GEOCHEMISTRY AND GEOCHRONOLOGY OF MIDDLE PROTEROZOIC AND SILURIAN FELSIC SILLS IN THE BERKSHIRE MASSIF, MASSACHUSETTS

By

Paul Karabinos and David Morris, Department of Geosciences,
Williams College, Williamstown, MA 01267
Michael Hamilton and Nicole Rayner, Geological Survey of Canada,
601 Booth Street, Ottawa, Ontario K1A 0E8

ABSTRACT

Discontinuous sills of alaskite in the interior and western margin of the Berkshire massif and granite on the eastern margin of the massif were mapped by Ratcliffe (1984a,1984b; 1985) and Ratcliffe and Hatch (1979), and interpreted by them as syntectonic anatectic melts that intruded Taconic thrusts. The alaskite sills are most commonly found in the Middle Proterozoic Tyringham Gneiss and many of the mapped Taconic thrusts within the massif closely follow the distribution of the alaskite bodies. The granite sills are found in both Middle Proterozoic basement and the Late Proterozoic Hoosac Formation.

We collected one sample of the Tyringham Gneiss and thirteen samples of alaskite, ranging in composition from granite to trondhjemite, for geochemical analysis and SHRIMP analysis to date the age of thrusting in the Berkshire massif. Geochemically, the alaskite sills are diverse, suggesting that some combination of partial melting of different source rocks, different degrees of partial melting, fractionation, and contamination during transport was involved in their genesis. Zircons from the Tyringham Gneiss contain cores with oscillatory zoning and thin homogeneous rims. The weighted average of eight $^{206}Pb/^{238}U$ analyses from the cores is 1179 +/- 9 Ma, whereas nine $^{206}Pb/^{238}U$ spot analyses from the rims yield an age of 1004 +/- 9 Ma; we interpret these to represent the crystallization age of the Tyringham Gneiss protolith and subsequent high grade metamorphism, respectively. Zircons from three samples of alaskite commonly contain xenocrystic cores that yield a wide range of ages from approximately 1050 to 1230 Ma surrounded by broad rims which commonly display oscillatory zoning. Many grains also show oscillatory zoning with no cores. The weighted average of sixteen $^{206}Pb/^{238}U$ analyses from grains without cores and rims of grains with cores in one alaskite sample is 997 +/- 10 Ma, the weighted average of eight analyses from the second sample is 1004 +/- 19 Ma and seven spot analyses from a third sample give a weighted average of 1003 +/- 8 Ma. We suggest that the alaskite bodies formed during either the Ottawan or Rigolet phase of the Grenville orogeny and that they have no connection to the Taconic orogeny.

We also collected five samples of granitic sills from the eastern margin of the Berkshire massif that intruded both Middle Proterozoic basement and the Late Proterozoic Hoosac Formation near their contact. These sills were also interpreted as syntectonic intrusives along Taconic faults (Ratcliffe and Hatch, 1979). Geochemically, the sills, which we informally refer to as the granite of Becket Quarry, are very consistent, suggesting that they formed by partial melting of a single source rock. The concordia plot for one sample shows a strong cluster of young ages that give a weighted average $^{206}Pb/^{238}U$ age of 432 +/- 3 Ma (n=11). The older core $^{207}Pb/^{206}Pb$ ages range from ca. 960 to 1250 Ma. The concordia plot for another sample also has a strong cluster of young ages that give a weighted average $^{206}Pb/^{238}U$ age of 434 +/- 5 Ma (n=8). The older core $^{207}Pb/^{206}Pb$ ages for this sample range widely from ca. 790 to 1170 Ma. We interpret the 432 +/- 3 Ma and 434 +/- 5 Ma ages as the time of crystallization of the granite of Becket Quarry. The older cores are xenocrystic and their ages indicate that Middle Proterozoic basement rocks were partially melted to produce the granite during the Silurian.

The western, basal contact between Middle Proterozoic rocks of the Berkshire massif and underlying Early Paleozoic rocks is clearly a thrust, but there is no independent evidence that movement occurred during the Taconic orogeny, and it may be an Acadian fault. Many contacts within the Berkshire massif mapped as Taconic thrusts that follow the distribution of the alaskite sills must either be Middle Proterozoic faults or, more likely, intrusive contacts between older basement gneisses and younger anatectic melts. Instead of being deformed into an imbricate stack, the massif may have behaved as a rigid block during Paleozoic uplift. Finally, the eastern margin of the massif may be a Silurian fault, possibly related to extension and the opening of the Connecticut Valley trough, rather than a Taconic thrust.

INTRODUCTION

The tectonic history of the Berkshire massif is central to the story of the collision between Laurentia and the Shelburne Falls arc during the Ordovician Taconic orogeny. Cored by Middle Proterozoic basement rocks, it forms a boundary between Late Proterozoic to Ordovician shallow-water shelf sequence rocks west of the massif and coeval deep-water slope and rise deposits to the east. Therefore, it is important to reconstruct the tectonic history of the Berkshire massif to understand more fully the kinematics of thrusting, especially the thrusts that apparently carried the deep-water deposits of the Taconic thrust sheets over the massif and onto the shelf sequence. Furthermore, because the massif is the eastern most exposure of Grenvillian crust in this part of western New England, it should record important details about the early stages of the collision between Laurentian crust and the Taconic arc.

The structural complexity of the Berkshire massif and adjacent tectonic units was brought to light by detailed mapping during the 1960's and 1970's by D.S. Harwood, N.L. Hatch, S.A. Norton, N.M. Ratcliffe, and R.S. Stanley. Ratcliffe and Hatch (1979) emphasized the importance of Taconic thrusting in shaping the structural geometry of the massif. They argued that Taconic thrusts (1) carried the Middle Proterozoic basement rocks and unconformably overlying Late Proterozoic to Cambrian Dalton Formation and Cheshire Quartzite over the marbles of the Cambrian to Ordovician Stockbridge Formation, (2) pushed the younger Late Proterozoic to Cambrian Hoosac Formation over the eastern margin of the basement rocks, and (3) dissected the massif into approximately a dozen thrust sheets that shortened it to one third of its pre-Taconic width (current width 20 km).

Ratcliffe and Hatch (1979) and Ratcliffe (1984a, 1984b, 1985) described felsic sills which they interpreted as syn- to late-tectonic intrusives along Taconic thrusts throughout the massif. We began this project with the goal of dating the felsic sills to constrain the age of Taconic thrusting, but unexpectedly discovered that the sills were intruded during two widely separated episodes, one during the Middle Proterozoic at ca. 1 Ga and the other during the Silurian at ca. 430 to 435 Ma. The older group is found along the western margin of the massif and near many of the major mapped thrusts within the massif, whereas the younger group is concentrated along the eastern boundary of the massif. This guide describes the field setting, geochemistry, and geochronology of these two groups of felsic sills. Our new age data require a thorough reassessment of the prevailing view of the Berkshire massif discussed above. (1) Although the evidence for a thrust or reverse fault contact along the western boundary of the Berkshire massif is very strong, faulting could have occurred during either the Taconic or Acadian orogeny, or possibly the Alleghenian orogeny. (2) If the contact between Grenvillian basement rocks and the Hoosac Formation on the east side of the massif is indeed a fault, it may have been active during the Silurian and be related to crustal extension and the opening of the Connecticut Valley trough. (3) Contacts mapped as Taconic thrusts within the massif that we examined in detail are either Middle Proterozoic faults or, more likely, intrusive contacts without faults. Thus, the massif appears to have behaved as a rigid block during Paleozoic uplift rather than as an imbricate thrust stack or duplex.

GEOLOGIC SETTING

Lithotectonic Units

The Berkshire and Green Mountain massifs are cored by Middle Proterozoic Grenvillian basement (see Karabinos and Aleinikoff (1990), Ratcliffe et al. (1997), and Karabinos et al. (1999) for some geochronological constraints). West of the massifs, the Taconic klippen are composed of Late Proterozoic to Middle Ordovician slate and phyllite originally deposited as shale and siltstone on the continental slope and rise of the passive Laurentian margin (Fig. 1). The klippen structurally overlie a coeval sequence of clastic and carbonate rocks, which formed on the continental shelf of Laurentia. East of the massifs, the Hoosac Formation in Massachusetts and the Tyson, Hoosac, and Pinney Hollow Formations in Vermont are equivalent to the basal units found in the Taconic klippen. The Rowe Formation in Massachusetts and the Ottauquechee and Stowe Formations in Vermont form the remnants of an accretionary wedge of oceanic crust and sediments, and the Moretown Formation contains forearc basin deposits (Fig. 1; Rowley and Kidd, 1981; Stanley and Ratcliffe, 1985). The Shelburne Falls arc (Fig. 1) is composed of the Barnard

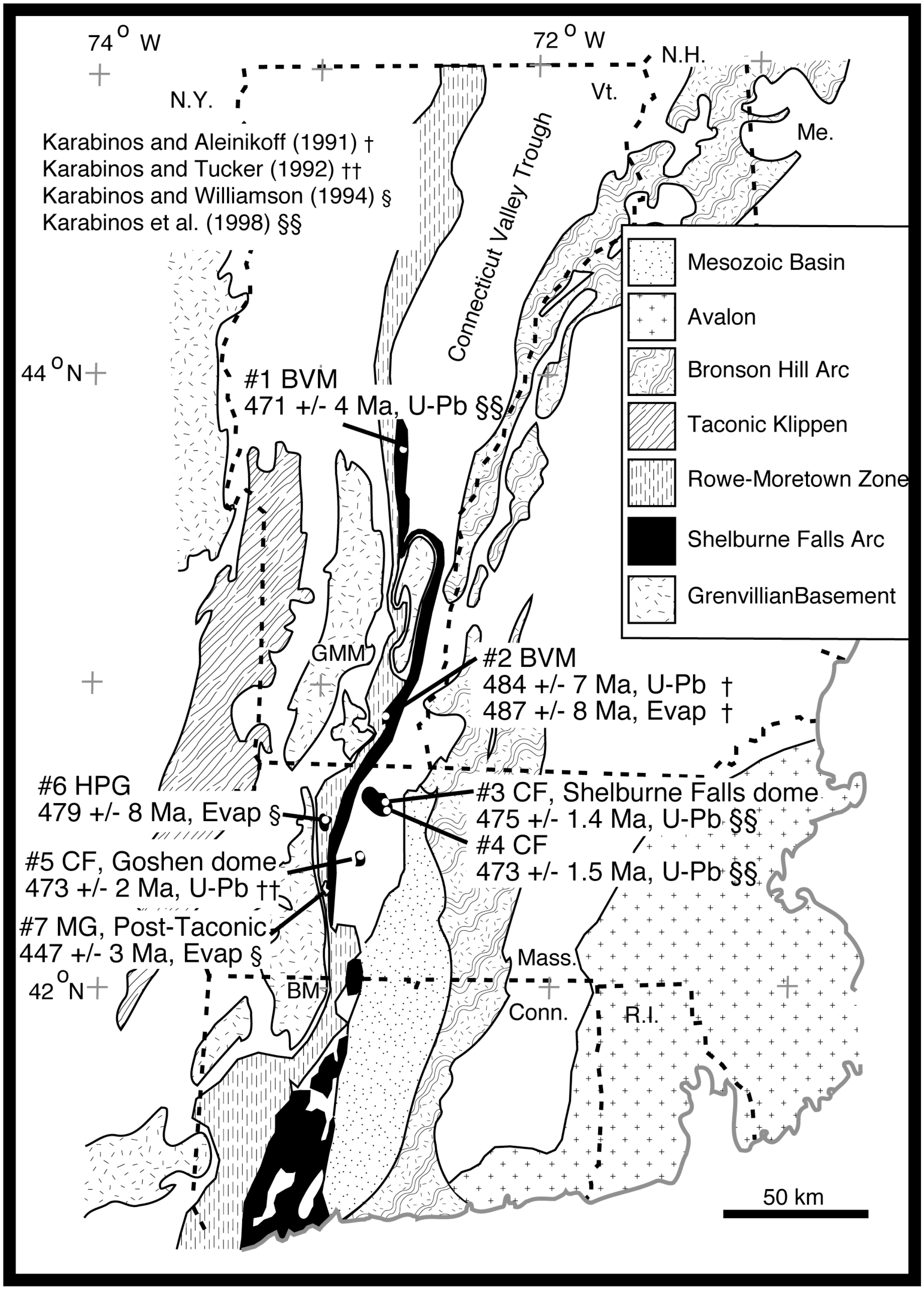

Figure 1. Tectonic map of New England and summary of U-Pb and single-grain evaporation (evap) zircon ages from the Shelburne Falls arc in western New England. Shelburne Falls arc rocks include the Barnard Volcanic Member (BVM), Collinsville Formation (CF), and Hallockville Pond Gneiss (HPG). The post-Taconic Middlefield Granite (MG) indicates that Taconic thrusting ended before ca. 447 +/- 3 Ma. GMM- Green Mountain massif. BM- Berkshire massif. Modified from Karabinos (2001).

Volcanic Member of the Missisquoi Formation in Vermont and the Hawley Formation in Massachusetts (Karabinos et al., 1998). The Collinsville Formation and the Hallockville Pond Gneiss in Massachusetts are also part of the Shelburne Falls arc, but they form isolated bodies. The Connecticut Valley trough (Fig. 1) contains metasedimentary and metavolcanic rocks of Silurian to Early Devonian age.

Taconic and Acadian Orogenies

During the Ordovician Taconic orogeny (470 to 455 Ma), Laurentia collided with an island arc that formed above an east-dipping subduction zone. The characteristic deformation pattern was westward-directed thrusting of rocks of the continental margin, accretionary wedge, forearc basin, and arc complex (Rowley and Kidd, 1981; Stanley and Ratcliffe, 1985). Until recently the Bronson Hill arc in western New Hampshire and central Massachusetts and Connecticut (Fig. 1) was commonly identified as the arc that collided with Laurentia. However, Tucker and Robinson (1990) pointed out that the 454 to 442 Ma age range of volcanic and plutonic rocks in the Bronson Hill arc is younger than some metamorphic cooling ages from rocks caught in the Taconic collision zone (e.g. Laird et al., 1984). Karabinos et al. (1998) argued that the older Shelburne Falls arc (485 to 470 Ma) in eastern Vermont and western Massachusetts (Fig. 1) collided with Laurentia during the Taconic orogeny, and that the Bronson Hill arc formed above a west-dipping subduction zone after a reversal in subduction polarity. Karabinos et al. (1998) further suggested that this new west-dipping subduction zone accommodated plate convergence, thus bringing the Taconic orogeny to an end and setting the stage for the Acadian orogeny. According to this model, the Laurentian margin was active during the Silurian and the Connecticut Valley trough formed as an extensional back-arc basin above a west-dipping subduction zone (Karabinos et al., 1998; Karabinos, 1998).

The Acadian orogeny began in the Late Silurian and continued into the Middle Devonian; it resulted from the protracted collision of Laurentia and Composite Avalon (Robinson et al., 1998, Bradley et al., 2000, Tucker et al., 2001). Studies using high-precision geochronology have demonstrated that what was formerly regarded as a single 'Acadian' orogeny is, in fact, a complex series of tectonic events spanning tens of millions of years (Robinson et al., 1998; Bradley et al., 2000, Tucker et al., 2001). Bradley (1983) proposed that the collision occurred above two subduction zones, one dipping beneath each continental margin, but other models invoke a single subduction zone under Avalon (e.g. Robinson et al, 1998, Tucker et al., 2001).

The Berkshire Massif

The Berkshire massif in western Massachusetts is cored by Middle Proterozoic rocks that were deformed and metamorphosed to hornblende granulite grade during the Grenville orogenic cycle (Ratcliffe and Hatch, 1979). There are very few geochronological constraints on the Middle Proterozoic igneous and metamorphic history of the basement rocks, mostly because the zircons separated from these rocks are complex and not amenable to the isotope dilution methods that prevailed during the time of the original field investigations (e.g. Ratcliffe and Zartman, 1976). It is widely assumed that the Grenville orogenic cycle, as reconstructed for the Adirondack Mountains (McLelland et al., 1996) affected basement rocks of the Berkshire massif and the Green Mountain massif in Vermont.

The basement rocks of the Berkshire massif must have been close to the Late Proterozoic rifted margin of Laurentia because they are unconformably overlain by rift clastics of the Dalton Formation, which is composed of interbedded conglomerate, arkose, phyllite, and quartzite. Along the western margin of the massif, the Dalton Formation is overlain by the Cheshire Quartzite, indicating that some, if not all, of the basement rocks of the massif were overlain by the Cambrian to Ordovician shallow water shelf sequence. Because the eastern boundary of the massif is interpreted to be a tectonic contact, it is difficult to determine if the facies transition between the western shelf sequence and the eastern slope-rise sequence occurred over the currently exposed basement rocks or not. Only at the north end of the Berkshire massif, near Hoosac Mountain, does the Hoosac Formation rest unconformably on basement rocks (Ratcliffe et al., 1988). Hoosac Mountain is also unusual in that it is the only part of the Berkshire massif where the ca. 960 Ma, post-Grenville Stamford Granite Gneiss (Karabinos and Aleinikoff, 1990; Ratcliffe et al., 1988) is exposed.

The western boundary of the massif is a fault that carried the basement rocks and unconformably overlying Dalton Formation and Cheshire Quartzite over the Stockbridge and unconformably overlying

Walloomsac Formation. Ratcliffe and Harwood (1975) described blastomylonitic fabrics from rocks above and below the western boundary of the massif and argued that they formed during a late stage of Taconic thrusting, after emplacement of the Taconic thrust sheets, now located west of the massif.

The eastern contact of the massif juxtaposes the Hoosac Formation structurally above basement rocks (Norton, 1975; Ratcliffe and Hatch, 1979). Granite sills are commonly found at the contact and close to it in either the basement rocks or the Hoosac Formation. Preliminary Rb/Sr analysis suggested that one of the granite sills might be Ordovician (Ratcliffe and Mose, 1978), and this age assignment, which was never verified, was applied to the diverse assemblage of felsic sills in the massif (e.g. Ratcliffe, 1984a, 1984b, 1985)

The interior of the massif contains a diverse group of metamorphosed Middle Proterozoic igneous and sedimentary rocks. The units were described in detail by Ratcliffe and Zartman (1976). In terms of exposure area, some of the most extensive units are the Tyringham Gneiss, Washington Gneiss, and Biotite-quartz-plagioclase Gneiss. These and other units are found throughout the massif; there do not appear to be any important variations in the lithologic assemblage that correlate with the proposed thrust sheets within the massif, except for the the Hoosac Mountain area at the north end of the Berkshire massif, as previously noted. Indeed, many of the faults shown by Ratcliffe (1984a, 1984b, 1985) within the massif are, at least in part, within individual basement units. Displacement on such faults cannot be great. Many, but not all, of the mapped thrusts within the massif coincide with exposures of felsic sills referred to as alaskite by Ratcliffe (1984a, 1984b, 1985).

ALASKITE SILLS AND TYRINGHAM GNEISS

Field Characteristics of Sills

The alaskite sills were shown by Ratcliffe (1984a, 1984b, 1985) on the USGS 7.5' quadrangle maps of Pittsfield East, East Lee, and Monterey as Ordovician intrusives and labelled Oa and Oam (for magnetite-rich bodies). On the geologic map of Massachusetts, these rocks are labelled Ogr (Zen et al., 1983). The alaskite sills are thin, elongate, and discontinuous bodies with sharp contacts. The mapped bodies vary from approximately 10 to 200 m in thickness and from 25 to 700 m in length. Actual exposures of alaskite are commonly much smaller. Figure 2 shows the location of the mapped alaskite sills in the Berkshire massif.

The alaskite sills are white to light gray and contain quartz, plagioclase, microcline, biotite, and muscovite. Some of the sills (i.e. Stop 3) contain too much biotite to meet the requirements of the definition for an alaskite (< 5% mafic minerals), but we have retained the term alaskite at this time to be consistent with published quadrangle maps. Some of the alaskite sills contain a significant amount of disseminated magnetite and some have cm-thick magnetite veins. The sills vary in composition from granite to tonalite or trondhjemite (Fig. 3). The degree of fabric development is highly variable; some exposures are massive whereas others contain a very strong gneissic foliation defined by alternating quartz-feldspar-rich and mica-rich layers. Fabric in the alaskite sills is parallel to the gneissosity in the surrounding basement rocks. In thin section, even the massive alaskite samples show evidence for deformation.

Where exposed, the contacts between the alaskite sills and the surrounding basement gneisses are well defined and sharp. We did not observe strong deformation gradients near the contacts or other features that require the contacts to be faults, i.e. fabrics observed in the alaskite sills and in basement gneisses near the contacts are not demonstrably different from those in the sills and basement rocks farther from the contacts. The alaskite sills are found in the following basement units: the Tyringham Gneiss, the Washington Gneiss, and the Biotite-quartz-plagioclase Gneiss. Most of the alaskite sills are surrounded by basement units and many of them are contained within a single unit. One large exposure on the west side of the massif in the Monterey 7.5' quadrangle (samples 3019 and 3020, Stop 5) is located between the Biotite-quartz-plagioclase Gneiss and the Stockbridge Formation. Another mapped exposure in the Pittsfield East 7.5' quadrangle 100 m upslope from Mill Brook (sample 3028, see Fig 2) is located within the Washington Gneiss but only 50 m above the mapped contact with Dalton Formation. This latter exposure is almost certainly different from the other alaskite sills and should not be included with them for two reasons. First, it is geochemically quite different from the other samples (see geochemistry section). More importantly, zircons separated from this sample are rounded, pitted, frosted, and diverse in color and

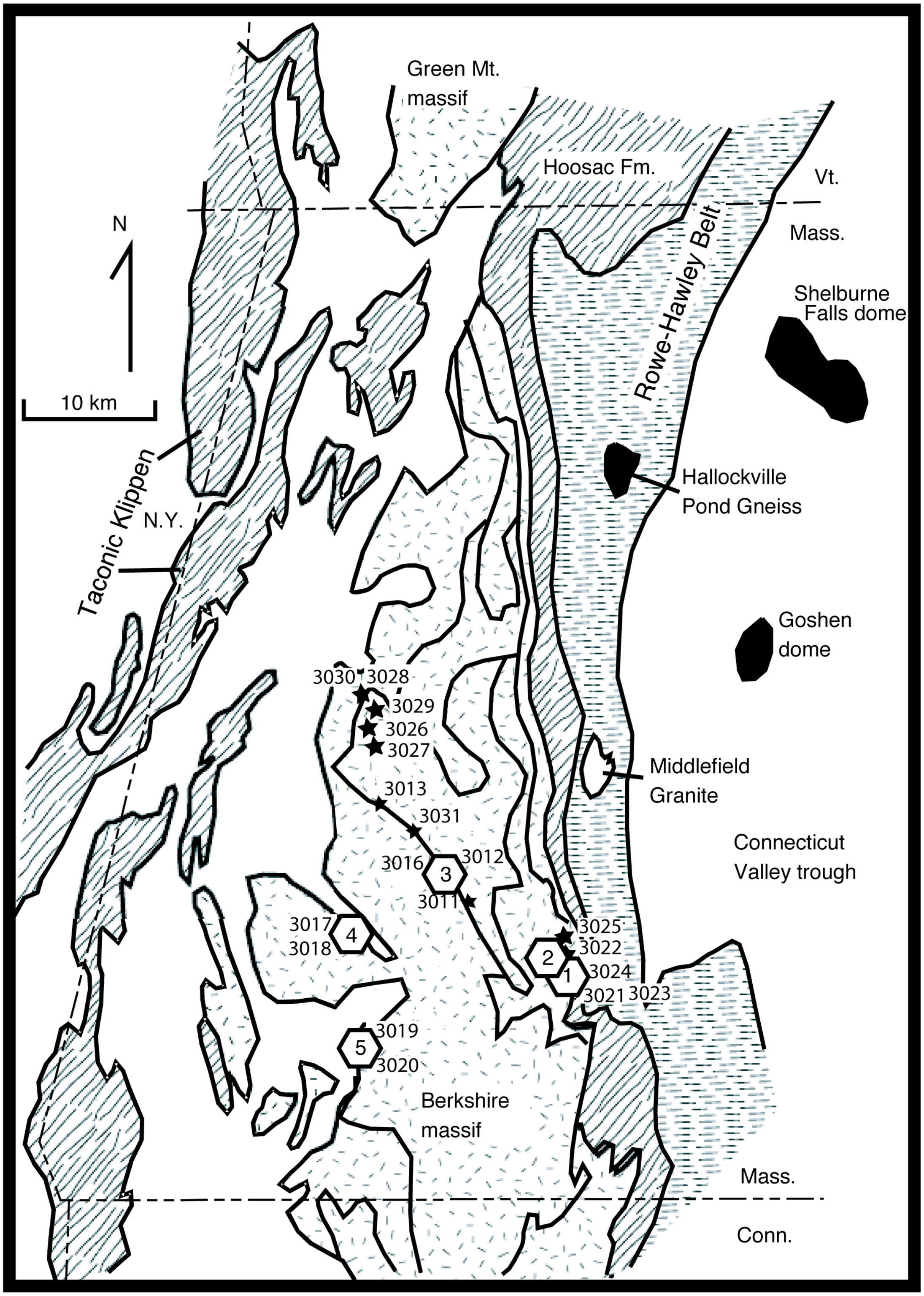

Figure 2. Generalized geologic map of western Massachusetts showing sample locations (black stars) and field trip stops (hexagons). Geology from Karabinos and Hepburn (2001). Heavy black lines within the Berkshire massif are mapped faults (Zen et al., 1983).

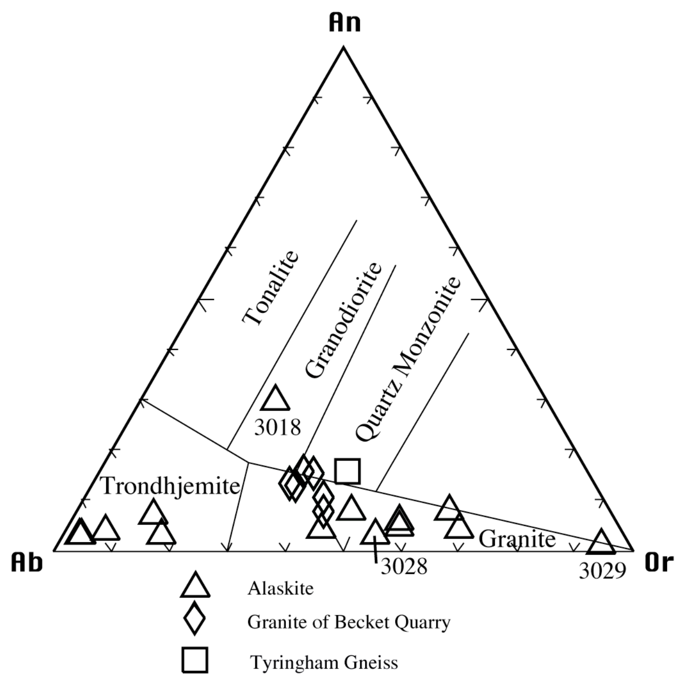

Figure 3. Felsic igneous rock variation diagram showing normative components of albite (Ab), anorthite (An), and orthoclase (Or).

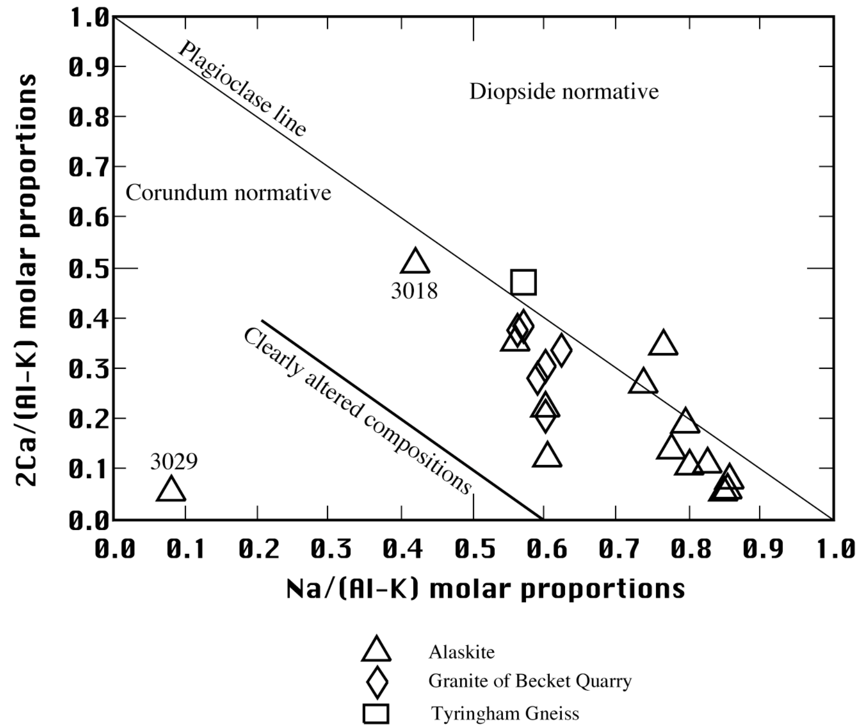

Figure 4. Alteration diagram for felsic rocks showing the alaskite (triangles), the granite of Becket Quarry (diamonds), and the Tyringham Gneiss (square) data. Diagram after Schumacher (1988) and Hollocher (1993).

shape, indicating a detrital origin for the population. This unit is most likely a volcaniclastic layer of the same age as the Washington Gneiss.

Geochemistry of the Alaskite Sills and the Tyringham Gneiss

Thirteen samples of mapped alaskite and one sample of the Tyringham Gneiss were collected for geochemical analysis. All of the alaskite samples and the Tyringham Gneiss sample are peraluminous. All but one of the alaskite samples plot in the granite or trondhjemite field in a normative albite, anorthite, and orthoclase diagram (Fig. 3). The one exception, sample 3018, which plots in the granodiorite field, came from a small lens in Tyringham, Massachusetts, near Stop 4 that is quite different in appearance from all of the other exposures. This lens is a coarse-grained migmatitic rock that is either unrelated to the rest of the alaskite occurrences or may have crystallized from a late residual melt. Another sample, 3029, came from a streambed and was significantly weathered. Sample 3028, the only sample that yielded detrital zircons, does not appear to be anomalous in this diagram, but in other plots it differs substantially from the other alaskite sills. The Tyringham Gneiss sample plots in the quartz monzonite field very close to the granite field.

Almost all of the samples fall into the field of unaltered felsic igneous rocks (Fig. 4, Schumacher, 1988; Hollocher, 1993). Weathering and hydrothermal alteration tend to enrich rocks in Al, which would displace samples towards the origin in Figure 4. Only sample 3029 is in the clearly altered field. Because sample 3018 does not lie in the altered field, the geochemical differences between it and the majority of the alaskites must be due to the origin of this small lens.

The alaskite samples range from 70.7 to 77.6% SiO_2, when the three anomalous samples are ignored. On multielement discrimination diagrams normalized to ocean ridge granites (Pearce et al., 1984), trace element concentrations vary by an order of magnitude (Fig. 5a). Figure 5b shows that rare earth element abundances in the alaskites vary between 1 and 100 times chondritic abundances (Nakamura et al., 1974). Along with the significant variations in concentration of trace and rare earth elements, Figures 5a and 5b also show that the alaskite samples do not have consistent trends in relative element concentrations. For example, some show positive Eu anomalies in Figure 5b, whereas others show negative anomalies, suggesting a range of fractionation histories with respect to plagioclase. Incompatible element trends of most of the alaskite samples in Figure 5a, specifically the enrichment of Rb and Ba and depletion in Y and Yb are characteristic of rocks from volcanic arc settings (Pearce et al., 1984). However, some samples, including 3019 and 3020 (Stop 5), do not show a typical volcanic arc trend.

On tectonic discrimination diagrams (Pearce et al., 1984) the alaskite samples typically cluster in the volcanic arc granite and syn-collisional granite fields. All but one of the alaskite samples plot in the volcanic arc granite field in a Yb vs. Ta plot (Fig. 6a), again with substantial scatter. On Y+ Nb vs. Rb (Fig. 6b) and Ta + Yb vs. Rb (Fig. 6c) plots all but two of the alaskite samples plot in the volcanic arc field, but again with significant scatter.

The two most important points are that the alaskite samples are geochemically diverse and that they tend to show geochemical affinities to volcanic arc granites.

Geochronology of the Alaskite Sills and the Tyringham Gneiss

Zircons from all of the samples studied are complex and commonly have core and rim textures that define separate age domains reflecting the multistage history of the rocks. The multiple age domains make it very difficult to define precisely the crytallization or metamorphic ages of the rocks using isotope dilution methods (e.g. Ratcliffe and Zartman, 1976; Zartman et al., 1986). To overcome this problem, we used the sensitive high-resolution ion microprobe (SHRIMP II) at the Geological Survey of Canada in Ottawa. Morris and Karabinos separated zircons at Williams College using conventional mineral separation methods. Hamilton and Rayner prepared mounts, imaged grains by cathodoluminescence (CL) and back-scattered electron (BSE), and analysed carefully selected spots on individual grains using the SHRIMP II in Ottawa.

Tyringham Gneiss. To provide context for interpreting the alaskite samples and a better understanding of the Grenvillian basement in the Berkshire massif, we collected a sample of the Tyringham Gneiss, sample 3016 (Stop 3). Ratcliffe and Zartman (1976) reported $^{207}Pb/^{206}Pb$ ages between 1040 to 1080 Ma for slightly discordant zircons from the Tyringham Gneiss, but the crystallization age of

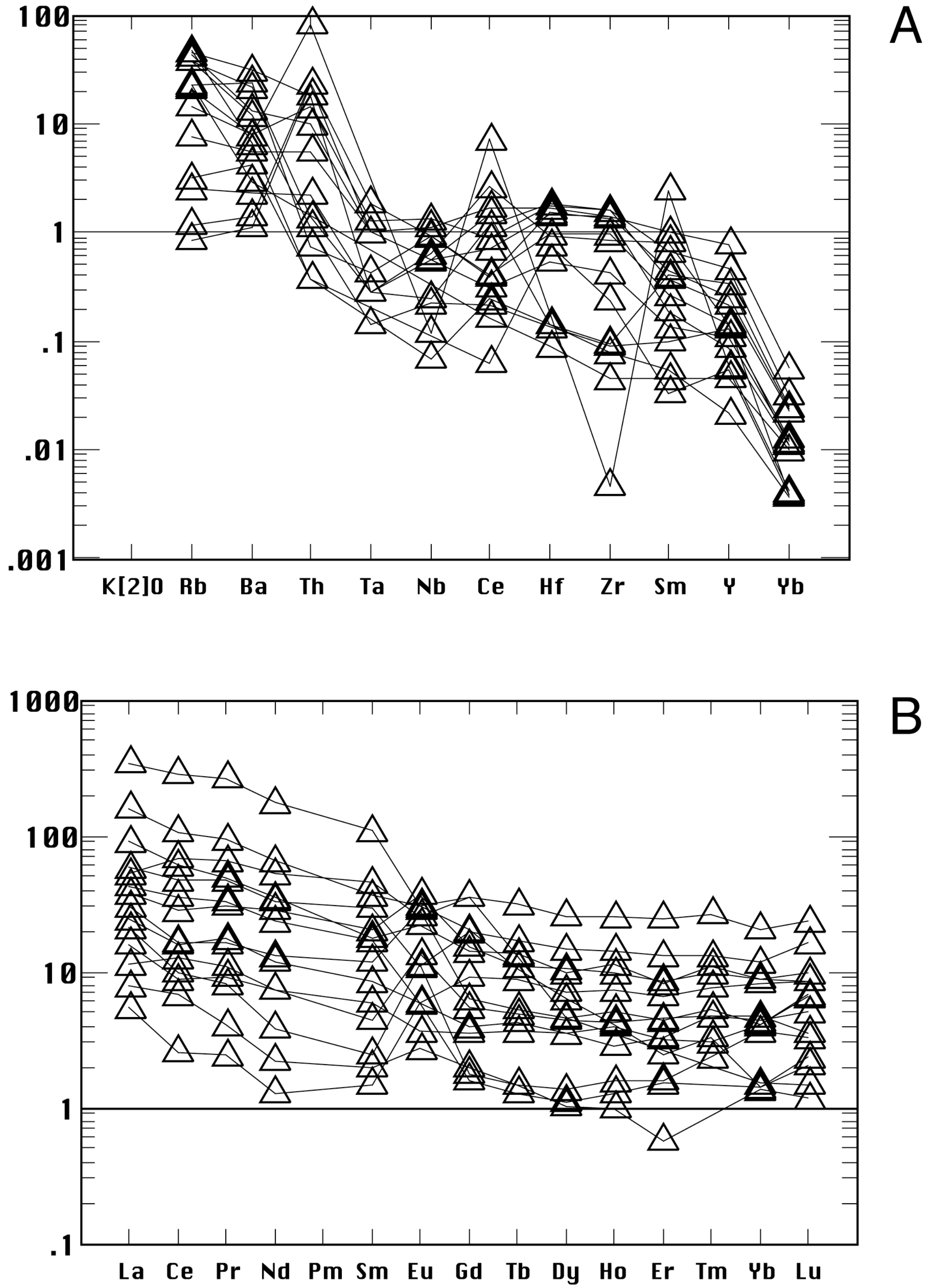

Figure 5. (A) Ocean ridge granite(ORG)-normalized incompatible element diagram (Pearce et al., 1984) for all alaskite samples. (B) Chondrite-normalized rare-earth-element plot for all alaskite samples. (Nakamura et al., 1974).

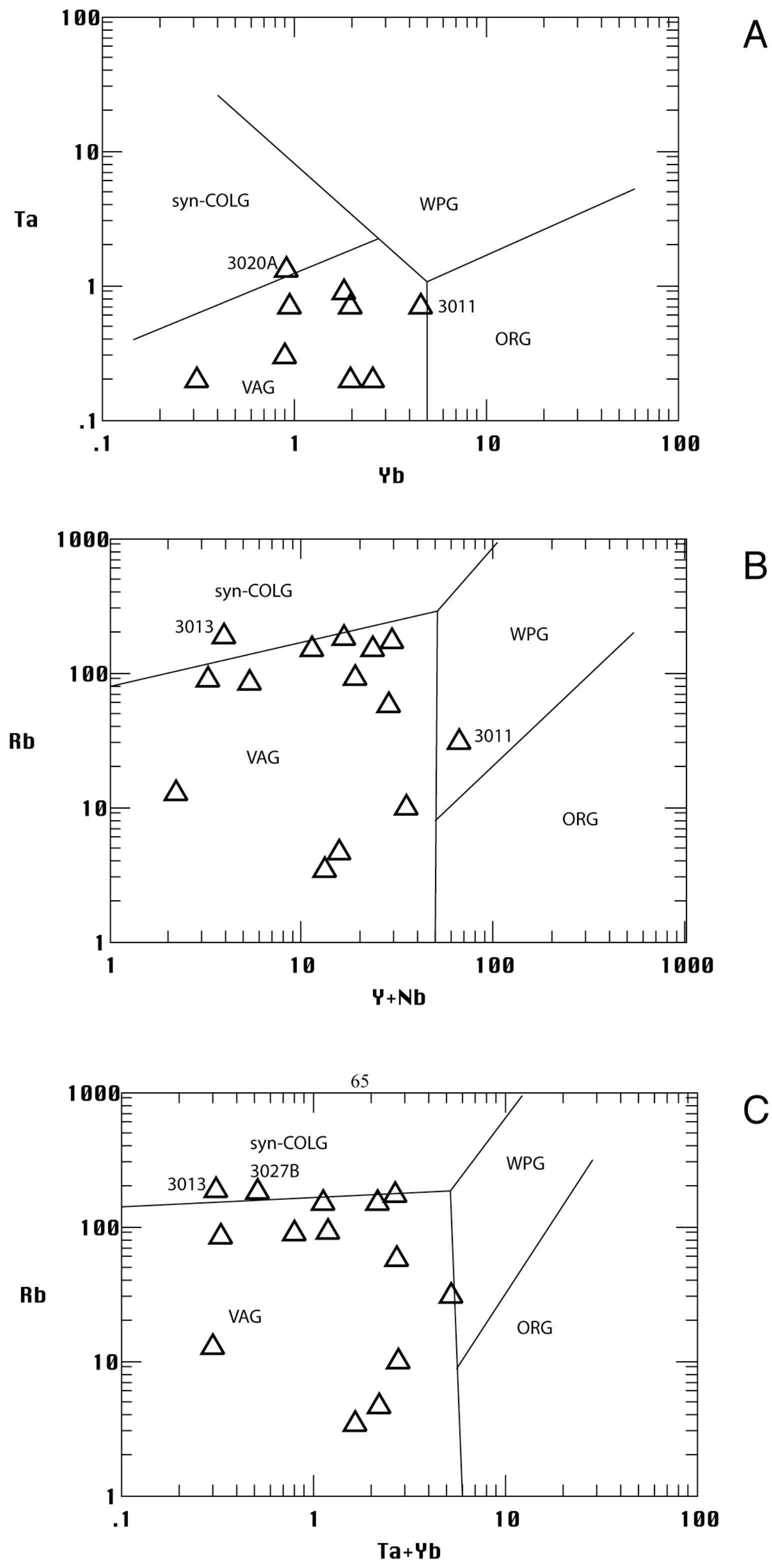

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Figure 6. Tectonic discrimination diagrams for felsic igneous rocks showing data from alaskite samples . VAG- volcanic arc granite, syn-COLG- syn-collisional granite, WPG- within plate granite, and ORG- ocean ridge granite, after Pearce et al. (1984).

this unit remained uncertain. Zircon grains are elongate and euhedral and lack frosting or pitting, morphology and surface characteristics typical of crystallization from a melt. Closer examination by BSE (Fig. 7a), however, reveals that many of the grains have cores with oscillatory zoning and unzoned rims or mantles. The histogram and concordia plots of $^{206}Pb/^{238}U$ ages (Figs. 7b and 7c) show two strong clusters of ages, and the weighted averages of these two groups are 1179 +/- 9 Ma (n=8) and 1004 +/- 9 Ma (n=9). The older ages consistently come from spots in the cores of grains and the younger ages consistently come from rims, although some grains do not have older cores.

The most straightforward way of interpreting the age data is that the older core ages, ca. 1180 Ma, represent crystallization of the Tyringham Gneiss from a melt and the younger rims formed during intense metamorphism at ca. 1000 Ma. The geological significance of the intermediate ages is unclear, but they may be related to one or more of the other deformational episodes of the Grenville orogenic cycle. A crystallization age of 1180 Ma for the Tyringham Gneiss would make it a contemporary of the well documented igneous pulse of the anorthosite-mangerite-charnokite-granite suite in the Adirondack Mountains (McLelland et al., 2001). Intense metamorphism in the Adirondacks occurred during the Ottawan phase of the Grenville orogenic cycle and significantly earlier (> 50 m.y.) than the 1000 Ma metamorphic rims in the Tyringham Gneiss (McLelland et al., 2001). The younger metamorphism in the Berkshire massif may reflect the time transgressive nature of the Ottawan phase or record the younger Rigolet phase proposed by Rivers (1997).

Alaskite Sills. Zircon grains from three alaskite samples were analysed using the SHRIMP II. Two of the samples, 3011 and 3012 are from the interior of the massif, within a km of each other, and along strike in the same elongate, discontinuous belt of alaskite sills within the Tyringham Gneiss (Fig. 2, Stop 3). The third sample, 3019, is from the west side of the massif, below the Biotite Gneiss and above the Stockbridge Formation (Fig. 2, near Stop 5). Zircon grains from all alaskite samples are commonly elongate and euhedral, and in CL and BSE images many of the grains show cores with oscillatory zoning and rims that show faint oscillatory zoning or are unzoned (Figs. 8a, 9a, 10a).

The histogram and concordia plots for sample 3011 show a single maximum and a wide scatter of other ages (Figs. 8b and 8c). The weighted average of sixteen $^{206}Pb/^{238}U$ rim ages is 997 +/- 10 Ma. The $^{206}Pb/^{238}U$ ages from cores range from approximately 1050 to 1200 Ma without a clear maximum. Sample 3012 (Stop 3) is from the same large outcrop as the dated Tyringham Gneiss sample. The histogram and concordia plots for this sample show a number of rim ages at ca. 1000 Ma and a wide scaterring of core ages from approximately 1070 to 1210 Ma (Figs. 9b and 9c). The weighted average of eight $^{206}Pb/^{238}U$ rim ages is 1004 +/- 19 Ma. Sample 3019, from the west margin of the massif, also shows a tight cluster of ages at ca. 1000 Ma and a wide scatter of ages from 1100 to 1220 Ma (Fig. 10b). The weighted average of seven $^{207}Pb/^{206}Pb$ ages is 1003 +/- 8 Ma.

The wide range of core ages from all three alaskite samples suggests that the zircon cores are xenocrystic, that is they are relicts of incompletely dissolved zircon grains from the rocks that were partially melted to produce the alaskite magma. The rim ages from all three samples are identical, within analytical uncertainty, and approximately 1000 Ma. We interpret this as the crystallization age of the alaskite sills and suggest that partial melting of basement rocks occurred during the intense metamorphism that produced metamorphic rims on zircon grains in the Tyringham Gneiss.

Tectonic Significance of the Middle Proterozoic Alaskite Sills

Ratcliffe and Hatch (1979) and Ratcliffe (1984a, 1984b, 1985) interpreted the alaskite sills as syntectonic intrusives along Taconic thrust faults. This interpretation held that the sills were either the result of anatexis driven by shear heating on faults or metasomatism caused by fault zone migration of fluids. The Ordovician age assignment required by this interpretation is inconsistent with our new age data. Zircon rims from the three dated alaskite sills give, within uncertainty, identical Middle Proterozoic ages of ca. 1000 Ma, which we interpret as the crystallization age of these rocks. The wide range in age of the xenocrystic cores of zircons from the alaskite sills, from approximately 1050 to 1220 Ma for all three samples, suggests that the magma for the sills was generated by partial melting of paragneisses in the Grenvillian basement rocks of the massif. This conclusion is entirely consistent with the S-type granite characteristics of the sills (two-micas, peraluminous). The alaskite sills range widely in composition from granite to trondhjemite (Fig. 3), and there is considerable variation in the concentration of trace and rare

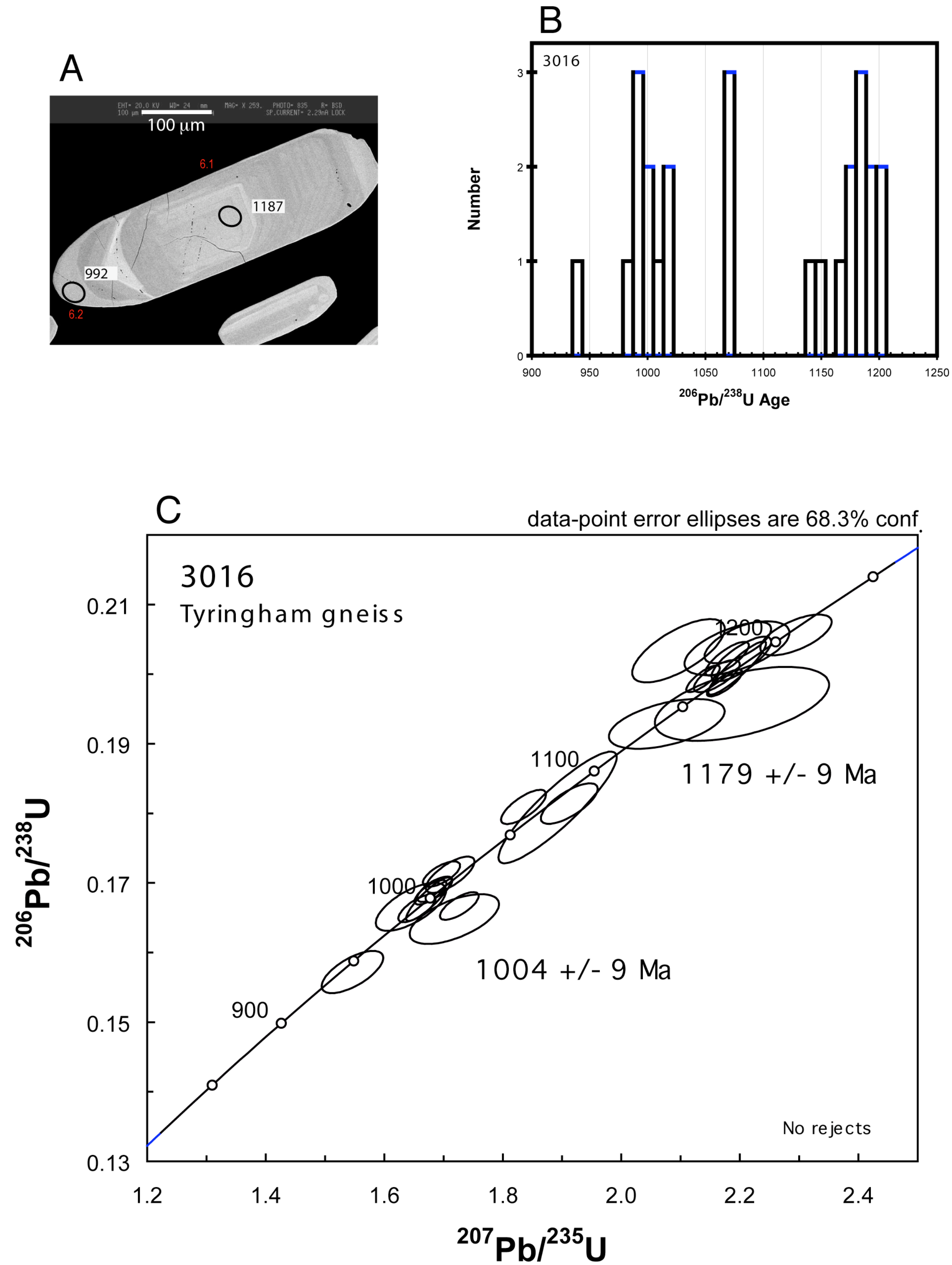

Figure 7. Sample 3016, Tyringham Gneiss. (A) Back-scattered electron image of zircon grains with spot analyses and 206Pb/238U ages. (B) Histogram of 206Pb/238U ages with 10 million year bin size. (C) Concordia plot of error ellipses for all spot analyses.

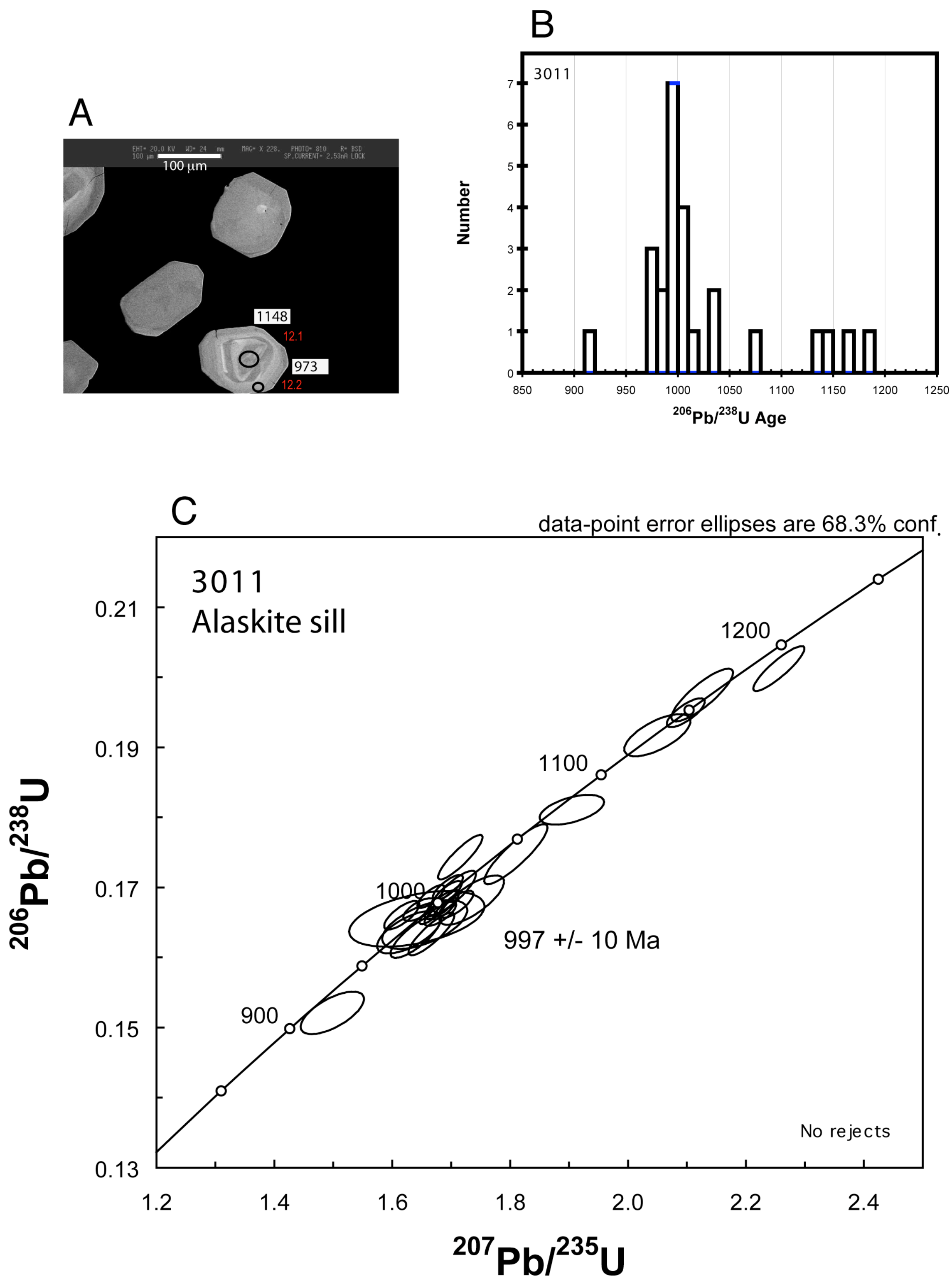

Figure 8. Sample 3011, alaskite sill. (A) Back-scattered electron image of zircon grains with spot analyses and 206Pb/238U ages. (B) Histogram of 206Pb/238U ages with 10 million year bin size. (C) Concordia plot of error ellipses for all spot analyses.

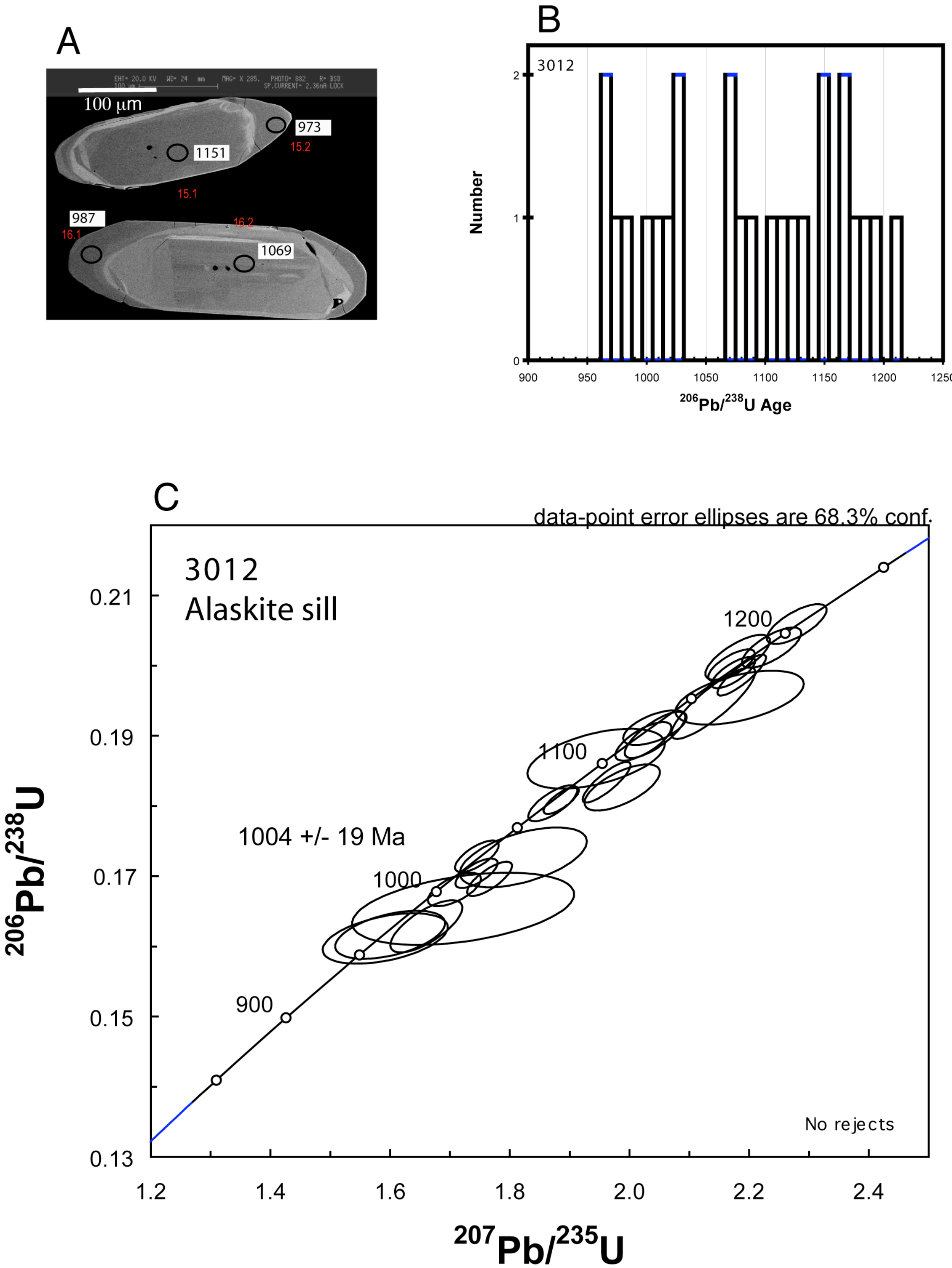

Figure 9. Sample 3012, alaskite sill. (A) Back-scattered electron image of zircon grains with spot analyses and 206Pb/238U ages. (B) Histogram of 206Pb/238U ages with 10 million year bin size. (C) Concordia plot of error ellipses for all spot analyses.

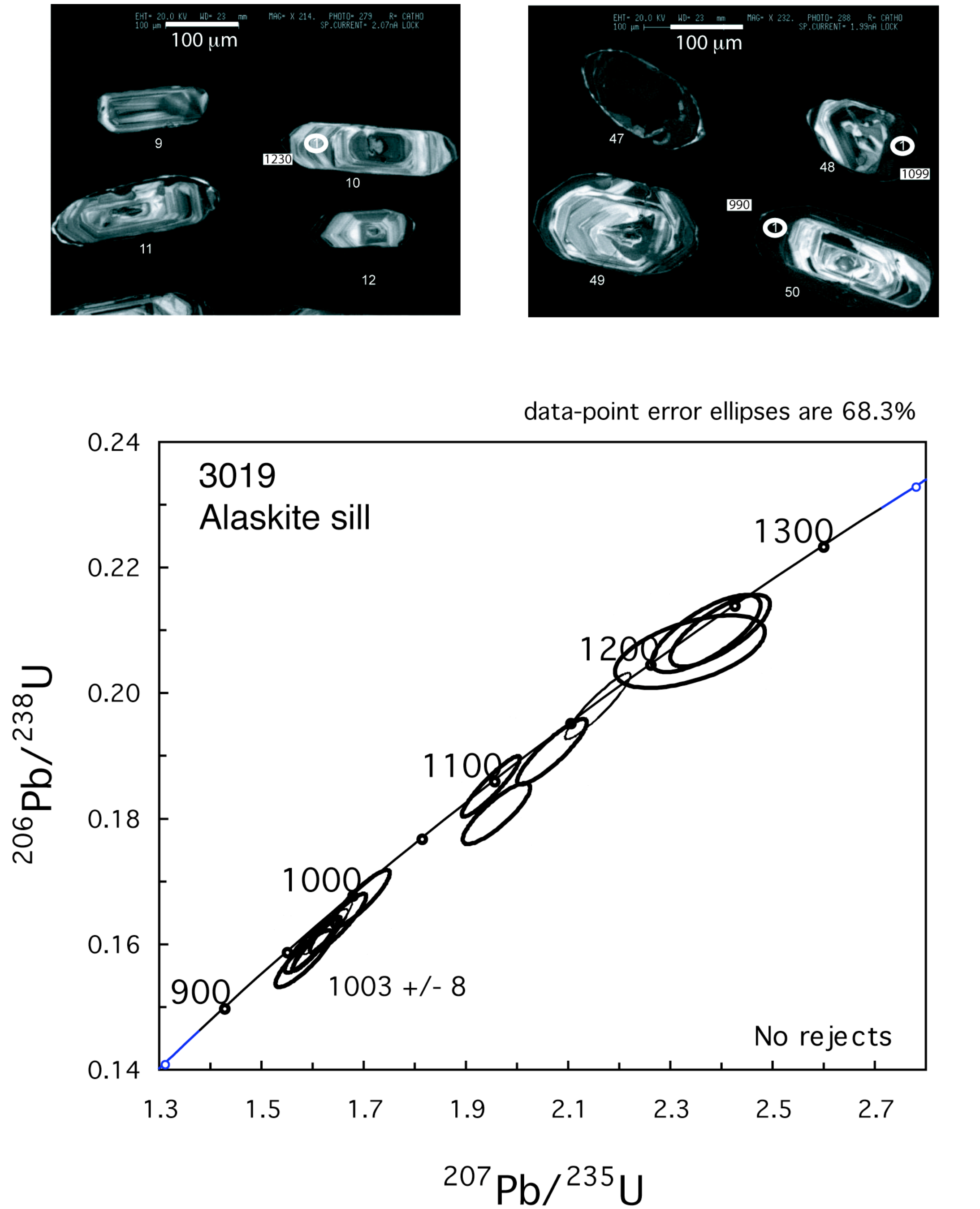

Figure 10. Sample 3019, alaskite sill. (A) Cathodoluminescence images of zircon grains with spot analyses and 207Pb/206Pb ages. (B) Concordia plot of error ellipses for all spot analyses.

earth elements (Figs. 5). The variability in composition of the alaskite sills probably reflects some combination of the following four factors: (1) partial melting of different source rocks, (2) different degrees of partial melting of source rocks, (3) fractionation of magma during transport, and (4) contamination of magma by wall rocks during transport.

The volcanic arc geochemical characteristics of the alaskite sills most likely reflect the geochemistry of the source rocks rather than the tectonic environment at the time the sills formed. It is important to note that the alaskite sills represent a very small percentage of the volume of the Berkshire massif. If there had been a subduction zone active at approximately 1 Ga, when the sills were generated during a period of continent-continent collision (McLelland et al., 1996), arc related igneous rocks would presumably be quite voluminous in the massif. During the Elzevirian orogeny (ca. 1350-1185 Ma), arc terranes accreted along the continental margin (McLelland et al., 1996). These arc related rocks may have been recycled to produce the sediments that were later metamorphosed during the Ottawan orogeny (ca. 1090-1000 Ma), such as the Washington Gneiss and the Biotite Gneiss. Partial melting of paragneisses derived from arc terranes may have imparted the observed geochemical signature to the alaskite sills.

To summarize, the alaskite sills formed at approximately 1 Ga by partial melting of paragneisses, and perhaps some orthogneisses, of the Berkshire massif. Anatexis occurred during a high-grade metamorphic event that is recorded by metamorphic overgrowths of zircon grains from the Tyringham Gneiss. The arc-related affinity of the alaskite sills probably reflects the geochemistry of the source rocks rather than the tectonic environment in which the sills formed.

Our results have far-reaching implications for the long-standing structural interpretation of the Berkshire massif and its role during the Taconic orogeny. There is very strong evidence for a fault along the western boundary of the massif, but it is not certain that this faulting occurred during the Taconic orogeny. The Ordovician age assignment for faulting was based on a reasonable correlation of thrusting in the massif with thrusting in the Taconic thrust sheets just west of the massif; the preliminary Rb-Sr age data from a sill of the granite of Becket Quarry that suggested, but did not prove, an Ordovician age (Ratcliffe and Mose, 1978); and the interpretation that the felsic sills of alaskite and the granite of Becket Quarry were coeval and syntectonic intrusives along thrusts. In light of this new age data, we should renew our efforts to constrain independently the age of faulting of the Berkshire massif, and to treat the Taconic age assignment of thrusting as a testable hypothesis rather than an established fact. Consider the Long Range massif in Newfoundland, which occupies a similar structural position to the Berkshire and Green Mounatin massifs, and was faulted onto the shelf sequence rocks during the Acadian orogeny (Cawood and Williams, 1988).

Another long-standing interpretation of the Berkshire massif is that the basement gneisses were shortened and stacked into about a dozen thrust sheets during the Taconic orogeny (e.g. Ratcliffe and Hatch, 1979). This structural interpretation also relied, to a large degree, on the interpretation of the felsic sills as sytectonic intrusives and the preliminary Ordovician age assignment of a sill of the granite of Becket Quarry. Many of the mapped thrusts within the massif correlate well with the distribution of alaskite sills and are located, at least in part, within a single basement unit. We did not observe structural evidence for faulting near the alaskite sills that we studied, but if such faults are present and related to the alaskite sills, they must be Middle Proterozoic faults and have relatively small displacement. We favor the interpretation that the boundary between the alaskite sills and the surrounding basement gneisses are intrusive contacts, perhaps with some localized shearing.

It seems reasonable that the quartz-feldspar-rich gneisses of the Berkshire massif behaved very differently, rheologically, than the slate, phyllite, and schist dominated rocks of the Taconic thrust sheets. There may indeed be some Taconic thrusts with limited displacement within the Middle Proterozoic gneisses, but it appears that that massif behaved as a rigid basement uplift, not unlike some of the classic Laramide uplifts (Bump, 2003).

GRANITE OF BECKET QUARRY

Field Characteristics

We informally call the sills found along the east margin of the Berkshire massif the granite of Becket Quarry after an excellent and accessible exposure (Stop 2). These rocks do not appear on published 7.5' quadrangle maps in the area of this field trip. Norton (1974) mapped the Becket 7.5' quadrangle but did not map the distribution of the granite sills. There are no published maps available for the Otis and Tolland Center 7.5' quadrangles, which also contain numerous exposures of these rocks. Large exposures of the granite of Becket Quarry appear on the geologic map of Massachusetts as Ogr (Zen et al., 1983), the same designation as the alaskite sills already described, and their distribution is based on field work by Ratcliffe (personal communications, 2003). Ratcliffe and Hatch (1979) showed the distribution of the granite sills near the boundary of the Becket and Otis 7.5' quadrangles and divided the rocks into two groups, the Algerie Road type and the Cushman Brook type. As discussed below, the geochemical data suggest a common origin for both types. The rocks we studied are similar to, and may be correlative with, granite exposures in the South Sandisfield 7.5' quadrangle (Harwood, 1979) studied by Zartman et al. (1986) and informally called the granite at Yale Farm by them.

The granite of Becket Quarry exposures vary in size from approximately 1 to 100 m thick sills. Several quarries provide excellent exposures of the granite and the contacts with surrounding units. The granite intruded the Washington Gneiss and the Biotite-quartz-plagioclase Gneiss of the basement complex and the Hoosac Formation in the cover sequence. The granite contains quartz, plagioclase, microcline, biotite, and muscovite. Contacts between the granite and host rocks, where exposed, are sharp. The fabric in the granite is typically weakly foliated. In well exposed quarries the fabric intensity increases with proximity to both upper and lower contacts and the foliation is approximately parallel to both the contact and the foliation in the surrounding rocks. Far from contacts in quarries, the granite commonly has a wispy or schlieren texture.

Geochemistry of the Granite of Becket Quarry

Five samples of the granite of Becket Quarry form a tight cluster in the granite field in Figure 3 and none of the samples shows evidence of alteration in Figure 4. Four of the samples (3021, 3022, 3023, and 3024) are from "Algerie Road type" outcrops of Ratcliffe and Hatch (1979) and one (3025) is from a "Cushman Brook type" outcrop. The multielement discrimination plot normalized to ocean ridge granite (Fig. 11a) shows that the five samples have nearly identical trace element concentrations. The enrichment in Rb, Ba, and Th, along with the depletion in Y and Yb are characteristics of volcanic arc granites. Chondrite normalized rare earth element abundances between the samples are not identical, but are quite similar. The granite samples have rare earth element abundances between 1 and 175x chondritic abundances, are enriched in light rare earth elements (La_N/Yb_N ranges from 20.1 to 87.6), and there are no pronounced Eu anomalies (Fig. 11b).

In tectonic discrimination diagrams the granite of Becket Quarry plots in the volcanic arc granite or syn-collisional granite field. In plots of Yb vs. Ta, Y + Nb vs. Rb, and Ta + Yb vs. Rb (Figs. 12a, b, and c) all samples are tightly clustered in the volcanic arc field. The geochemical consistency of the granite of Becket Quarry samples is quite different from the widely scattered patterns observed in geochemical plots of the alaskite samples. Based on geochemistry, there does not appear to be an important difference between the "Algerie Road type" and "Cushman Brook type" of granite (Ratcliffe and Hatch, 1979).

Geochronology of the Granite of Becket Quarry

Two samples of the granite of Becket Quarry were analysed with the SHRIMP II. One sample, 3022, is from the Becket Quarry (Fig. 2, Stop 2) and is a weakly foliated, >50 m thick sill within basement gneisses. The other sample, 3024, is a more strongly foliated, 2 m thick sill within the Hoosac Formation (Fig. 2, Stop 1). Zircon grains from both samples are elongate and euhedral. Many grains show oscillatory zoning with no cores whereas others contain cores with oscillatory zoning and rims that also show oscillatory zoning (Fig. 13a, 14a).

The histogram and concordia plots for sample 3022 (Fig. 13b, 13c) show a strong cluster of young ages that give a weighted average $^{206}Pb/^{238}U$ age of 432 +/- 3 Ma (n=11). The older core $^{207}Pb/^{206}Pb$ ages range from ca. 960 to 1250 Ma. The histogram and concordia plots for sample 3024 (Fig. 14b, 14c) also

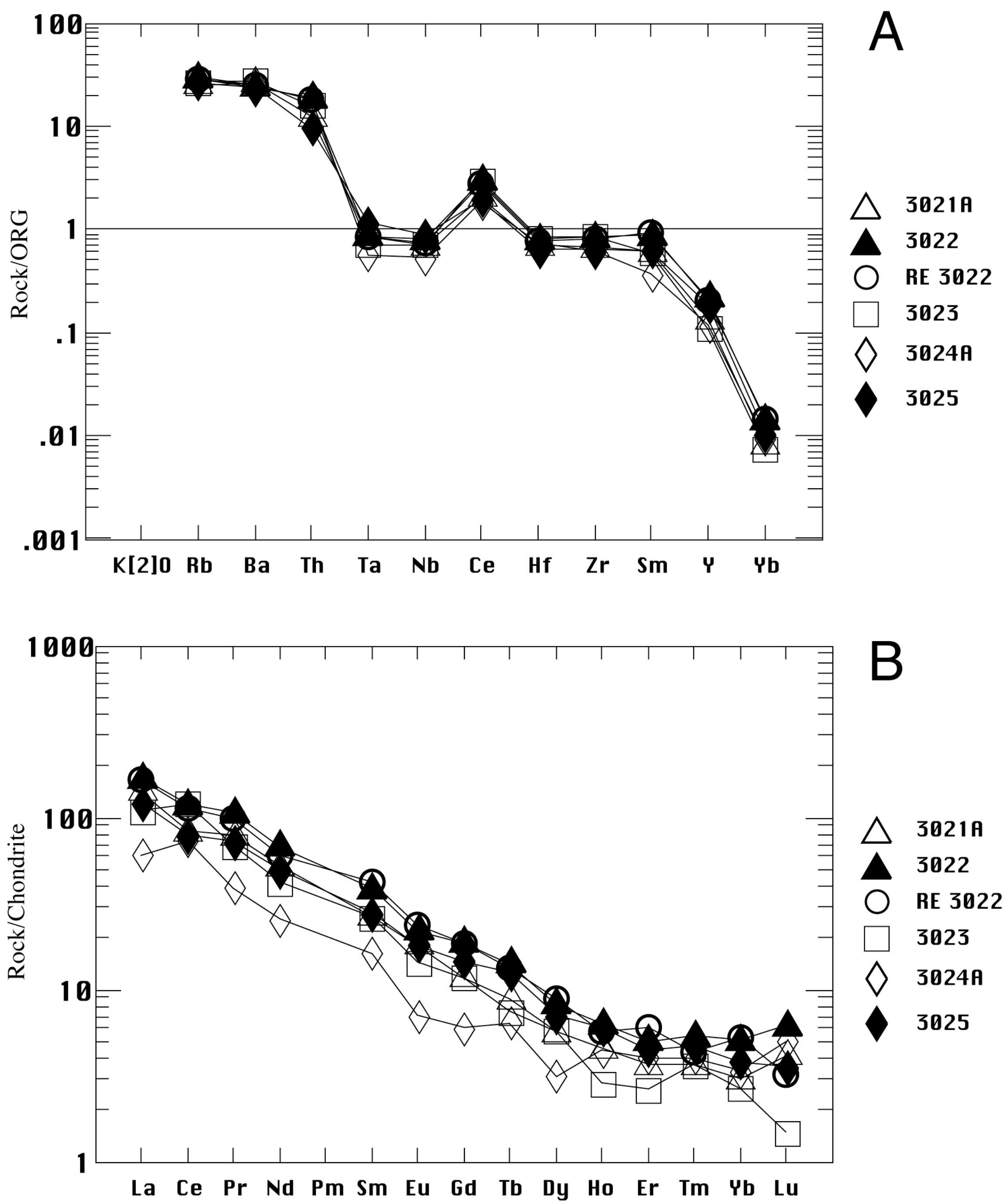

Figure 11. (A) Ocean ridge granite (ORG)-normalized incompatible element diagram (Pearce et al., 1984) for all granite of Becket Quarry samples. (B) Chondrite-normalized rare-earth-element plot for all granite of Becket Quarry samples. (Nakamura et al., 1974).

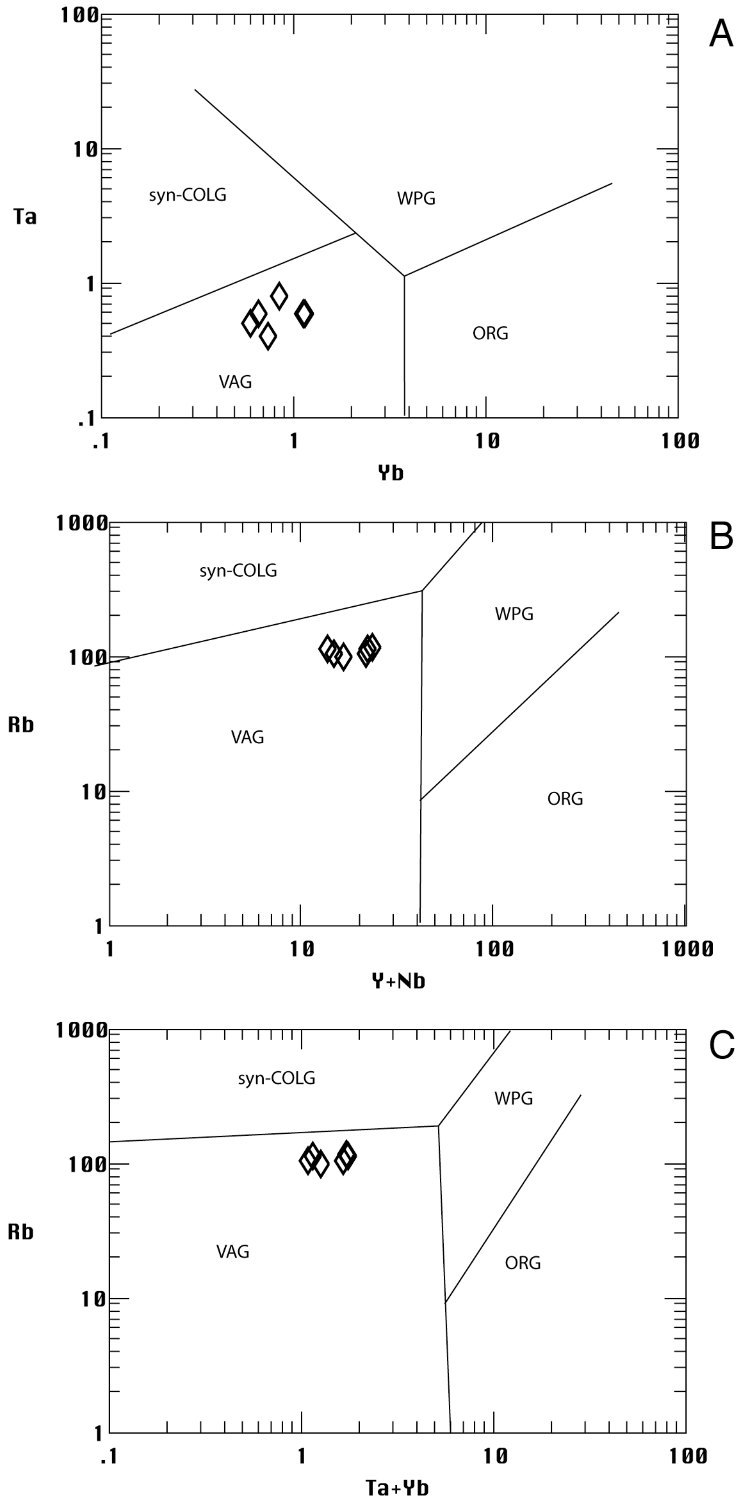

Figure 12. Tectonic discrimination diagrams for felsic igneous rocks showing data from samples of granite of Becket Quarry. VAG- volcanic arc granite, syn-COLG- syn-collisional granite, WPG- within plate granite, and ORG- ocean ridge granite, after Pearce et al. (1984).

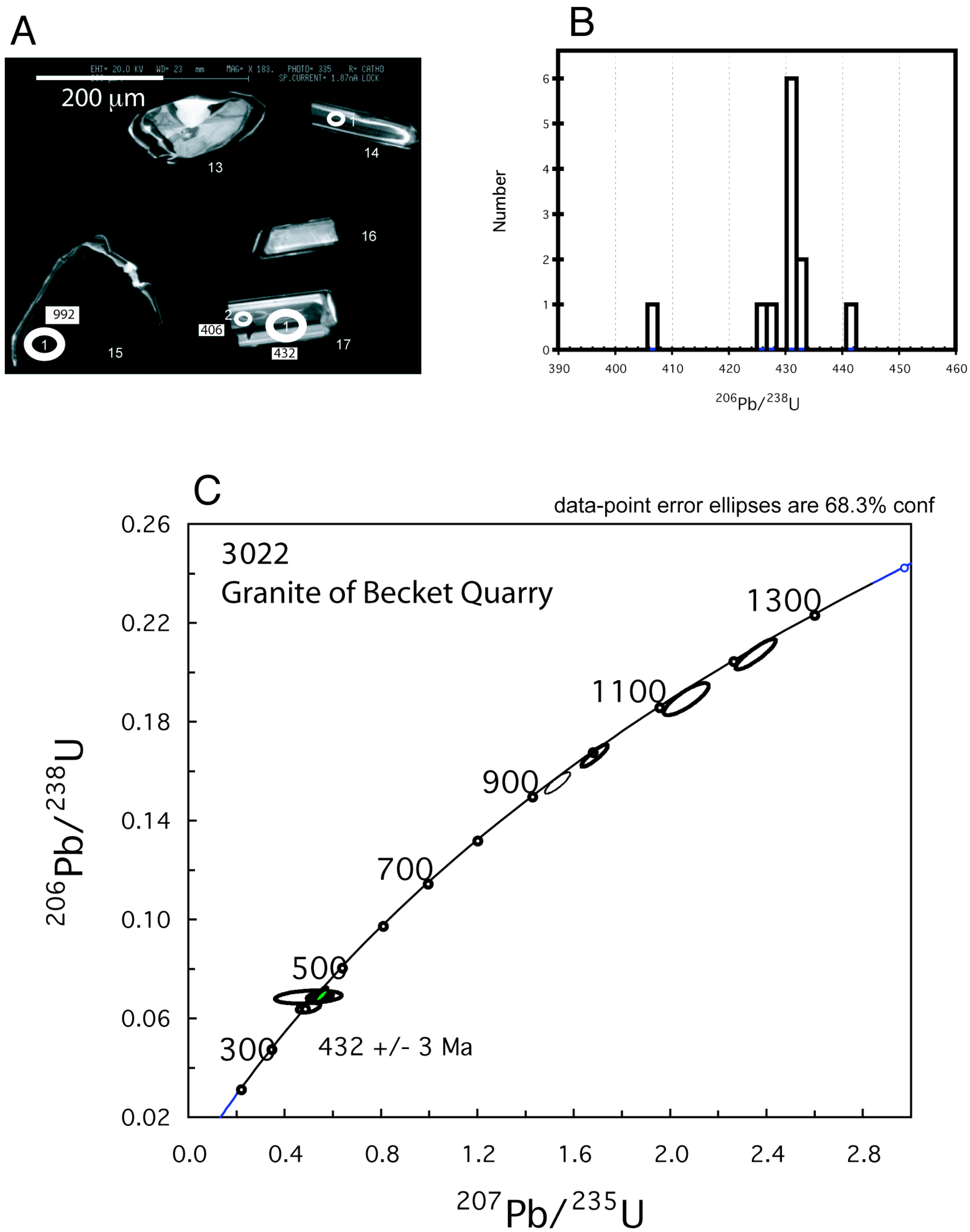

Figure 13. Sample 3022, granite of Becket Quarry. (A) Cathodoluminescence image of zircon grains with spot analyses and 206Pb/238U ages. (B) Histogram of 206Pb/238U ages younger than 450 Ma with 10 million year bin size. (C) Concordia plot of error ellipses for all spot analyses.

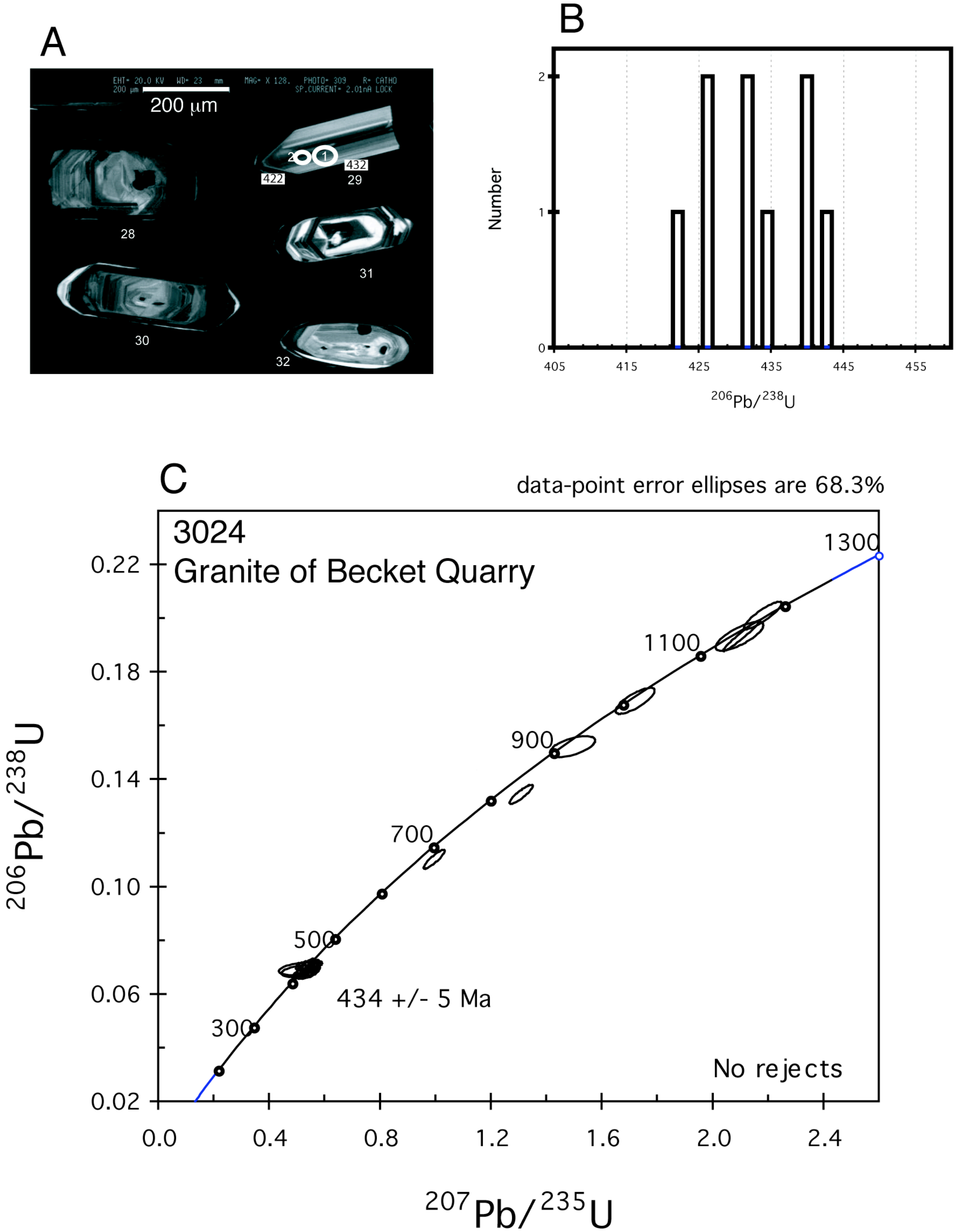

Figure 14. Sample 3024, granite of Becket Quarry. (A) Cathodoluminescence image of zircon grains with spot analyses and 206Pb/238U ages. (B) Histogram of 206Pb/238U ages younger than 450 Ma with 10 million year bin size. (C) Concordia plot of error ellipses for all spot analyses.

show a strong cluster of young ages that give a weighted average $^{206}Pb/^{238}U$ age of 434 +/- 5 Ma (n=8). The older core $^{207}Pb/^{206}Pb$ ages for this sample range widely from ca. 790 to 1170 Ma.

We interpret the 432 +/- 3 Ma and 434 +/- 5 Ma ages as the time of crystallization of the granite of Becket Quarry. The older cores are xenocrystic and their ages indicate that Middle Proterozoic basement rocks were partially melted to produce the granite during the Silurian.

Zartman et al. (1986) studied granitic exposures in the southern part of the Berkshire massif in Massachusetts and Connecticut and analyzed numerous highly discordant multi-grain zircon fractions from eight samples. One of their samples, which they informally called the granite at Yale Farm, gave a lower age intercept of 430 +/- 10 Ma and an upper age intercept of 1050 +/- 40 Ma, based on three highly discordant fractions. It is possible that the granite at Yale Farm is the same age and had a similar origin as the granite of Becket Quarry, and we plan to investigate this possibility. If these two rocks are related it would be important because the granite at Yale Farm is near the western margin of the Berkshire massif in Norfolk, Connecticut, in the South Sandisfield 7.5' quadrangle (Harwood, 1979), whereas the granite of Becket Quarry sills are concentrated on the east side of the Berkshire massif.

Tectonic Significance of the Silurian Granite of Becket Quarry

We interpret the 432 +/- 3 Ma and 434 +/- 5 Ma weighted average $^{206}Pb/^{238}U$ ages for the two samples as the time of crystallization of the granite of Becket Quarry. The S-type granite has a consistent geochemistry (Figs. 11 and 12) and the zircon grains commonly have xenocrystic cores with $^{207}Pb/^{206}Pb$ ages ranging from approximately 790 to 1250 Ma (Figs. 13 and 14). These observations suggest that the granite formed by partial melting of a single metasedimentary source rock in the Grenvillian basement. Pegmatites are common in the Hoosac Formation and the basement units that contain the sills, but the host rocks are not migmatitic, suggesting that anatexis occurred well below the present exposure level of the sills.

Ratcliffe and Hatch (1979) interpreted the sills of the granite of Becket Quarry as Ordovician syntectonic intrusives along Taconic thrust faults. As noted previously, the Ordovician age assignment was based on preliminary Rb-Sr isotopic data that permitted, but did not prove an Ordovician age (Ratcliffe and Mose, 1978). The sills of the granite of Becket Quarry are concentrated along the eastern margin of the Berkshire massif, and this contact was interpreted as a thrust that carried the Late Proterozoic Hoosac Formation over the Middle Proterozoic basement rocks of the Berkshire massif (Ratcliffe and Hatch, 1979; Zen et al., 1983). Our Silurian age assignment for the granite sills is clearly in conflict with this interpretation; if the sills did intrude along faults, they could not have been Taconic thrusts.

The contact between the Hoosac Formation and basement units along the east side of the Berkshire massif is structurally complex and may be a fault zone (e.g. Norton, 1974, 1975), but the amount and sense of displacement is unclear. In light of the ca. 430 to 435 Ma age of the granite sills, it seems worth considering the possibility that instead of Taconic thrusting the contact reflects Silurian extension, possibly related to the formation of the Connecticut Valley trough. It is important to note that the younger Late Proterozoic Hoosac Formation is structurally above the Middle Proterozic basement along the eastern margin of the massif, a relationship more consistent with normal faulting than thrusting. Karabinos et al. (1998) suggested that the Connecticut Valley trough formed as a back-arc basin above a west-dipping subduction zone, following the cessation of arc magmatism that produced the Bronson Hill arc. Many of the stratigraphic and structural problems in the Connecticut Valley trough can be explained with a back-arc basin model in which deposition was synchronous with rifting (Karabinos, 1998). This possibility is consistent with work by Castonguay et al. (1997) who presented $^{40}Ar/^{39}Ar$ muscovite ages of 421 +/- 2 to 425 +/- 2 Ma from Quebec and suggested that they record Silurian extension.

ACKNOWLEDGEMENTS

This work was supported by NSF grant EAR-0125476. We thank R.A. Wobus for many useful discussions and Art Goldstein and Tracy Rushmer for visiting the outcrops and sharing their ideas. Robert Hahn assisted with the road log and Anne Karabinos carefully proofread the manuscript.

ROAD LOG

0.0 Assemble at 8:00 am at the eastern intersection of Route 8 and Route 20 where Route 8 heads north, also known as Bonny Rigg Corners. The assembly point is in the East Lee 7.5 x 15' quadrangle. (Note that there is a western intersection of these roads where Route 8 heads south; you do not want to start there.)

Drive south on Bonny Rigg Hill Road.

1.6 Paved road turns to dirt.

1.9 Park to side of road.

Continue on foot up dirt road to the southeast. At approximately 600 m go straight through the intersection of two dirt roads. After another 300 m, near the top of the small rise, there is an outcrop visible about 15 m to the north of the dirt road.

STOP 1. SILURIAN SILLS, GRANITE OF BECKET QUARRY, IN THE HOOSAC FORMATION.
Otis 7.5 x 15' quadrangle, UTM coordinates: 18T 663395 m E and 4677985 m N.

The host rock here is plagioclase-quartz-muscovite-biotite schist of the Late Proterozoic Hoosac Formation. Veins of pegmatite are present in the schist and some of them are folded. The granite sills are composed of microcline, plagioclase, quartz, biotite, and muscovite. One sill is about 2 m thick but thins along strike until it piches out. The bottom of the other sill is not visible, but it is at least 2 m thick. The alaskite has a distinct planar fabric, which is defined by the alignment of micas and is parallel to the fabric in the schist and the contact. There is no clear evidence for faulting along the schist-granite contact, nor are there abundant asymmetric features indicative of important ductile shearing..

The weighted average ^{206}Pb/^{238}U age of eight spot analyses on zircon rims and grains without rims is 434 +/- 5 Ma (sample 3024, Fig. 14). We interpret this as the crystallization age of the granite. ^{207}Pb/^{206}Pb ages on xenocrystic zircon cores from this sample range widely from 793 +/- 15 to 1170 +/- 6 Ma. These ages suggest that the parent rock of the granite was a Middle Proterozoic paragneiss from the Berkshire massif.

Return to car. Turn around and drive back on Bonny Rigg Hill Road.

2.4 Turn right, east, on Quarry Road.

2.9 Paved road turns to dirt.

3.3 Park in Becket Quarry lot on right side of road.

Walk south on wide hiking trail about 800 m. Turn right near an old truck and follow path about 25 m to main quarry pit which is now filled with water and suitable for swimming.

STOP 2. Becket Quarry, SILURIAN SILL, GRANITE OF BECKET QUARRY, IN MIDDLE PROTEROZOIC BASEMENT.
Otis 7.5 x 15' quadrangle, UTM coordinates: 18T 663661 m E and 4678644 m N.

This excellent and accessible exposure of the granite is the source for our informal name for this unit, the granite of Becket Quarry. The quarry extracted medium-grained, weakly-foliated, microcline-plagioclase-quartz-biotite-muscovite granite. Locally, there are 30 to 50 cm long biotite-rich streaks approximately 1 cm thick that have a quartz-feldspar-rich halo around them. On the north side of the quarry at water level are several meter-scale xenoliths of Biotite-quartz-plagioclase Gneiss, one of the units in the Middle Proterozoic basement. It is a bit hard to see and it may be necessary to swim out there to convince yourself that the biotite gneiss forms xenoliths rather than the lower contact of the sill. The upper contact between the granite and gneiss is visible on the north side of the quarry if you position yourself on the southeast side on one of the accessible talus cones. The dark gray biotite gneiss is clearly visible in the cliffs above the granite. An inaccessible, light gray, 1 to 2 m thick pegmatite with an irregular, wavy bottom intruded the gneiss. Pegmatites are common in rocks that were intruded by the granite.

Eleven spot analyses on zircon rims and grains without cores from this quarry (sample 3022, Fig. 13) give a weighted average $^{206}Pb/^{238}U$ age of 432 +/- 3 Ma. The older zircon core $^{207}Pb/^{206}Pb$ ages range from 962 +/- 15 to 1247 +/- 13 Ma. Again, we believe these ages suggest that the parent rock of the granite was a Middle Proterozoic paragneiss from the Berkshire massif.

Return to car. Return to Bonny Rigg Hill Road on Quarry road.

4.2 Turn right, northwest, onto Bonny Rigg Hill Road.

5.5 Turn left, west, onto Route 20/Route 8.

10.7 Intersection with Route 8 South, continue west on Route 20.

13.2 Entering Lee.

13.6 Turn right, north, onto Becket Road (also called Tyne Road), and drive uphill.

14.5 Park on right near sign for Appalachian National Scenic Trail.

Walk southeast on trail about 250 m. After a very small drainage crossing the trail turns right and starts going downhill. Leave the trail where it turns downhill and continue southeast at a constant elevation. Look for traces of an old dirt road which contours and follow it. As you continue southeast, the slope to your left, northeast, becomes gradually steeper. About 300 m beyond the Appalachian trail, turn left and walk up the slope about 50 m to abundant outcrops.

STOP 3. MIDDLE PROTEROZOIC ALASKITE SILL IN THE TYRINGHAM GNEISS.

East Lee 7.5 x 15' quadrangle, UTM coordinates: 18T 652692 m E and 4683799 m N.

The upper contact of the alaskite sill with the Tyringham Gneiss is exposed sporadically over 400 m along strike on this slope. The alaskite is a medium-grained granite composed of microcline, plagioclase, quartz, biotite, muscovite, and epidote. There is too much biotite in this rock for it to be accurately called an alaskite, but at present it seems desirable to be consistent with the maps of Ratcliffe (1984a, 1984b, 1985), and we retain the term. Foliation in the granite is approximately parallel to the foliation in the Tyringham Gneiss and to the contact. The Tyringham Gneiss is a coarse-grained, strongly-foliated augen gneiss with a granite composition and mineralogy similar to the sill. The Tyringham Gneiss contains numerous pegmatite veins near the contact with the sill. The deformation fabric in the Tyringham Gneiss close to the contact is similar to the fabric in the gneiss hundreds of meters away from the contact upslope; there is no clear evidence for fault-related deformation in either the gneiss or the sill. Ratcliffe (1985) mapped a Taconic-age thrust through here that carried Tyringham Gneiss over itself and he interpreted the alaskite sill as an Ordovician syntectonic intrusive in the fault. He suggested that frictional heating along the fault or widespread metasomatism produced the alaskite sills during the Taconic orogeny.

Our geochronological data are inconsistent with Ratcliffe's (1985) interpretation. The crytallization age of the alaskite sill here is 1004 +/- 19 Ma (sample 3012, Fig. 9). Another sill, 2 km to the southeast, gave a crystallization age of 997 +/- 10 Ma (sample 3011, Fig. 8). Both samples contain abundant xenocrystic zircon cores that range widely from 1050 to 1210 Ma. The Tyringham Gneiss crystallized at 1179 +/- 9 Ma and many of the zircon grains have metamorphic rims that grew at 1004 +/- 9 Ma (sample 3016, Fig. 7). We suggest that the contact between the alaskite sill and the Tyringham Gneiss is intrusive and that the alaskite was generated by anatectic melting of Middle Proterozoic paragneisses during high grade metamorphism at approximately 1 Ga. If a fault does cut through the Tyringham Gneiss, there is no solid evidence for it being a Taconic thrust.

Walk back to car. Turn around and head back downhill to Route 20.

15.4 Turn right, west, on Route 20.

19.4 Turn left, south, on Route 102.

19.5 Bear left, south, on Tyringham Road.

23.7 Turn right, southwest, onto Jerusalem Road.

23.8 Bear right.

24.0 Turn right into parking lot for Tyringham Cobble.

The trail from parking lot through this wonderful Trustees of the Reservation property is a loop that intersects the Appalachian trail. Walk across field, go through stile, and turn left. The loop trail follows the Appalachian Trail briefly, but then diverges uphill to the northeast. Walk up to the very top of Cobble Hill (a name which is, in this part of Massachusetts, jarringly redundant).

STOP 4. THRUST OF MIDDLE PROTEROZOIC BASEMENT OVER PALEOZOIC SHELF SEQUENCE, ALASKITE SILL IN BASEMENT ROCKS.
Otis 7.5 x 15' quadrangle, UTM coordinates: 18T 647625 m E and 4678156 m N.

At the top of the Cobble is Middle Proterozoic gneiss mapped by Ratcliffe (1984a) as Biotite-quartz-plagioclase Gneiss that contains a fabric typical of the Grenvillian basement. The basement gneisses belong to the Beartown Mountain "slice" of Ratcliffe (1984a). This outcrop was described by Ratcliffe and Hatch (1979, their stop 4). Downslope to the east, just off the trail, are strongly foliated, mylonitic rocks. The gneisses contain a strongly foliated alaskite sill and a mafic layer. Below the cliffs, the trail goes through a covered interval in the woods and there are good exposures of marble beyond the woods in the pasture. The contact between the gneisses and the marble is a thrust and it is reasonable to assume that the mylonitic fabric is related to deformation concentrated near the fault. Mylonitic fabric, such as observed here, is not present near the Tyringham Gneiss-alaskite contact at Stop 3.

The alaskite sill from this outcrop has the composition of a granodiorite. It was not dated but it is similar enough in appearance and geochemistry to the three dated Middle Proterozoic alaskite samples that we believe it too is Middle Proterozoic. Therefore, although it is possible, and even likely, that the thrust here was active during the Taconic orogeny, there is no independent evidence to support this age assignment.

Hike back to car. Drive down Jerusalem Road back to Tyringham Village.

24.2 Turn right, southeast, onto Main Road.

25.6 Turn right, southwest, onto Monterey Road.

29.5 Monterey Village, turn left, east onto Route 23.

29.7 Turn right, southeast, onto Sandisfield Road.

31.0 Turn right, south, onto Wallace Hall Road.

31.5 Good outcrop of alaskite in stream on north side of road. This is the location for 3019, one of the dated Middle Proterozoic alaskite samples.

31.8 Intersection, go straight.

32.0 Pull over to right.

Follow path that starts on the east side of Harmon Brook and the north side of the road and walk north-northwest downslope.

STOP 5. CONTACT BETWEEN MIDDLE PROTEROZOIC ALASKITE AND ORDOVICIAN STOCKBRIDGE FORMATION, FRONTAL THRUST OF BERKSHIRE MASSIF.

Otis 7.5 x 15' quadrangle, UTM coordinates: 18T 648147 m E and 4667943 m N.

There is very good outcrop of weakly foliated alaskite in the brook all the way down to an elevation of 405 m. Even the lowest outcrops of alaskite, near the contact with the Stockbridge Formation, are only weakly foliated. There is a 50 m covered interval and the next outcrops downstream are marble of the Stockbridge Formation. At the same elevation as the first marble outcrop, much or all of the stream, depending on water flow, disappears into a sinkhole. Bedding in the marble is almost vertical and the water probably flows straight down parallel to a particularly soluble bed. Continue downstream about 50 m to a cliff or waterfall, depending on the time of year, where a large fold in bedding is visible in the stream slopes. This may be a fault-bend-fold over a ramp in a structually lower thrust within the Stockbridge Formation.

The alaskite sill here (sample 3020) and in the brook at mile 31.5 (sample 3019) are both trondhjemitic in composition. We dated zircons from sample 3019, and they show a tight cluster of ages at ca. 1000 Ma and a wide scatter of ages from 1100 to 1220 Ma (Fig. 10). The weighted average of seven $^{207}Pb/^{206}Pb$ ages is 1003 +/- 8 Ma. We interpret this as the crystallization age of the alaskite.

The alaskite exposure here and to the east along Wallace Hall Road were mapped by Ratcliffe (1984a) above the Beartown Mountain thrust that carried Middle Proterozoic basement over the Cambrian and Ordovician Stockbridge and Walloomsac Formations. The upper contact of the alaskite is with Biotite-quartz-plagioclase paragneiss and Leucocratic biotite Gneiss and granulite of the Middle Proterozoic basement. Ratcliffe (1984a) interpreted the alaskite as a syntectonic intrusive into the thrust fault and used the preliminary Rb-Sr Ordovician age from a sill of the granite of Becket Quarry (Ratcliffe and Mose, 1978) to argue that the frontal thrust of the Berkshire massif must be a Taconic fault.

The frontal thrust of the Berkshire massif certainly could be a Taconic structure, but the Middle Proterozoic age of the alaskite means that the sill cannot be used as evidence for this interpretation. We should try to confirm the Taconic age assignment independently, rather than accepting it as proven. It is possible that uplift of the massif occurred during the Acadian orogeny, and even Alleghenian uplift cannot be ruled out.

END OF TRIP

Retrace the trip through Monterey and Tyringham to Lee. An entrance to the Massachusetts turnpike is located near the intersection of Route 102 and Route 20 that we passed at mile 19.4.

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