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LATE PROTEROZOIC STRATIGRAPHY AND STRUCTURE IN THE AVALONIAN MAGMATIC ARC, SOUTHWEST OF BOSTON, MASSACHUSETTS

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ABSTRACT. The Avalon zone in southeastern New England contains calc-alkaline granitoids and volcanic rocks formed during Late Proterozoic arc magmatism. Southwest of Boston, Massachusetts, arc-related units include the Dedham Granite, rhyolitic ash-flow tuffs of the Mattapan Volcanic Complex, and the Westwood Granite. Roxbury Conglomerate and interbedded Brighton Volcanics overlying these "basement" units have previously been interpreted as distinct rift-related deposits formed during the tectonic transition from Avalonian magmatic arc to stable Cambrian platform. The present study shows that several east-northeast-trending faults control thickness changes and clast assemblage variations in the conglomerate, thus strengthening the case for Late Proterozoic rifting. The calc-alkaline Brighton Volcanics, however, are here expanded beyond traditionally accepted interbeds near the base of the Roxbury Conglomerate to include geochemically similar andesites and basaltic andesites on the west side of the map area formerly assigned to the Mattapan Volcanic Complex. The expanded Brighton Volcanics with minor sedimentary interbeds measure at least 2100 m on the west and interfinger eastward with the Roxbury Conglomerate to form a volcanic-sedimentary complex that is locally conformable on the Mattapan Volcanic Complex. These relationships indicate continuing arc magmatism throughout Roxbury deposition. In this context, the Roxbury/Brighton Complex (proposed name) is interpreted as graben fill in depressions reflecting intra-arc extension as found in modern and ancient arc systems. The Avalonian arc/platform transition should be sought stratigraphically above the Roxbury/Brighton Complex.

INTRODUCTION

The volcanic arc model first proposed for Late Proterozoic volcanic, plutonic, and associated volcaniclastic sedimentary rocks in the Avalon Peninsula of Newfoundland (Hughes, 1970; Hughes and Bruckner, 1971) was soon extended to correlative assemblages in the northern Appalachians and the British Isles (Rast and others, 1976). This relatively undeformed arc sequence, together with overlapping platformal Cambrian strata containing Atlantic realm trilobite faunas, comprises the Avalon tectonostratigraphic terrane. The area described here is located southwest of Boston, Massachusetts within the southeastern New England portion of this zone (inset in fig. 1, opp. p. 732). The arc interpretation for the Late Proterozoic rocks in this area derives primarily from the calc-alkaline character and trace element geochemistry of granitoids (Dedham, Esmond, and Westwood) and felsic volcanic rocks (Lynn Volcanic Complex and Mattapan Volcanic Complex) (Hermes and others, 1981; Smith and Hon, 1984; Hermes and Murray, 1990). Available U-Pb zircon ages from these rocks fix magmatic activity between 650 to 600 Ma (Kaye and Zartman, 1980; Zartman and Naylor, 1984; Hermes and Zartman, 1985; Markus and others, 1993).

Late Proterozoic Cambridge Argillite and Roxbury Conglomerate of the Boston Bay Group (Lenk and others, 1982) cap calc-alkaline "basement" units around Boston. Several recent interpretations construe Roxbury Conglomerate deposition in terms of rifting that dismembered the former magmatic arc (Hon and Smith, 1987; Nance, 1990; Rast and Skehan, 1990; Smith and Socci, 1990). The present study supports rift-related conglomerate sedimentation based on evidence that several faults (both long known and newly recognized) in the map area were active syndepositionally with the Roxbury Conglomerate and associated Brighton Volcanics (altered basalts and andesites also called the Brighton Melaphyre by LaForge, 1932; Billings, 1929 and 1976; Zen, 1983). The calc-alkaline Brighton Volcanics (Cardoza and others, 1990), however, are here shown to be thicker and more laterally extensive than previously thought, indicating that arc volcanism continued significantly throughout Roxbury deposition. The interfingering Roxbury/Brighton Complex (proposed name) is interpreted to have accumulated in a graben that was an integral part of the Avalonian magmatic arc and thus to record intra-arc extension as found in modern and ancient arc systems.

BRIGHTON VOLCANICS

The Brighton Volcanics appear in the accepted stratigraphy of Boston as approx 200 m of intermediate to mafic flows, pyroclastic rocks, and intrusive rocks near the base of the 1310 m thick Roxbury Conglomerate (fig. 1 *in* Billings, 1976). This representation is based on surface mapping in Brookline and Newton, Massachusetts, augmented by subsurface sections in water supply, drainage and sewerage tunnels (Billings and Tierney, 1964; Tierney and others, 1968) on the east side of figure 1. Intermediate to mafic volcanics are also found, however, west of the northwest-trending Mother Brook Fault (MBF in fig. 1; name based on LaForge, 1932) where conglomerates are rare. One basaltic series (Zmm, fig. 1) occurs near the top of the rhyolitic High Rock Tuff and thus clearly belongs to the Mattapan Volcanic Complex. A second, much thicker series of basaltic andesite and andesite extending from Eliot Hill on the west side of the map to the Mother Brook Fault has been interpreted previously both as Mattapan ("intermediate" and "laharic" members of Nelson, 1975) and as Brighton (Zen, 1983). This ambiguous series, temporarily called the western volcanic rocks below, has been re-mapped and compared geochemically with unequivocal Brighton and with mafic

Mattapan in order to establish a consistent volcanic stratigraphy in the map area.

The western volcanic rocks as exposed at Eliot Hill (S1, figs. 1 and 2) are approx 810 m thick and consist primarily of gray, green, and purple-mottled breccia, tuff-breccia, and tuff. Several flows and white to pale-green ash beds are also present. The flows are most easily recognized in thin section by sericitized plagioclase with sub-ophitic or intersertal textures (fig. 3A). Interstitial chlorite, epidote, and opaque material may be altered glass or mafic minerals. Vesicles, when present, are filled with quartz and epidote ± chlorite. The tuffs are also highly altered, but locally they retain pumice fragments (fig. 3B) and rounded ash concretions interpreted as accretionary lapilli (fig. 3C). The breccias are poorly sorted with mafic and felsic volcanic clasts ranging from less than 1 cm to tens of centimeters. Some of these breccias are matrix supported (lahars of Nelson, 1975), but others are clast supported and thus may represent lag deposits of pyroclastic flows ("co-ignimbrite lag-fall deposits" of Wright and Walker, 1977) or hyperconcentrated flood flow deposits (Smith, 1986).

Conglomerate and sandstone are also present at Eliot Hill (fig. 2). Some of these are epiclastic facies in the volcanic sequence. For example, conglomerate at Station 644 in figure 1 (projected into the covered interval in the middle of fig. 2) is green and contains abundant subangular intermediate-mafic volcanic clasts typically ranging from a few millimeters to 2 cm in size. Some of the clasts are jasper, which has not been reported in typical Roxbury Conglomerate east of the Mother Brook Fault (further discussion of clast assemblages in later section). Sandstone at Station 644 contains pale pink- to buff-colored ash laminations. More typical of the eastern Roxbury Conglomerate are gray to purple conglomerate and associated trough cross-bedded sandstone at the top of figure 2 and at Station 635 and vicinity in figure 1. These conglomerates contain subrounded clasts measuring 2 to 8 cm and have clast assemblages dominated by felsic volcanic lithotypes.

The western volcanic rocks with minor sedimentary interbeds continue northeastward from Eliot Hill to the Mother Brook Fault. The north-dipping sequence comprising stratigraphic column S2 in figure 1 measures approx 2100 m. Above this, outcrop is poor, and the only visible bedding is in penetratively deformed breccia and tuff (sample loc. 3 and 4 in fig. 1) which strike nearly parallel to the S2 section line. Because of these structural complications, the total thickness of the western volcanic sequence remains uncertain. Nevertheless, it appears to be considerably thicker than unequivocal Brighton Volcanics interbedded with the Roxbury Conglomerate on the east side of the map area.

Four new XRF analyses from the western volcanic rocks (analyses 1-4 in table 1) were compared for possible geochemical correlation with available analyses for unequivocal Brighton Volcanics (16 published analyses, table 2a *in* Cardoza and others, 1990; five additional unpublished analyses *in* Durfee-Cardoza, ms) and mafic Mattapan (analyses 5

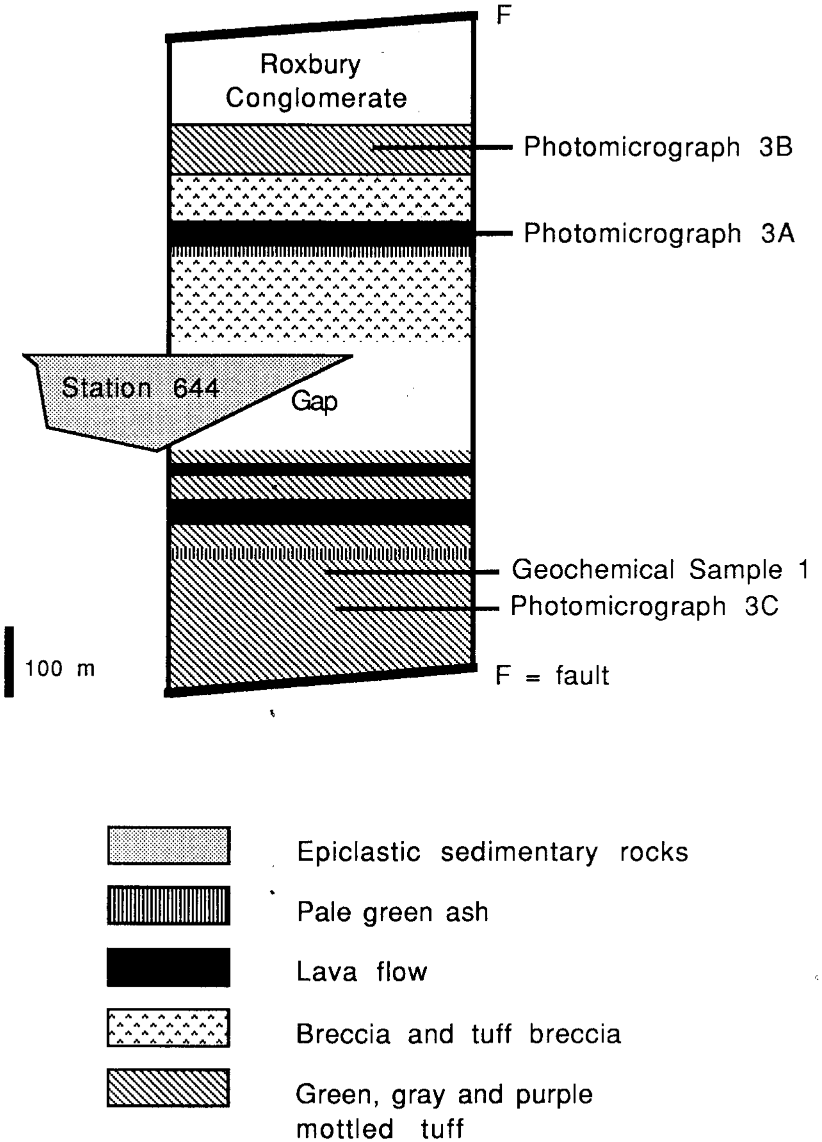

Fig. 2. Stratigraphic sequence at Eliot Hill (S1 on the west side of fig. 1) consists of andesitic and basaltic andesitic flows and pyroclastics with minor sedimentary interbeds. Sedimentary interbeds in the middle of the column (projected eastward from Station 644 in fig. 1) include green, jasper-bearing conglomerate that differs from typical gray-to-purple Roxbury Conglomerate at the top of the section. Thickness of section below Roxbury Conglomerate is approx 810 m.

and 6 in table 1). This approach has some inherent limitations. First of all, major elements in unequivocal Brighton analyses are referenced to unignited powders so that some samples have low totals compared to new analyses in table 1 which are referenced to ignited powders. Furthermore, both data sets show alkali mobility manifested by K_2O/Na_2O ratios, sometimes higher but usually lower than normal, probably reflecting the pervasively altered condition of analyzed samples.

Geochemical comparison reveals that all three groups of volcanic rocks overlap in terms of individual major element abundances. Both the western volcanic rocks and the mafic Mattapan fall virtually entirely within published major element ranges for unequivocal Brighton Volcanics (last column in table 1). More instructive for correlation is a variation diagram showing TiO_2 versus Al_2O_3, elements considered immobile in altered volcanic rocks (Winchester and Floyd, 1977). On this plot (fig. 4A), western volcanic samples cluster nicely with unequivocal Brighton samples, while the two mafic Mattapan samples fall well outside this cluster (sample 5 with much higher Al_2O_3, sample 6 with much higher TiO_2). These data support a correlation between the western volcanic rocks and the unequivocal Brighton Volcanics. Both are clearly distinct from rhyolitc ash-flow tuffs (plotted as felsic Mattapan in fig. 4A) that form the bulk of the Mattapan Volcanic Complex. Without wider sampling, however, it remains unclear whether or not the mafic Mattapan is truly separate from the Brighton Volcanics.

SiO_2 in the expanded Brighton (unequivocal Brighton and western volcanic rocks) varies from 49.12 to 61.56 wt percent (table 1). Ratios of immoble trace elements plotted according to Winchester and Floyd (1977) indicate compositions from basalt to andesitic basalt to andesite (fig. 4B). Rare earth signatures are calc-alkaline in character (Cardoza and others, 1990).

RELATIONSHIP BETWEEN BRIGHTON VOLCANICS AND ROXBURY CONGLOMERATE

Stratigraphic columns from several parts of the map area (S1, S2, and S3 in fig. 1; fig. 5) show dramatic changes in the thickness and position of the Brighton Volcanics with respect to the Roxbury Conglomerate. On the west side of the map area, approx 810 m of Brighton Volcanics underly 200 m of Roxbury Conglomerate in column S1, whereas in column S2 somewhat thicker conglomerate interbeds occur approx 380 m above the exposed base of a predominantly volcanic section measuring approx 2100 m. East of the Mother Brook Fault in column S3, there are approx 50 m of volcanic rocks near the base and approx 500 m of volcanic rocks near the top of a 2200 m section composed mainly of Roxbury Conglomerate.

All three stratigraphic columns are truncated at the bottom by the Eliot Fault (proposed name; EF in fig. 1) which passes eastward from Eliot Hill and south of the John Eliot School (geochemical sample loc. 3 in fig. 1) into Newton. In the absence of any regionally distinctive marker bed, the Eliot Fault has been taken as a reference level for tying these