[AMERICAN JOURNAL OF SCIENCE, VOL. 300, JUNE, 2000, P. 528–538]

440 Ma IGNEOUS ACTIVITY IN THE MEGUMA TERRANE, NOVA SCOTIA, CANADA: PART OF THE APPALACHIAN OVERSTEP SEQUENCE?

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ABSTRACT. Abraded zircons from the basal rhyolitic tuff member of the White Rock Formation, which disconformably overlies the Cambrian-Early Ordovician Meguma Group, have yielded a nearly concordant U-Pb age of 442 ± 4 Ma interpreted as the age of extrusion. This age straddles the ~443 Ma Ordovician-Silurian boundary. Abraded zircons from the Brenton granite lie on a chord with an upper intercept age of 439 +4/−3 Ma, which is intepreted to be the age of intrusion, thus supporting its inferred subvolcanic nature. On the other hand, monazite from the Brenton pluton yielded a nearly concordant analysis with a $^{207}Pb/^{206}Pb$ age of 380 ± 3 Ma, which is interpreted to be the time of the low pressure, high temperature metamorphism. Using these new data, the following observations suggest that the Meguma and Avalon terranes were neighbors during the Silurian-Early Devonian: (1) both have latest Ordovician-earliest Silurian, bimodal, subaerial, alkalic-tholeiitic, rift-related, volcanic rocks with Nd signatures indicating a similar continental basement source; (2) both show a similar progression of depositional environments: subaerial in the earliest Silurian, progressively deeper-water marine strata in the Llandovery and Wenlock, switching to gradually shallowing marine environments in the Ludlow, and reverting to subaerial in the Pragian; and (3) both contain Rhenish-Bohemian Early Devonian fauna. Furthermore, the southeast to northwest transition from an offshore sandbar to a beach sand in the Silurian White Rock Formation suggests the presence of land to the north, now recognized as Avalonia. These conclusions support published suggestions that the Siluro-Devonian successions in the Meguma and Avalon terranes form part of the overstep sequence that extends across most of the northern Appalachians. Published data indicate that Avalonia was adjacent to Gondwana in the Neoproterozoic, that it separated from Gondwana in the Early Ordovician, and was accreted to eastern Laurentia in the Late Ordovician–Early Silurian. On the basis of the data and correlations presented here, we suggest that the Meguma Terrane travelled with Avalonia. This is consistent with the absence of a phase of deformation between the Cambro-Ordovician Meguma Group and the Silurian White Rock Formation.

INTRODUCTION

Volcanic and plutonic rocks dated in this study occur at or near the base of the White Rock Formation, which crops out along the northwestern margin of the Meguma terrane in southern Nova Scotia, Canada (fig. 1). The Meguma terrane occupies an unique position on the southern side of the Avalon Composite terrane, where it is the farthest outboard terrane in the northern Appalachians (fig. 1). The contact between these two terranes is the Minas Fault system, which was active in the Late Paleozoic and Early Mesozoic (Keppie, 1982).

The Meguma terrane represents a Paleozoic passive-margin sequence characterized by thick Cambro-Ordovician turbidites of the Meguma Group: mainly coarse clastic rocks in the Goldenville Formation overlain by predominantly slates of the Halifax Formation, the latter containing Tremadocian grapolites (Schenk, 1970). The Halifax Formation is disconformably overlain by the White Rock Formation (fig. 2). The lower part of the White Rock Formation consists of unfossiliferous subaerial to shallow marine, bimodal, alkalic-tholeiitic, within-plate volcanic rocks and shallow marine, shoreface quartzites in which facies changes indicate a proximal shoreline to the north (Crosby, 1962; Smitheringale, 1973; Lane, 1976; Keppie and Dostal, 1980). The upper part of the

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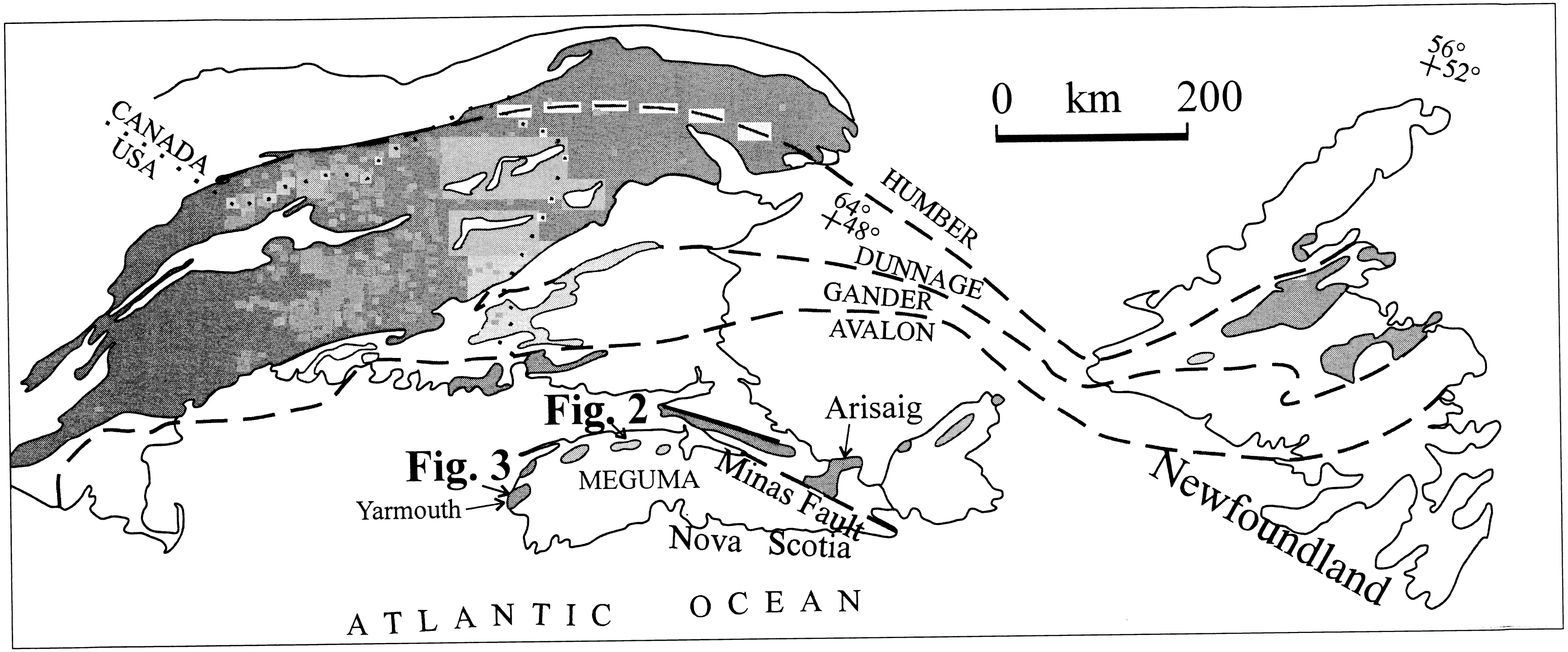

Fig. 1. Map of the northern Appalachians showing the tectonic zones, the extent of the late Ordovician-Devonian overstep sequence (shaded), and the locations of figures 2 and 3. Modified from Keppie (1989).

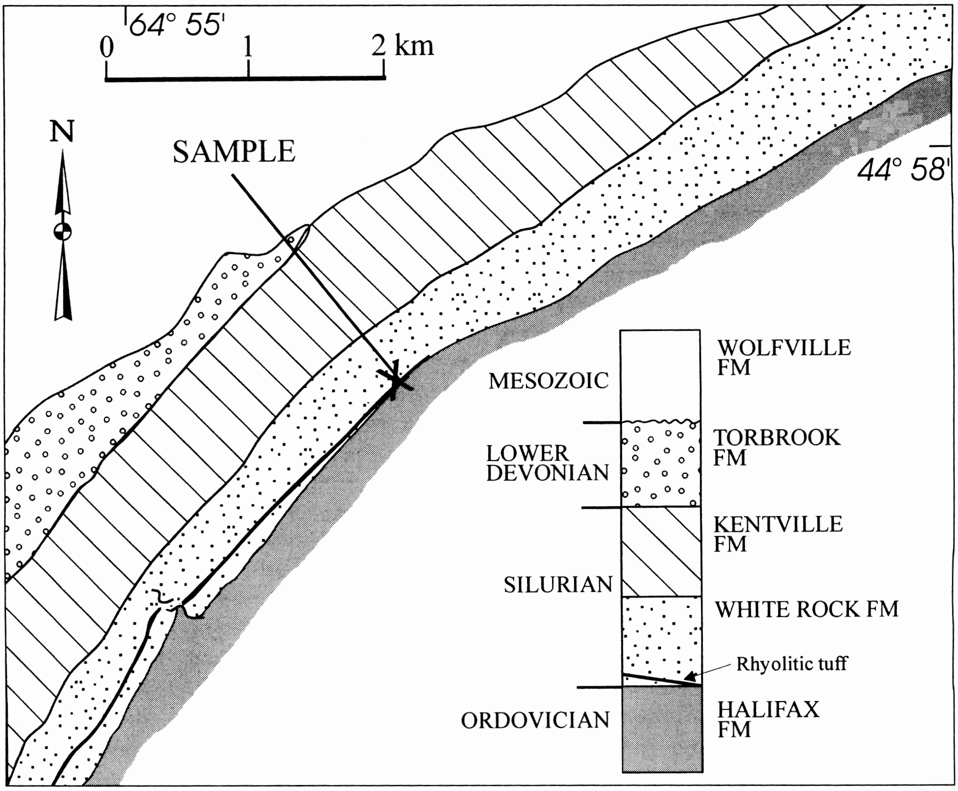

Fig. 2. Geological map of Fales River area showing the location of the rhyolite sample from the White Rock Formation (modified from Smitheringale, 1973).

White Rock Formation is laterally equivalent to the Kentville and New Canaan formations in other parts of the Annapolis Valley, and these units collectively are composed of fossiliferous Ludlovian quartzites, siltstones, and slates, with local volcanic rocks (Crosby, 1962; Smitheringale, 1973). At Fales River, the Silurian rocks are conformably overlain by paralic marine, silty shales, mudstones, sandstones, and limestones of the Torbrook Formation, which contains an Early Devonian Rhenish-Bohemian shelly fauna (fig. 2)(Boucot, 1960). All these Cambrian-Devonian rocks were deformed, regionally metamorphosed, and intruded by late syntectonic Late Devonian granitoids during the Acadian Orogeny (Keppie and Dallmeyer, 1995). Following rapid exhumation, they were unconformably buried by continental and minor marine Carboniferous rocks, that are, in turn, unconformably overlain by Early Mesozoic rocks along the northwestern margin of the Meguma terrane.

Heretofore, the ages for the volcanic rocks of the White Rock Formation were provided by fossils in over- and under-lying units: Tremadocian in the Halifax Formation and Ludlovian in the upper part of the White Rock Formation. According to the time scale of Tucker and McKerrow (1995), these fossils place the age of the volcanic rocks within a large interval: ~490 and 424 Ma. Hence the reason for the U-Pb isotopic analysis presented herein.

The foliated Brenton granite lies within and appears to cut the basal part of the White Rock Formation near Yarmouth (fig. 3). The contact is not exposed, however, and Taylor (1967) has inferred that the granite and the volcanic rocks are cogenetic. The southeastern margin of the Brenton granite lies within the Deerfield shear zone (fig. 3).

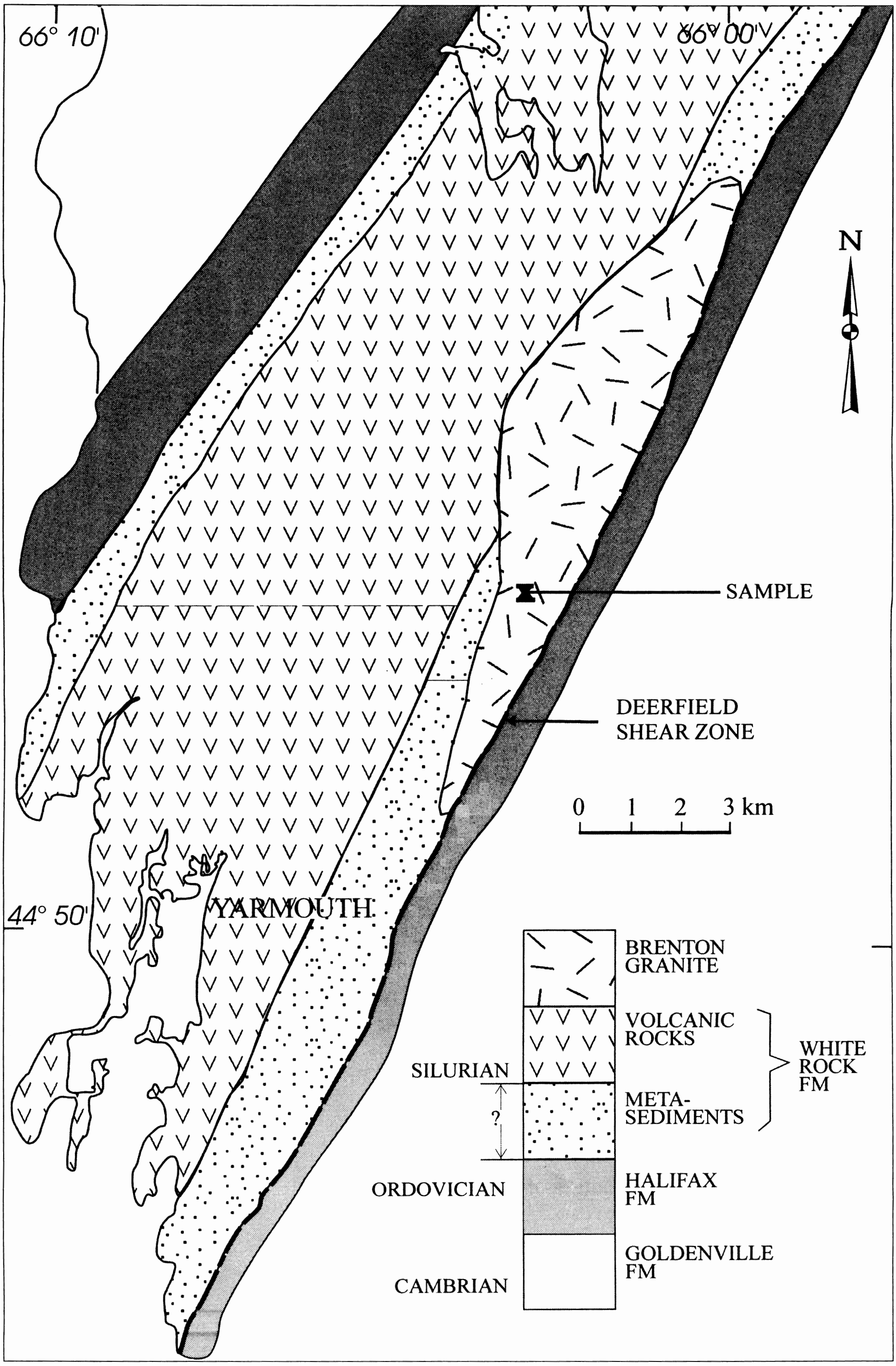

Fig. 3. Geological map of the Yarmouth area showing the location of the Brenton pluton and the sample location (modified from Taylor, 1967).

The Brenton granite has yielded the following $^{40}Ar/^{39}Ar$ ages: discordant ~370 to 400 Ma on hornblende (Muecke, Elias, and Reynolds, 1988) and plateau ages of 322 ± 4 and 318 ± 8 Ma on muscovite and 325 ± 4 Ma on biotite (Reynolds, Zentilli, and Muecke, 1981; Dallmeyer and Keppie, 1987). As these ages are much younger that the inferred protolith age, we sampled the Brenton granite to see if it is indeed a subvolcanic intrusion.

A major question concerning the Meguma terrane is the nature of its basement. The base of the Meguma Group is not exposed, but several lines of evidence suggest that a continental basement was present in the Late Devonian: (1) a gneiss dome intruded into the Meguma Group in the Late Devonian exposes amphibolite-granulite facies gneisses and schists of the Liscomb Complex (Clarke, Chatterjee, and Giles, 1993); (2) granulite-facies metaigneous and metasedimentary xenoliths occur in Late Devonian lamprophyre dikes intruding the Meguma Group (Eberz and others, 1991); (3) Late Devonian granitoid rocks intruding the Meguma Group contain zircons that indicate a source age of 628 ± 33 and ~732 Ma (Keppie and Krogh, 1999). Unfortunately, these Late Devonian intrusions post-date the Late Silurian-Early Devonian onset of the Acadian Orogeny during which the basement units may have been tectonically thrust beneath the Meguma Group prior to intrusion (Keppie and Dallmeyer, 1987). The only evidence for a continental basement depositionally beneath the Meguma Group comes from the chemistry of the Ordovician-Silurian bimodal volcanic rocks of the White Rock Formation (Keppie and Dostal, 1980; Keppie and others, 1997).

RESULTS

Two samples were collected for U-Pb isotopic analysis: one from the basal terrestrial rhyolitic ash-fall or ash-flow tuff of the White Rock Formation in Fales River (Smitheringale, 1973), and the other from the Brenton granite on the road between Yarmouth and Deerfield (Taylor, 1967)(figs. 2 and 3). The rhyolitic tuff consists of feldspar and quartz phenocrysts and shards set in a cryptocrystalline matrix of sericite, quartz, and albite, with minor calcite, chlorite, biotite, opaque minerals, and apatite. The foliated granite is composed of feldspar phenocrysts (microcline, perthite, and albite) in a matrix of quartz, biotite, and muscovite. These samples were prepared and analyzed using the methods detailed in Krogh and Keppie (1990) and Keppie and Krogh (1999).

The rhyolite sample from the White Rock Formation yielded two nearly concordant multi-grain, abraded zircon analyses with $^{207}Pb/^{206}Pb$ ages of 441.3 ± 5 and 441.6 ± 3 Ma (table 1; fig. 4). A chord through these points and zero yields an upper intercept of 442 ± 4 Ma, which is interpreted as the age of eruption. Other analyses are more discordant, indicating the presence of some older components with or without recent lead loss.

Multi-grain, abraded zircon analyses from the Brenton granite sample yielded data that fall on a chord from 23 to 439 +4/-3 Ma (excluding #2, which lies off the chord) with a 55 percent probability of fit and with points 0.7, 2.3, 3.0, 5.2, 8.7, and 18.6 percent discordant from the chord (fig. 5). The upper intercept is inferred to be the time of intrusion. The crystallization ages of the White Rock rhyolite and the Brenton pluton are the same within analytical error. This supports the cogenetic relationship proposed by Taylor (1967). A nearly concordant multi-grain analysis of monazite yielded a $^{207}Pb/^{206}Pb$ age of 379.9 ± 2.7 and a $^{207}Pb/^{235}U$ age of 373 ± 2 Ma (table 1; fig. 5). This age is the same as the intrusive ages of most of the granitoid plutons in the Meguma terrane and the associated low-pressure amphibolite-facies metamorphism that affected the Brenton pluton and adjacent rocks (Keppie and Dallmeyer, 1995; Keppie and Krogh, 1999). Therefore, the growth of monazite is attributed to this latter tectonothermal event.

TABLE 1

U-Pb isotopic data on abraded zircon and monazite from the Brenton pluton and the White Rock Formation, Meguma terrane, Nova Scotia, Canada

No.	Fraction	Weight (mg)	U (ppm)	Th/U	PbCom (pg)	207/204	206/238	1 sigma	207/235	1 sigma	207/206 Age (Ma)	1 sigma	% Disc.
	Brenton Pluton (BP)												
1	35 Ab zr, N0, cl	0.074	214	0.11	56	84.4	0.06899	0.00029	0.5327	0.0031	452.6	9.0	5.2
2	multi Ab zr, N0	0.160	271	0.16	24	457.0	0.06941	0.00022	0.5356	0.0017	451.0	2.8	4.2
3	multi Ab zr, N0, M0, crk	0.433	425	0.41	259	175.4	0.06473	0.00009	0.4968	0.0012	439.0	4.4	8.2
4	multi Ab zr, M2, cl, black incln	0.370	934	0.26	512	151.7	0.05808	0.00009	0.4451	0.0013	436.0	5.3	17
5	multi Ab zr, M2, cl, euh	0.180	293	0.08	283	61.1	0.07005	0.00012	0.5396	0.0037	447.1	15.1	2.5
6	multi Ab zr, N0, cl, euh, prism	0.140	366	0.16	17	733.6	0.06852	0.00007	0.5259	0.0007	439.0	1.6	2.8
7	multi Ab zr, M2, cl, euh	0.234	447	0.17	37	675.9	0.06707	0.00010	0.5144	0.0009	437.4	1.6	4.5
8	multi Ab monazite, cl, yel	3.200	54	5.43	101	357.7	0.05946	0.00007	0.4445	0.0008	379.9	2.7	2.1
	White Rock Rhyolite (WR)												
1	multi Ab zr, N1, frag	0.420	144	0.15	90	180.4	0.07032	0.00023	0.5403	0.0020	441.3	5.1	0.7
2	multi Ab zr, M5, frag, cl	0.435	152	0.16	62	278.3	0.07070	0.00021	0.5433	0.0017	441.6	2.7	0.3
3	multi Ab zr, M5, cl, prism	0.115	726	1.77	609	49.2	0.07011	0.00011	0.5419	0.0050	454.6	20.5	4
4	22 Ab zr, N1, euh, prism, incln	0.146	186	0.50	170	56.0	0.07236	0.00009	0.5600	0.0042	457.4	16.4	1.6
5	multi Ab zr, M0, N0, cl, frag	0.152	141	0.10	12	495.1	0.07061	0.00009	0.5550	0.0025	491.8	8.7	10.9

Errors are given at 1 sigma.
Abbreviations: Number of grains analyzed is at beginning, Ab–abraded; zr–zircon; euh–euhedral; crk–cracked; cl–clear; incln–inclusions; frag–fragment; yel–yellow.
N–non-magnetic; M–magnetic number following this abbreviation refers to degree of tilt on the Frantz Isodynamic Separator at full current.
PbCom–Common Pb, assuming all has blank isotopic composition.
Th/U calculated from radiogenic 208Pb/206Pb ratio and 207Pb/206Pb age assuming concordance.
%Disc–percent discordance for the given 207Pb/206Pb age.

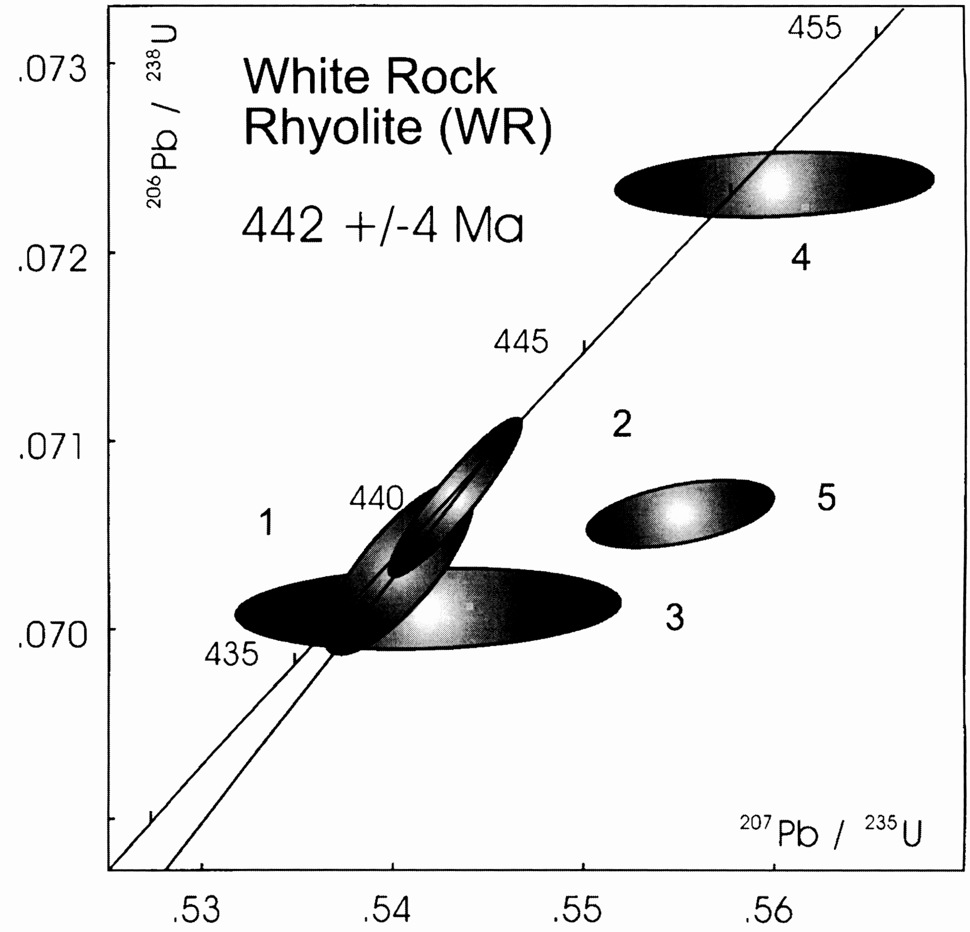

Fig. 4. U-Pb concordia plot for zircon from the rhyolitic tuff at the base of the White Rock Formation on Fales River, Meguma terrane, Nova Scotia (see fig. 2 for location).

TECTONIC SIGNIFICANCE

The 442 ± 4 and 439 +4/-3 Ma ages of the White Rock rhyolitic tuff and the Brenton granite straddle the Ordovician-Silurian boundary, which Tucker and McKerrow (1995) place at ~443 Ma. These age constraints allow temporal comparisons to be made between the Silurian-Early Devonian sequences in the Meguma and Avalon terranes, and several similarities may be observed (fig. 6). At Arisaig, in the Antigonish Highlands (Avalon terrane), the basal units of the Arisaig Group (Dunn Point and Bears Brook formations) are penecontemporaneous with deposition of the Beechhill Cove Formation, which contains early Llandoverian fossils (Boucot and others, 1974, that is, the same age as the volcanic rocks at the base of the White Rock Formation). The Dunn Point and Bears Brook formations consist of bimodal, alkalic-tholeiitic, within-plate, subaerial volcanic rocks that were extruded in an extensional tectonic setting (Keppie and others, 1997) and thus are similar to the volcanic rocks in the White Rock Formation. Furthermore, the Nd signatures in the volcanic rocks indicate a similar basement beneath the Avalon and Meguma terranes at the time (Keppie and others, 1997). Both volcanic suites are overlain by a shallow marine sequence that switches from

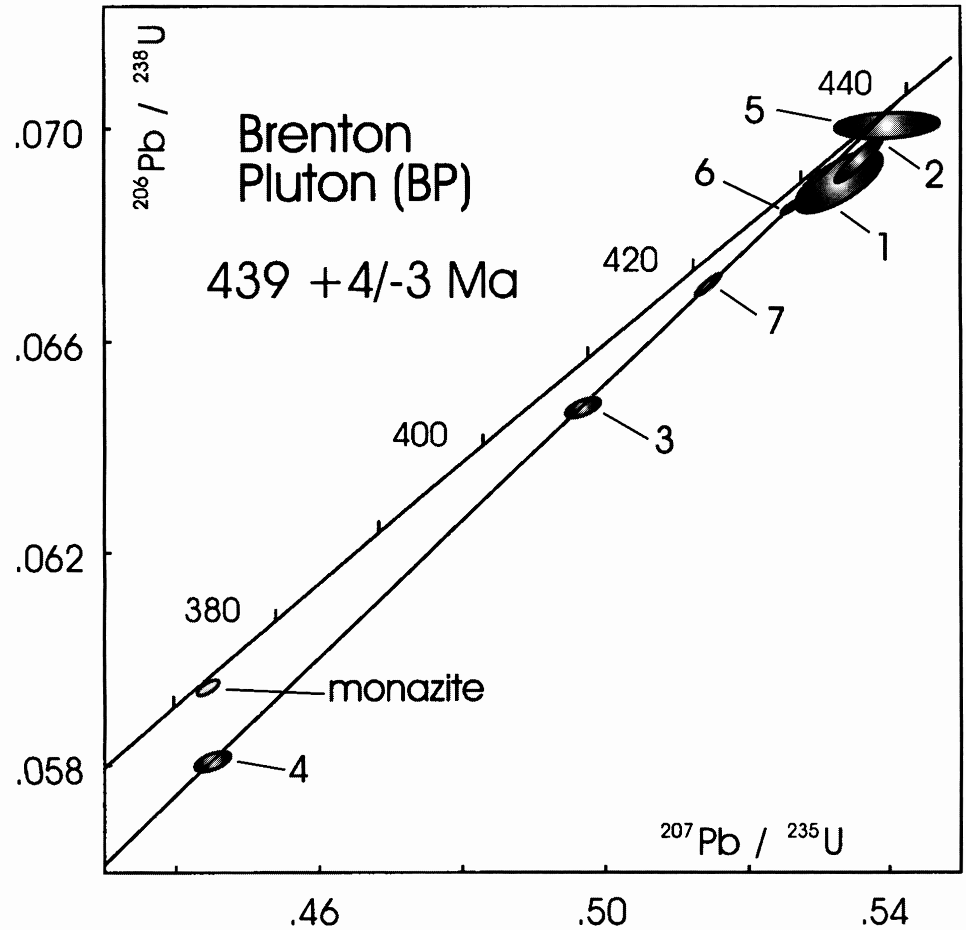

Fig. 5. U-Pb concordia plot for zircon and monazite from a granite sample of the Brenton near Yarmouth, Meguma terrane, Nova Scotia (see fig. 3 for location).

deepening to shallowing in the Ludlovian becoming subaerial again in the Pragian Stage of the Lower Devonian (Boucot and others, 1974; Schenk, 1995). Both Meguma and Avalon Lower Devonian sequences contain Rhenish-Bohemian fauna, a faunal province that gradually spread across the entire width of the northern Appalachians during the Early and Middle Devonian (Boucot, 1975).

Chandler, Loveridge, and Currie (1987) suggested that the Early Silurian rocks represent an overstep sequence across the Appalachian orogen. This suggestion is consistent with the Late Ordovician-Early Silurian deformation recording the accretion of Avalonia to eastern Laurentia (Keppie, 1993; Cawood and others, 1994) and the first appearance in the Early Silurian of Avalonia of a Laurentian Nd signature (Murphy and others, 1995). However, the place of the Meguma terrane in this scenario is controversial. Schenk (1981) implied that it represents the passive-margin deposit bordering northwestern Africa, which was not transferred to Laurentia until the Devonian Acadian Orogeny. This interpretation suggests that the Meguma Group was deposited on continental crust in the southwest with oceanic crust to the northwest. In this scenario the Minas Fault zone should represent the suture between Avalonia and Gondwana;

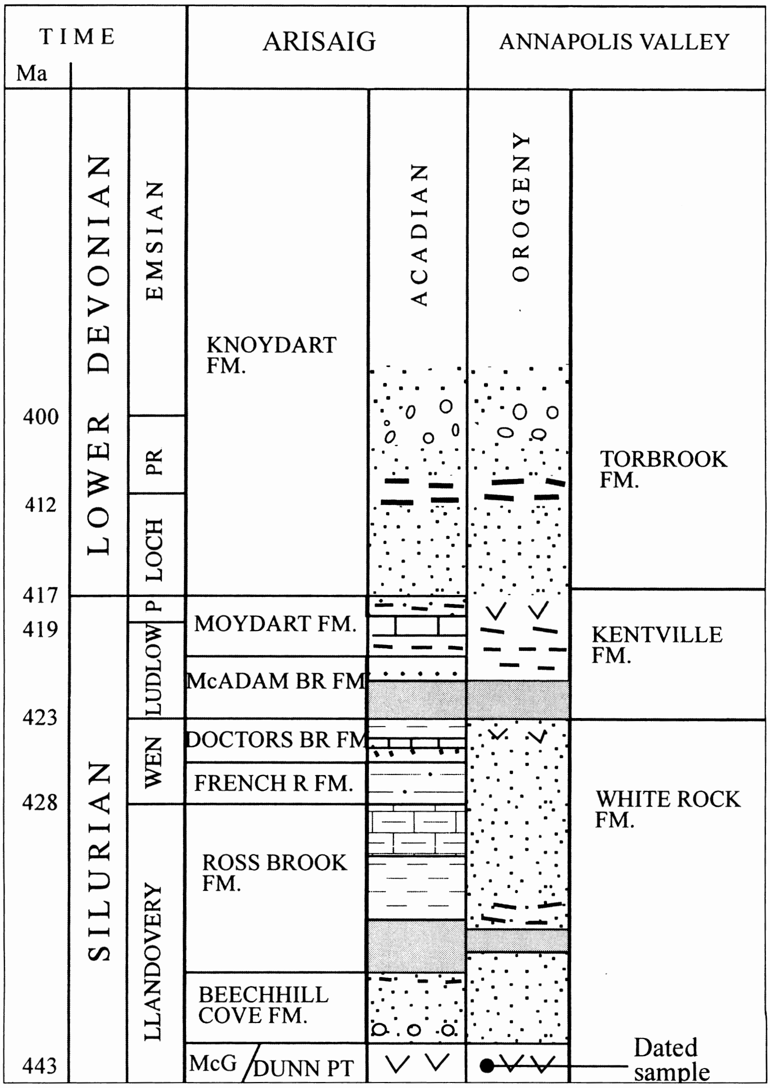

Fig. 6. Comparison of the Siluro-Devonian stratigraphy of the Meguma (Annapolis Valley) and Avalon (Arisaig) terranes in Nova Scotia. Symbols: circles = conglomerate; dots = sandstone; dashes = shales; gray shade = black shale; blocks = carbonate; v = volcanic rocks. Abbreviations: BR = Brook; FM = Formation; Loch = Lockhovian; Ma = million years; McG = McGillivray; P = Pridoli; Pr = Pragian; PT = Point; R = River; WEN = Wenlock. Time scale after Tucker and McKerrow (1995).

however, ophiolites, complex deformation, and high-medium pressure metamorphism associated with such sutures are absent.

On the other hand, other authors have proposed that the Meguma terrane represents a passive-margin deposit bordering the Avalon microcontinent because several lines of evidence suggest that the northwestern margin of the Meguma terrane was underlain by continental crust prior to the Acadian Orogeny (Keppie and Dostal, 1991; Keppie and others, 1997). Firstly, the chemistry of the ~442 Ma White Rock volcanic rocks bordering the northwestern margin of the Meguma Terrane show evidence of derivation from a continental basement (Keppie and others, 1997). Secondly, the quartzites in the overlying White Rock Formation show a southeast to northwest transition from an offshore sandbar to a beach sand (Lane, 1976). Thirdly, Early Devonian Rhenish fauna are common to both the Meguma and Avalon terranes (Boucot, 1975). These data, along with the close similarities between the Silurian-Early Devonian sequences in the Meguma and Avalon terranes, suggest that the Meguma terrane bordered Avalonia rather than northwestern Africa during this time interval supporting the idea that the Silurian-Early Devonian strata in the northern Appalachians form an overstep sequence.

Finally, integrating the conclusions of this paper about the relative location of the Meguma terrane into current knowledge of evolution of the northern Appalachians, the following sequence of events may be inferred (palinspastic maps depicting this scenario are available in Keppie and Ramos, 1999):

1. During the Neoproterozoic-Cambrian, the Meguma and Avalon terranes lay adjacent to Gondwana as documented by the detrital zircon ages (Krogh and Keppie, 1990; Keppie, Davis, and Krogh, 1998) and the southerly, African provenance of the Cambrian Goldenville Formation (lower unit of the Meguma Group)(Schenk, 1970);
2. During the Early Ordovician Avalonia (Prigmore, Butler, and Woodcock, 1997) and the Meguma terrane (this paper) separated from Gondwana: in the Meguma terrane this event may be represented by the Goldenville-Halifax formational boundary where coarse clastic rocks are abruptly replaced by fine clastic rocks;
3. During the Late Ordovician – Early Silurian Avalonia and the Meguma terrane were accreted to eastern Laurentia as recorded by accretionary deformation of this age (Keppie, 1993; Cawood and others, 1994) and the first appearance of a Laurentian Nd signature (Murphy and others, 1995).

ACKNOWLEDGMENTS

Funding for this study was provided by the Canada-Nova Scotia Mineral Development Agreements. JDK is grateful to the Instituto de Geología at the Universidad Nacional Autónoma de México for providing logistical support in the final stages of this project. We would like to thank Dr. D. Rankin and two anonymous reviewers for their constructive comments of the first draft of the paper. We acknowledge José Luis Arce Saldaña for drafting some of the figures.

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