were also dated from diamictite higher in the Squantum section. These included ca. 610 Ma porphyritic granophyre, ca. 600 Ma crystal-poor tuff and ca. 596 Ma welded tuff. Squantum deposition is younger than ca. 595 Ma based on all of these results.

The minimum age of the Roxbury Conglomerate is currently constrained by the age of the Cambridge Argillite which not only interfingers with but also overlies the conglomerate in the conventional stratigraphy of the Boston Basin (Fig. 2). The only available isotopic date from the argillite, however, comes from a volcanic ash bed in the Mystic River Quarry, Somerville, MA, i.e. near the base of the

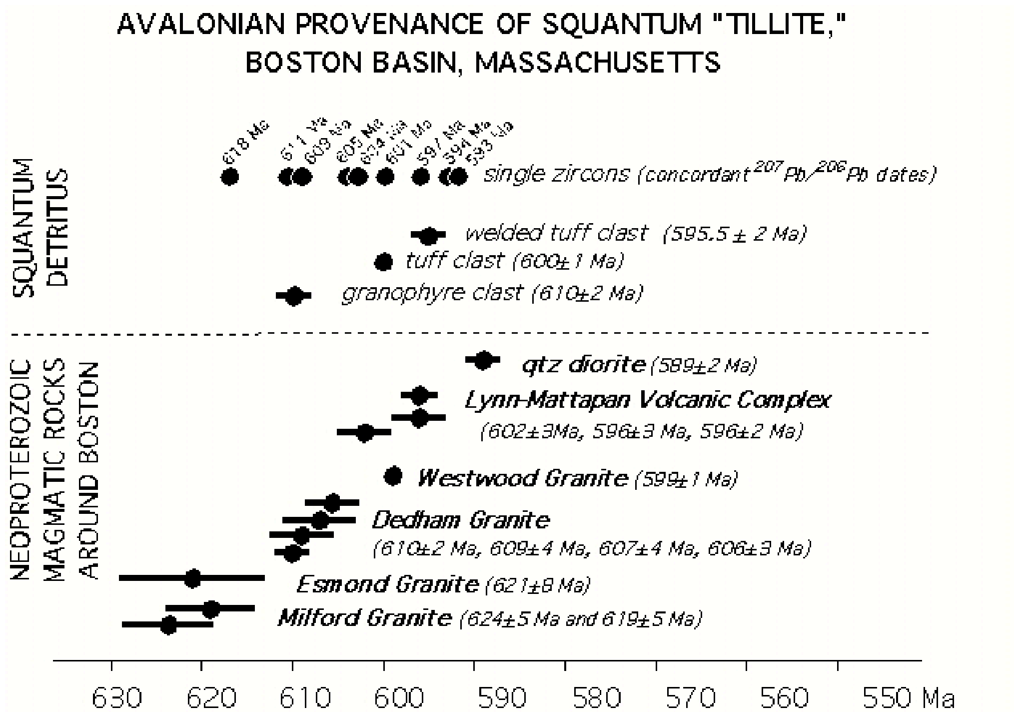


Fig. 4. Ages of detrital zircon from sandstone and igneous clasts from diamictite at Squantum Head, Quincy, MA (Thompson and Bowring, 2000) compared with ages of possible source rocks in the Avalonian magmatic arc complex surrounding the Boston Basin. Dates for source rocks from Kaye and Zartman (1980), Hermes and Zartman (1985), Hepburn and others (1993), Thompson and others (1996) and unpublished data of Thompson and Bowring.

approximately 2000 m thick argillite section in the northern half of the Boston Basin (thickness from Billings and Tierney, 1964). The utility of this ca. 570 Ma date (Thompson and Bowring, 2000) is tempered by its geographically removed position with respect to the Squantum section which is approximately located near control lines L and M in the southern portion of Figure 2, (though the Squantum section does not rest on igneous basement). Also, although 570 Ma appears to be a good estimate of the age of the ash bed, it is impossible to rule out the presence of younger zircons given that older, inherited or xenocrystic grains were also encountered in the sample ($^{206}Pb/^{207}Pb$ dates ranging back to 696 Ma reported in Thompson and Bowring, 2000). These limitations, along the with apparent faults cutting of the argillite in the north part of the basin (Thompson, 1997; Morell and others, 2004), leave room for questioning whether all the conglomerate in the Boston Basin is really younger than all the conglomerate. Single zircons from volcanic ash in the Nantasket section of Hull, MA have yielded intriguing Devonian dates (Thompson and Grunow, 2001).

PALEOMAGNETIC POSTSCRIPTS

Magnetization directions in some sections of Roxbury Conglomerate and associated Brighton volcanics are also consistent with at least localized Paleozoic deposition in the Boston Basin. Structurally corrected directions from gently folded basalt and red siltstone in the Webster Conservation area, Newton, Massachusetts (CH in Figure 1), for example, yield antipodal inclinations indicative of normal and reverse polarity, hence a probable primary magnetization. Previously reported random directions from clasts in overlying conglomerate support this interpretation (Fang and others, 1986). Similar directions were also obtained from a volcanic unit above conglomerate at the town landfill in Hull, MA. The NE-SW declinations in all of these samples, furthermore lie at right angles to declinations obtained from ca. 595 Ma Mattapan volcanic units (unpublished data of Grunow and Thompson) that match with ca. 606 Ma Harbour Main volcanics in the Newfoundland Avalon Zone (Seguin and Lortie, 1986). The best match for the Webster paleopole is the published Siluro-Devonian pole for the Pembroke Formation in New Brunswick, Canada (Roy and Anderson, 1981).

Tilt-corrected volcanic horizons at Nantasket Beach, Hull, MA (Stop 6 outside the east edge of Fig. 1) yield low inclinations and south-directed declinations that differ from both the Neoproterozoic and Siluro-Devonian directions. Paleopoles derived from these results indicate equatorial latitude and match Late Devonian results from both the Wamsutta rhyolite in the Narragansett Basin (ca. 373 Ma U-Pb zircon date from Thompson and Hermes, 2003) and from the Catskill red beds in the central Appalachians (van der Voo and others, 1979, for example).

These paleomagnetic results, combined with available U-Pb age constraints and with lithologic distinctions among conglomerate belts across the Boston Basin, suggest that conglomerates currently lumped under the Roxbury heading may indeed require subdivision along lines earlier envisioned by Clifford Kaye. The six stops outlined below in Crosby's Brookline-Roxbury belt and South Shore district will illustrate the range of characteristics in Boston-area conglomerates and provide a basis for discussing where possible breaks might lie.

ROAD LOG

Meet at Main Campus Parking Lot, Salem State College at 8:30AM. Best route to Boston depends on evolving "Big Dig" situation, so driving directions to Stop 1 will be distributed at this time. Bring lunch.

STOP 1. Puddingstone Park, Boston, MA. UTM $^{03}26^{562}$ E, $^{46}88^{686}$ N. The ledges here are remnants of the Parker Hill Quarry in the Roxbury district of Boston. Conglomerate was quarried here during the mid-1800's to early 1900's for use in local buildings and churches including the Basilica of Our Lady of Perpetual Help whose spires tower above the skyline. Other former quarries can still be seen in a belt extending southeastward across Columbus Avenue to Madison Park High School. These operations were at their height when the first geological references to "Roxbury" conglomerate or puddingstone began to appear (Shaler, 1869; Dodge, 1881; Mansfield, 1906). The rock at this *de facto* type locality is described below.

Conglomerate in Puddingstone Park and in surfaces exposed in the parking lot of the adjoining shopping area contains subangular to well rounded clasts in a brownish gray, coarse sandy matrix. The ten largest clasts in a representative square meter of outcrop surface range from 4 cm to13.5 cm in the parking lot and 4 cm to 9 cm midway up the paved park path. Igneous clasts include granites and pink, gray and reddish porphyritic and pyroclastic volcanic rocks (photomicrographs in Fig. 5). Sedimentary clasts include quartz arenite (commonly called quartzite) and dark, tuffaceous argillite composed of quartz+albite+ white mica±Kfeldspar, the same minerals found in ash-flow tuff clasts in the conglomerate. The sandy matrix surrounding all these clasts is lithic arenite averaging 60% lithic fragments, 31% quartz and 9% feldspar based on 500-point counts of two samples from this location and three others from quarries farther east. Feldspar includes both plagioclase and K-feldspar in all samples. Discrete sandstone layers have not been observed in these massive conglomerates, but clasts are locally aligned in horizons previously shown as bedding (Kaye, 1980). The WNW trending, gently north dipping attitude of this structure is very similar to regional cleavage, however, and pressure solution seams between clasts clearly record tectonic influence.

For discussion: Depositional mechanism? Tectonic provenance based on sandy matrix? Relationship to more northerly conglomerate (in Crosby's Newton Lower Falls-Brighton band of amygdaloid)?

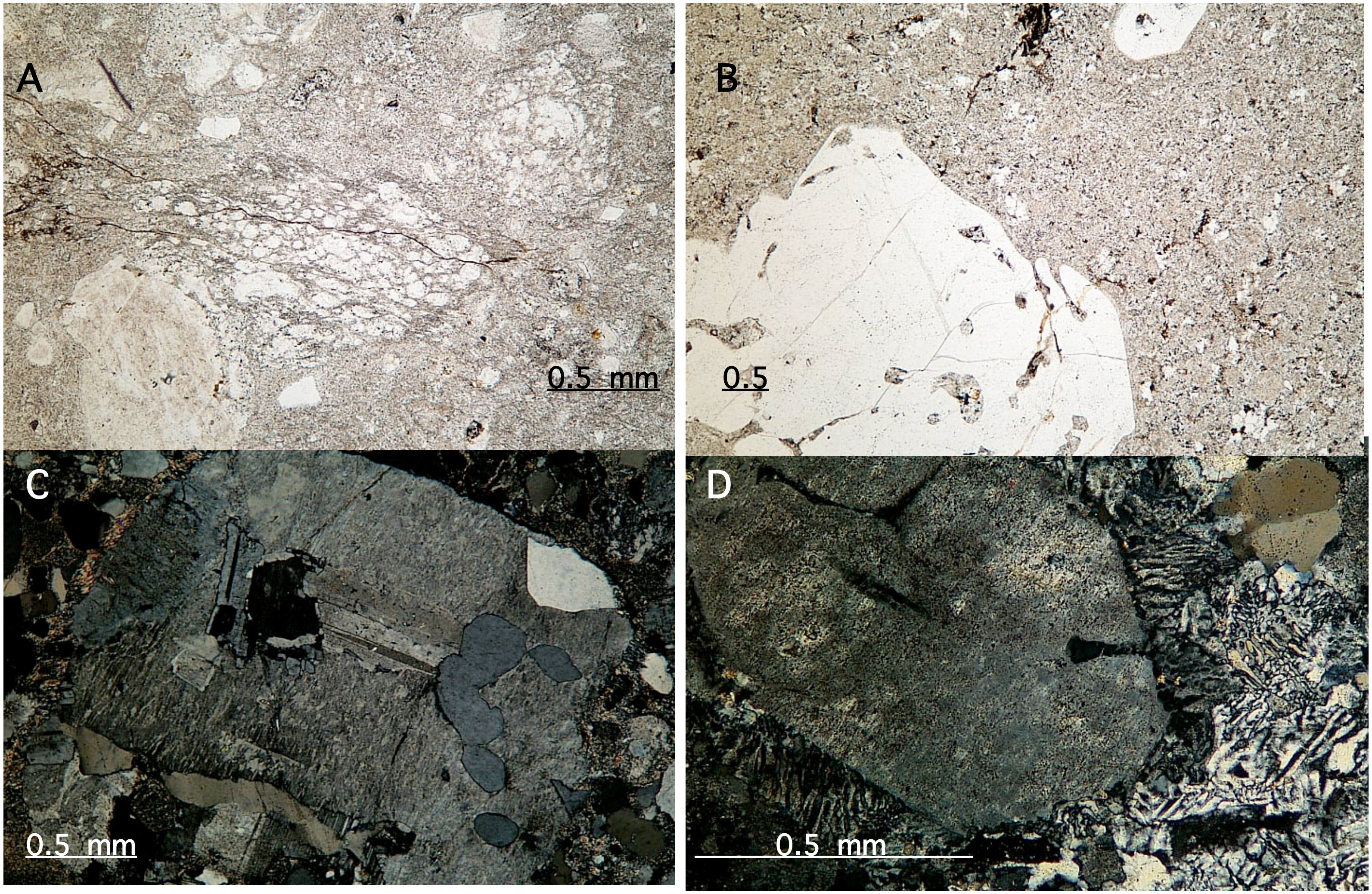


Figure 5. Igneous clasts in Roxbury Conglomerate, Puddingstone Park, Roxbury, Massachusetts. All but C are larger than the field of view.
A. Ash-flow tuff with pumice clasts (plane light). B. Volcanic porphyry with embayed quartz (plane light). C. Granite (crossed polars).
D. Granophyric granite (crosssed polars).

Mileage
0.0 Left out of parking lot onto Parker Hill St.,then second left onto Calumet St.
0.2 Left onto St. Alphonsus St.
0.3 Right at light onto Tremont St.
0.7 Right onto Columbus Avenue. *Note that this portion of Columbus Ave. and the neighboring train tracks follow the trend of a major NNE-trending fault.*
1.8 Cross Washington St. at Eggleston Square and continue on Columbus Ave.
2.5 Columbus Ave. becomes Seaver St.
2.7 Right onto Blue Hill Avenue
2.9 Right at light into Franklin Park (Glen Rd.) and continue past zoo on right.
3.5 Take right fork at triangular intersection, curve to right and park facing playing field on left. Walk WNW to prominent ledges on north side of paved path.

STOP 2. Glen Lane in Franklin Park, Boston, MA. UTM 19T $^{03}27^{016}$ E, $^{46}85\ ^{822}$ N. Franklin Park, designed by Frederick Law Olmstead, preserves the "picturesuesque scenery" and "magnificent exposures" much as Crosby would have seen them more than a century ago. Measurements of the10 largest clasts in one square meter of outcrop surface range from 12.5 cm to 33.5 cm in maximum diameter. These are coarser than clasts in any other conglomerate in the Brookline-Roxbury belt (Fig. 7), including those generally assigned to the Squantum Member at the next stop. Clasts are generally well rounded and in grain-to-grain contact, though sandy matrix is locally present. As at Puddingstone Park, the largest and most abundant clast types are granite, quartzite and felsic volcanic rocks. One approximately 15 cm stratified clast was observed outside of the counting square. A diffuse sand layer suggests that bedding in this otherwise massive conglomerate is nearly horizontal. An apparent dip of 14S is visible on a two-dimensional outcrop surface with UTM coordinates 19T $^{03}27^{168}$ E, $^{46}85\ ^{754}$ N. Both of these attitudes are consistent with observations reported by Crosby (1880).

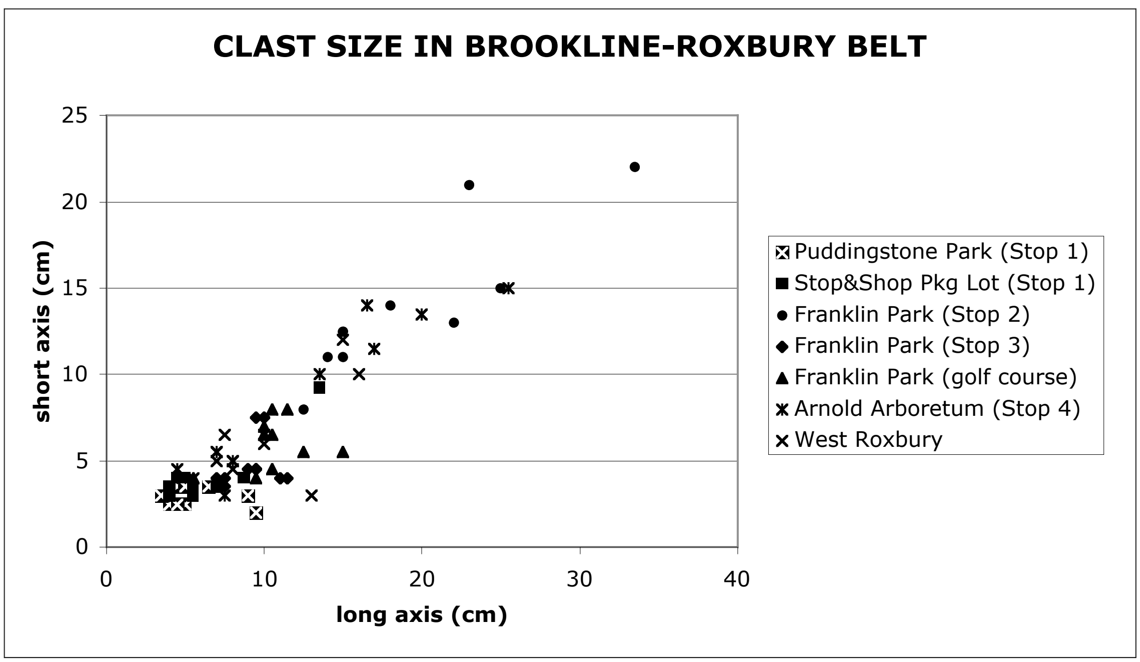


Figure 6. Long axis v. short axis dimensions for 10 largest clasts in a representative meter of outcrop surface in Roxbury Conglomerate in central portion of Boston Basin (Brookline and Roxbury belt of Crosby, 1880). Franklin Park golf course and West Roxbury Localities not included in this trip.

For discussion: North-to-south grain size trends in conglomerate? More debris flows?

3.7 Return to triangular intersection and turn right.
4.2 Left at circular flower bed onto Boston Park Maintenance road.
4.5 Park in area adjoining gate marked "Boston Park Department Maintenance Yard" and walk back to conglomerate escarpment bordering north side of pond.

STOP 3. West End of Scarboro Pond, Franklin Park, Boston, MA. UTM 19T $^{03}26^{890}$ E, $4^{6}84^{721}$ N. Conglomerate is conspicuously finer grained here than at the previous two stops with the ten largest clasts ranging from 7 cm to 11.5 cm in maximum diameter. Clast assemblage features quartzite, felsite, a few mafic volcanic rocks and one well stratified argillite, but interestingly no granite. Also in contrast to previous stops, conglomerate is interbedded with coarse, brownish gray pebbly sandstone making the 60-65° south dip obvious. The sands are neither cross bedded nor rippled, however. South of this escarpment, outcrop is very sparse because finer grained rocks in this part of the section have been more deeply eroded and covered with glacial drift. These units, including pinkish feldspathic sandstones and finely laminated pinkish purple argillite have been transected in the Dorchester Tunnel (Richardson, 1977) which runs parallel to Morton Street along Franklin Park's southwest boundary.

The cross section below (Fig. 7) shows a generally fining upward sequence of conglomerate in the southern half of the Brookline-Roxbury belt, with increasingly steep southerly dip defining the south limb of a broad anticlinal structure. The conglomerate at Puddingstone Park on the north side of the section occupies a block bounded by the fault following Columbus Avenue and the tracks of the MBTA Orange Line which run parallel (strand of Stony Brook Fault of Billings, 1976). If there is a simple regionally fining-upward conglomerate stratigraphy, the significantly finer Puddingstone Park conglomerate could represent the down-faulted upper part of the section.

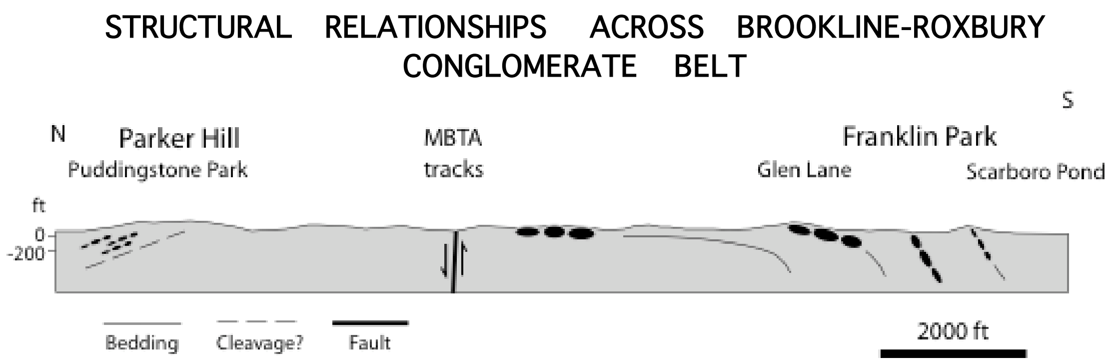


Figure 7. Cross section of Roxbury Conglomerate from Puddingstone Park (Stop 1) to Scarboro Pond (Stop 3). Ellipses schematically show clast sizes in Figure 6 (except for location east of MBTA tracks which is based on Crosby's 1880 report of very coarse conglomerate.

For discussion: What constitutes "typical" Roxbury Conglomerate?

4.9 Return to last intersection and turn left.
5.1 At rotary bear right to avoid elevated highway and head downhill (sign points to Washington St., Forest Hills and Roslindale)
5.4 Cross Washington St.
5.5 Left at traffic light beneath overpass and right at next light onto South St.
6.2 Right onto Bussey Street.
6.4 Park on right shoulder opposite chain-link gate on left.

STOP 4. Arnold Arboretum, Jamaica Plain, MA. UTM 19T $^{03}24^{648}$ E, $^{46}84^{554}$ N. Outcrops on both sides of Bussey Street are diamictite containing well rounded to angular clasts of felsite, granite and quartzite, but also including a few mafic volcanic types. Clasts are supported by olive gray matrix consisting mostly of very fine grained quartz, feldspar and K-phyllosilicate minerals studded with sand to silt sized quartz, siliceous volcanic rock fragments, other rock fragments, plagioclase and K-feldspar (in order of descending abundance). The ten largest clasts on a relatively fresh surface in an old quarry south of the road range from 25.5 cm to 4.5 cm in maximum dimension (Fig. 7). Typical clasts measure only 1-3 cm. Larger clasts including a 38 cm quartzite and two 36 cm granites can be seen on glaciated outcrops north of Bussey St., but systematic measurement is not possible because of the dark patina masking other clasts on these surfaces. No bedding can be identified across the outcrop belt which stretches approximately 100 m north to south, but the rock shows pervasive cleavage dipping steeply to the north. This conglomerate is generally assigned to the Squantum Member at the top of the Roxbury Conglomerate based on its poor sorting and matrix supported character.

For discussion: Are these diamictites the most poorly sorted Roxbury deposits? Why is the matrix olive colored rather than brownish or reddish as at the Squantum type locality? How significant is this difference?

6.5	Right onto Walter Street and next right onto Centre St.
7.5	Exit rotary at 90º onto Route 203 East (Arborway).
8.1	Keep left to stay on elevated highway.
8.6	Exit rotary at 180º to continue on Route 203 East (now Morton St).
10.0	Continue on Route 203 East across Blue Hill Avenue.
11.7	Fork left at light onto Gallivan Boulevard to continue on Route 203 East.
12.0	Right on Granite Avenue.
12.5	Right ramp onto 93 South (Southeast Expressway).
16.0	Stay left for Route 3 South (Exit 7).
24.2	Exit 14 and left at bottom of ramp onto 228 North (Hingham Street).
25.4	Cross Route 53 (Hingham St. becomes Main Street).
29.1	Turn right to stay on 228 North (and continue as street names change several times, ultimately becoming East Street).
30.5	Left on Kilby St. and immediate left on Summer St. (which is unmarked).
30.7	Cross Route 3A to stay on Summer St.
31.1	Straight through traffic light onto Martins Lane.
31.8	Enter Worlds End Reservation and follow gravel road to farthest parking lot.

STOP 5. Worlds End Reservation, Hingham, MA. Entrance at UTM 19T $^{03}45^{411}$ E, $^{46}79^{951}$ N. Seacliff exposures along the Rocky Neck portion of Worlds End Reservation show Dedham Granite unconformably overlain by conglomeratic units and interbedded basaltic lava flows. A clockwise traverse around Rocky Neck crosses eight map units slightly disjointed by faults (Fig. 8 revised from Bailey and Bland, 2001 by Ault, 2003). Granite (Unit 1) is overlain by clastic horizons (Unit 2) including red shale and sandstone southwest of the pond in the center of the map and by conglomerate to the northeast of the pond (P in Fig. 8). Units 1 and 2 are cut off by a WNW-trending fault, so that the sequence on the northern tip of the Rocky Neck passes from conglomerate (Unit 5 and Unit 6), into basalt associated with volcanic ash (Unit 7) and back into conglomerate (Unit 8). Recrossing the fault on the east side of the neck brings us through an older basaltic flow (Unit 3) and overlying conglomerate (Unit 4).

The ca. 597 Ma U-Pb zircon date at Rocky Neck was obtained from silica-rich, devitrified volcanic ash in Unit 7 (66.98 Wt% SiO_2). In thin section, this rock is dominated by secondary epidote, ferro-actinolite, titanite and calcite overprinting anhedral intergrowths of quartz, K-feldspar and albitized plagioclase (Fig. 9A). The ash settled to form discontinuous, laminated horizons over a submarine basaltic lava flow (46.20 Wt% and 42.40 Wt% SiO_2 in two analyses) composed of thoroughly altered, radiating plagioclase laths with interstitial epidote intergrown with chlorite, K-feldspar, magnetite, chalcocite and iron oxides (Fig. 9B). The flow was repeatedly disrupted by bursting pillows and spalling blocks so that ash in some places is engulfed by chilled basalt, while elsewhere basalt forms breccia blocks in the ash. Wet ash also exploded in contact with hot lava to shoot dike-like stringers and ash-filled vesicles through neighboring basalt (Ault and others, 2004). These varied and spectacular contact relations can be studied along the northern tip of Rocky Neck. The complex interfingering contact between this volcanic assemblage and underlying Unit 6 leaves no doubt that conglomerates at Worlds End were deposited in conjunction with volcanic activity. In this context, it is not surprising that "conglomerate" at Rocky Neck shows lithologic differences compared to those visited earlier in the trip where there are no associated volcanic rocks. The U-Pb date places this sequence in the midst of the Mattapan volcanic interval in the Southeastern New England Avalon Zone, i.e. within the basement beneath the Roxbury Conglomerate in Billings' regional stratigraphy.

For discussion: Clast assemblages? Matrix character? Conglomerate or volcanic breccia? Why do paleomagnetic directions conflict with age based on U-Pb date?

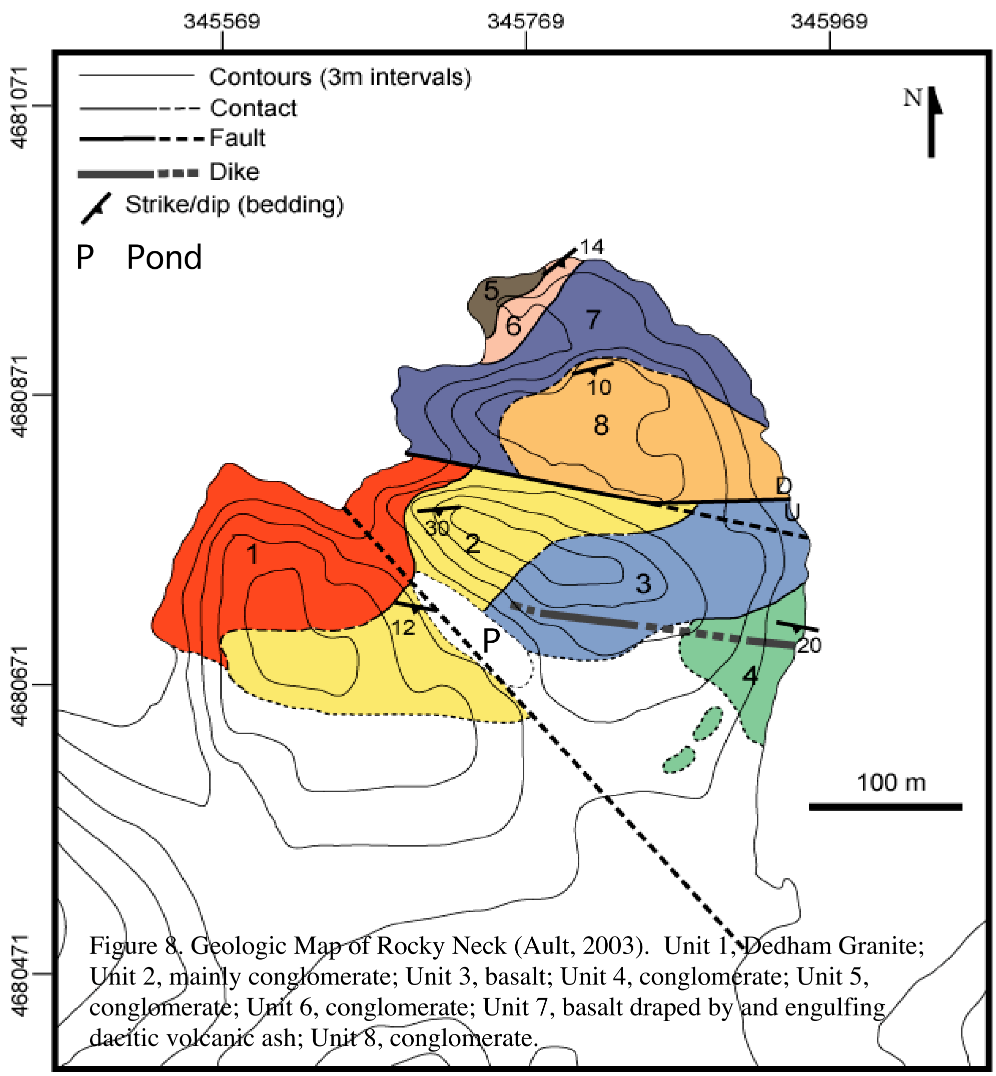


Figure 8. Geologic Map of Rocky Neck (Ault, 2003). Unit 1, Dedham Granite; Unit 2, mainly conglomerate; Unit 3, basalt; Unit 4, conglomerate; Unit 5, conglomerate; Unit 6, conglomerate; Unit 7, basalt draped by and engulfing dacitic volcanic ash; Unit 8, conglomerate.

32.7 Return to traffic light at head of Martins Lane and turn left on Rockland St.
33.0 Straight at light onto George Washington Blvd.
34.2 Right at light and "Welcome to Hull" sign (Rockland House Rd).
34.6 Left onto Nantasket Avenue.
34.65 Right into parking area at Nantasket Beach.

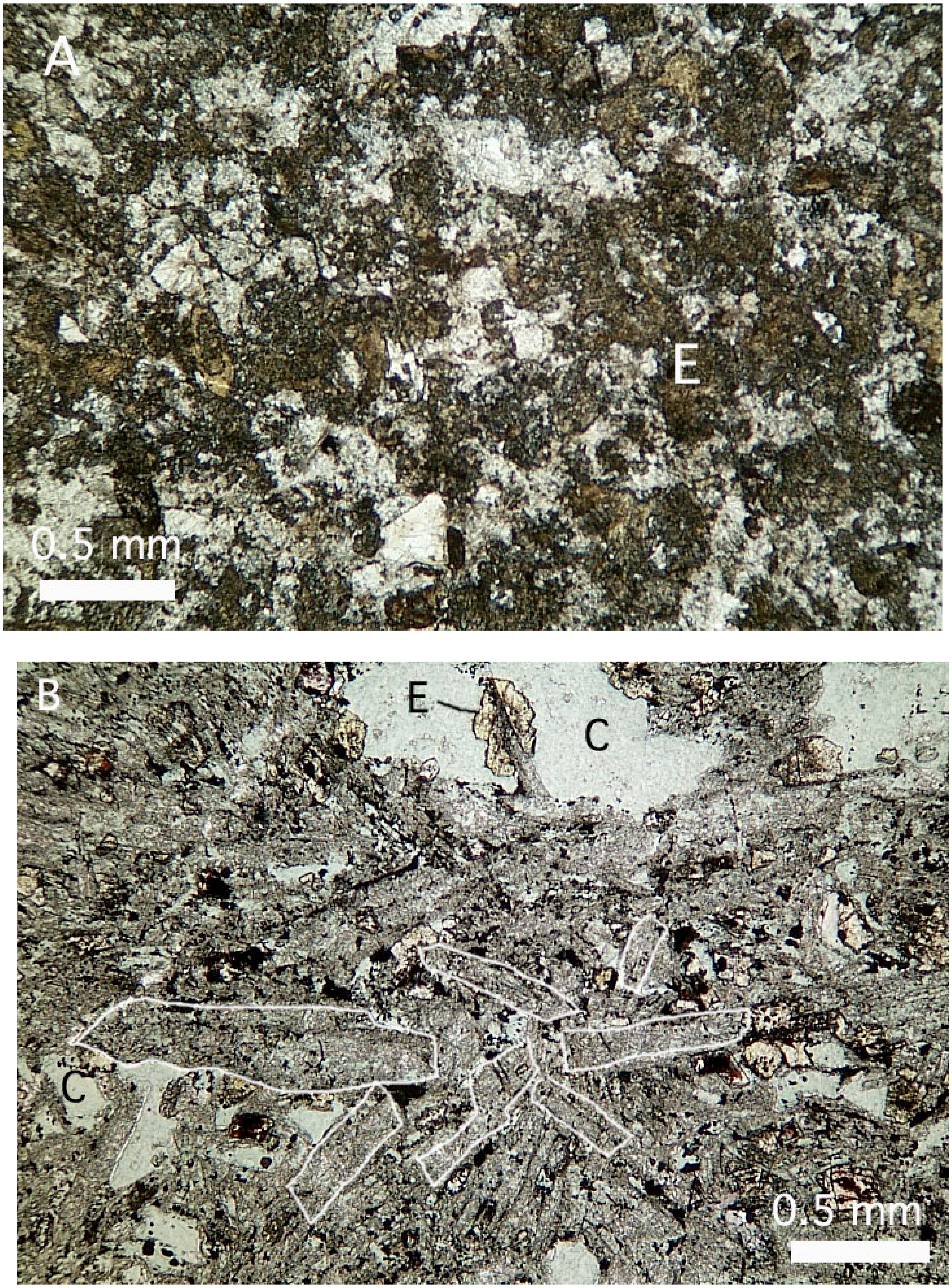


Figure 9. Volcanic textures at Rocky Neck (Stop 5), plane light. A. Volcanic ash shows epidote (E) and other secondary minerals overprinting intergrown quartz and feldspar in pale gray. B. Lava flows consist of altered plagioclase (outlined in white) with epidote (E) and chlorite (C) in angular interstices and rounded vesicles.

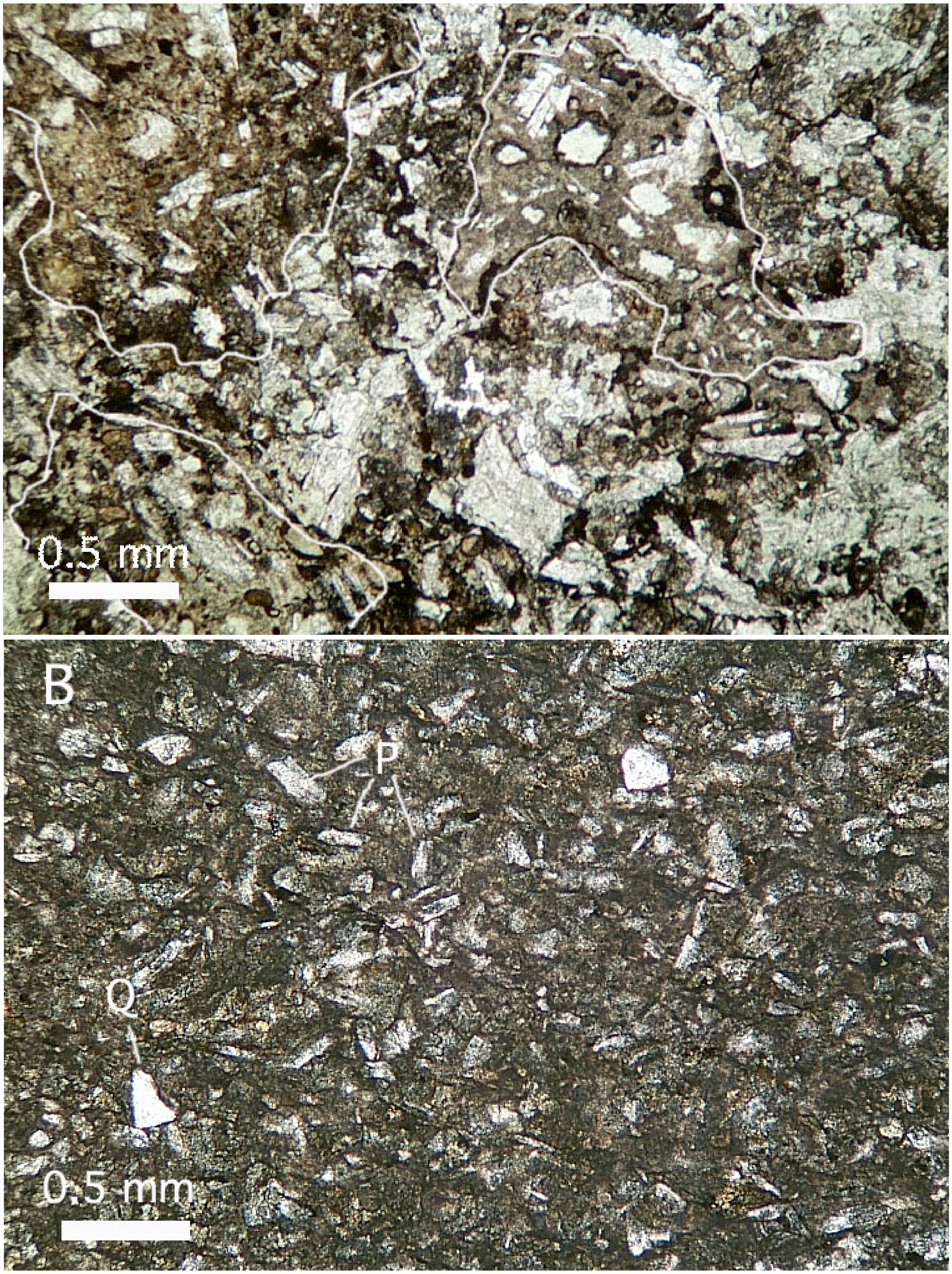


Figure 10. Volcanic textures at Atlantic Hill (Stop 6), plane light. A (top). Basaltic tuff with porphyritic and vesicular clasts outlined in white. B. Volcanic ash contains altered plagioclase laths (P) and sparse quartz (Q) in turbid epidote and chlorite rich matrix.

STOP 6 (Time and tide permitting). Long Beach Rock and Atlantic Hill, Hull, MA. UTM 19T $^{03}47^{509}$ E, $^{46}81^{122}$ N. Conglomerate forming the lowest part of this gently southeast-dipping section can only be seen at dead low tide. On a surface much obscured by barnacles and seaweed, the largest clasts are sub- to well-rounded and range from 9 cm to 20 cm. These clasts are in grain-to-grain contact, but smaller (and somewhat more angular) clasts are supported by green-tinged, epidotized matrix. This matrix is very compact, and the conglomerate itself is very tough. The clast assemblage consists of mafic volcanic rocks, felsic volcanic rocks and minor granite, but no quartzite. Above the conglomerate is laminated, silicified volcanic ash (slate of Crosby, 1893), succeeded by dark green, massive volcanic rock with irregular and distorted ash horizons much like those in Unit 7 at the last stop. After a covered interval, the section continues on Atlantic Hill with a pale olive, crudely stratified sequence that Crosby (1893, p. 48) correctly surmised to be volcanic tuff. Some horizons are coarser breccias with clasts varying from < 1 cm to a maximum of 8-10 cm. In thin section, the matrix of these breccias consists of densely packed, irregularly shaped, porphyritic and vesiculated volcanic mafic rock fragments measuring up to 5 mm (Fig. 10A). This rock is texturally distinct from volcanics found at Rocky Neck, even though the basaltic composition is generally similar (44.56 Wt% SiO_2). A fine-grained volcanic ash horizon slightly above high tide level contains < 1 mm albitized plagioclase laths in various stages of alteration to epidote, sparse quartz grains and volcanic rock fragments in a turbid matrix composed of K-feldspar, chlorite, albite and epidote with accessory apatite, titanite and zircon (Fig. 10B). This ash differs texturally from the ash at Rocky Neck and is also significantly less silica rich with only 57.25 Wt% SiO_2. These are the units that have yielded low latitude, apparently Devonian magnetizations and single zircons in this age range.

For discussion: Do lithologic differences between Atlantic Hill and Rocky Neck record a cryptic unconformity in the Roxbury/Brighton sedimentary/volcanic assemblage?

End of Trip. Route 3 North (reached via road log in reverse from 31.1 miles) connects to I93 and I95 at "Braintree Split." Left at split (towards Dedham) for 93 South and junction with 95. Right at split (towards Boston) for 93 North.

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