Timing of peak metamorphism and deformation along the Appalachian margin of Laurentia in Newfoundland: Silurian, not Ordovician

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ABSTRACT

U/Pb and Ar/Ar isotopic age data from the Corner Brook Lake region of the eastern Appalachian Humber zone in western Newfoundland indicate that regional deformation and peak amphibolite-facies metamorphism are Early Silurian. A lower limit on deformation is provided by a U/Pb zircon age of 434 +2/−3 Ma for a pegmatite that is affected by the regional foliation and is interpreted to be syntectonic. Monazite and rutile from a garnet-kyanite-staurolite schist, which records peak-metamorphic conditions and in which porphyroblasts have overgrown the regional foliation, gave U/Pb ages of 430 ±2 Ma and 437 ±6 Ma, respectively. Ar/Ar cooling ages for hornblende from amphibolites and muscovite from psammitic and pelitic schists range from 430 to 420 Ma. A Silurian age for deformation and metamorphism of the Laurentian margin is coincident with the timing of similar events along the Newfoundland Gondwana margin and suggests that the Silurian was a period of major continent-continent collision.

INTRODUCTION

Periods of metamorphism, deformation, and plutonism within the Newfoundland Appalachians have traditionally been ascribed to the Ordovician Taconian, the Devonian Acadian, or the Carboniferous Alleghanian orogenies. Terrane accretion associated with closure of the Iapetus ocean has been invoked as the driving mechanism for these orogenic pulses (Williams and Hatcher, 1983). The Taconian orogeny corresponded with accretion of the oceanic Dunnage zone to the Laurentian continental margin of the Appalachians, represented by the Humber zone. The Acadian orogeny was related to final ocean closure and accretion of the opposing Gondwana continental margin represented by the Gander and Avalon zones. The Alleghanian orogeny was restricted to localized strike-slip fault activity in Newfoundland but in the southern Appalachians was related to continued terrane accretion (Williams and Hatcher, 1983). The Silurian in Newfoundland has been regarded as a time of little orogenic movement (Colman-Sadd, 1982). In this paper we present new U/Pb and Ar/Ar isotopic dates for rock units from the eastern Humber zone in west Newfoundland that establish peak metamorphism and deformation as Silurian, and we discuss the implications of these data for understanding orogenic movements in the Newfoundland Appalachians.

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REGIONAL GEOLOGY

The Humber zone is divisible into a western external domain and an eastern internal domain on the basis of increasing deformation and metamorphism toward the eastern orogenic hinterland of the orogen (Fig. 1; Williams, 1994). The internal domain consists of polydeformed siliciclastic and calcareous schists of the Fleur de Lys Supergroup which, at least locally, unconformably overlie the Grenvillian basement to the Appalachian orogen (Cawood and van Gool, 1992; Hibbard, 1983). Metamorphic grade within the internal domain ranges from upper greenschist to amphibolite facies. The boundary between the Humber zone and accreted terranes to the east is marked by ophiolitic melange and is termed the Baie Verte–Brompton line. Direct age control on the rock units and orogenic events in the eastern Humber Zone is largely lacking, and interpretations on both age and tectonic setting are based on correlation with less deformed sequences in the western external parts of the Humber zone (e.g., Hibbard, 1983). Thus, evidence for westward emplacement of the Taconian allochthons in the external domain during the Middle Ordovician (e.g., Williams and Stevens, 1974) has led to the concept that deformation and metamorphism within the internal domain occurred during the Taconian orogeny associated with overthrusting of the Laurentian margin by the Dunnage zone (Williams, 1977; Hibbard, 1983; Jamieson and Vernon, 1987). The Baie Verte–Brompton line represents the root zone for the ophiolitic rocks of the Taconian allochthons. To constrain the time of orogenesis, we present new ages from metamorphic and syntectonic igneous rocks from the Corner Brook Lake region of the internal domain of the Humber zone.

GEOLOGY OF THE CORNER BROOK LAKE AREA

At Corner Brook Lake, Grenville basement gneisses and metasedimentary cover rocks of the Fleur de Lys Supergroup are repeated in a multiply deformed imbricate thrust stack (Fig. 2). The cover sequence is divisible into a lower siliciclastic unit—the South Brook Formation of psammite, pelite, and minor quartz-pebble conglomerate—and an upper carbonate unit—the Breeches Pond Formation of calc-schist, marble, and pelite. The thrust belt records peak-metamorphic mineral assemblages ranging from lower greenschist facies (muscovite + chlorite in pelites) in the lowest thrust sheets in the west, to amphibolite facies (garnet + biotite + kyanite in pelites) in the highest thrust sheets in the southeast near Corner Brook Lake (Cawood and van Gool, 1992). Peak-metamorphic mineral assemblages are found as porphyroblasts that have overgrown the principal foliation. Locally coarse-grained to pegmatitic granitic melts are found within the high-grade segments of the thrust belt. Although cut by the principal foliation, these granitoid rocks are variably deformed: the coarsest-grained pegmatitic phases show only a weak foliation, and the finer-grained phases are moderately to strongly deformed in places. Therefore, the

Data Repository item 9423 contains additional material related to this article.

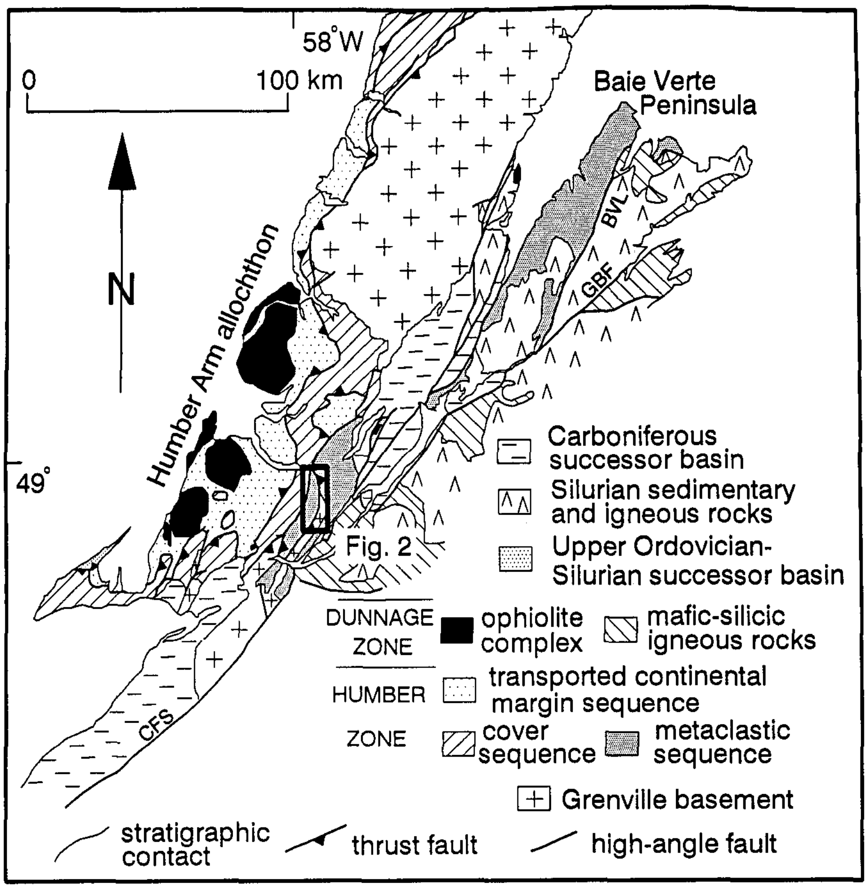

Figure 1. Geologic map of Newfoundland Humber zone showing location of Figure 2. BVL—Baie Verte line, CFS—Cabot fault system, GBF—Green Bay fault.

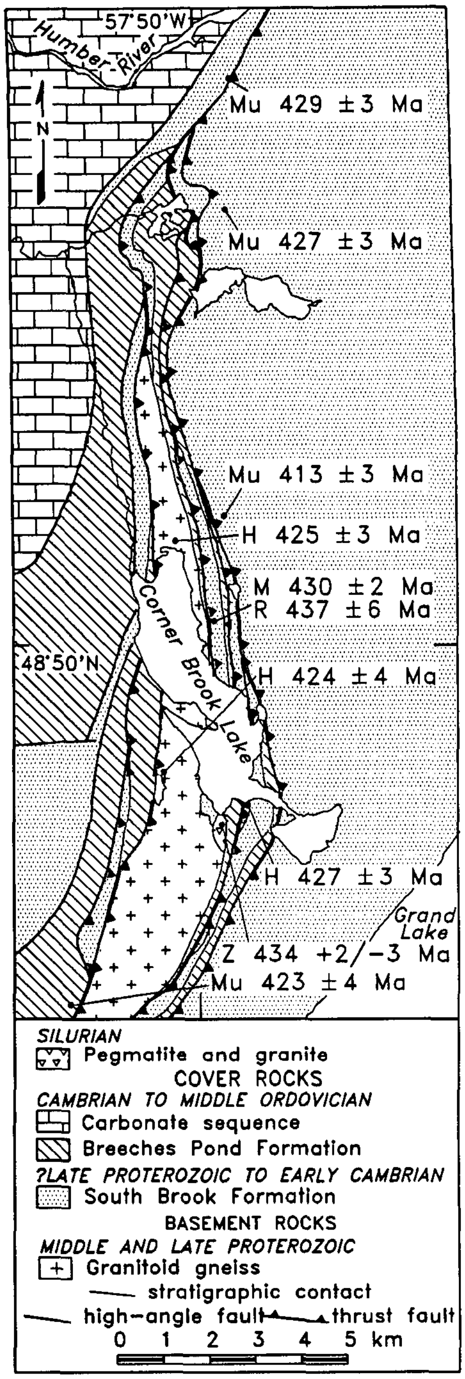

Figure 2. Simplified map of Corner Brook Lake area showing location and age of analyzed samples. H—hornblende, M—monazite, Mu—muscovite, R—rutile, Z—zircon.

igneous activity was probably contemporaneous with the main D_1 deformation event and probably represents an early expression of peak-metamorphic conditions.

Igneous zircon from the pegmatite and the metamorphic mineral phases monazite, rutile, hornblende, and muscovite from a variety of basement and cover rocks were separated for isotopic dating. All samples were collected from the zone of amphibolite-facies metamorphism. Figure 2 shows locations and ages of the samples; Figures 3 and 4, the U/Pb concordia and Ar/Ar release spectra, respectively. Table 1 details the U/Pb analytical data.[1]

Newly grown, low-Th zircon from a pegmatite intrusion into the basement and cover sequence defines a mixing line with a lower-intercept age of crystallization of 434 +2/−3 Ma and an upper-intercept age of 1021 ±68 Ma, interpreted to be the average age of the inherited component. A sample of garnet-kyanite-staurolite schist yielded metamorphic monazite and rutile. Duplicated concordant monazite fractions yielded a precise U/Pb age of 430 ±2 Ma. Duplicated rutile yielded $^{206}Pb/^{238}U$ ages of 439 ±10 Ma (fraction R1, Fig. 3, Table 1) and 437 ±6 Ma (fraction R2), the latter being the better analysis. The rutile analyses were not as precise as the monazite data because of the high common-Pb content of the rutile, but the dates from both clearly overlap. Hornblende separated from amphibolites at three localities within the basement sequence (Fig. 2) yielded Ar/Ar plateau ages (59% to 78% of gas released) of 427 ±3 Ma, 425 ±3 Ma, and 424 ±4 Ma (Fig. 3). Muscovite from four samples of psammitic and pelitic schists from the cover sequence gave Ar/Ar plateau ages (61% to 70% of gas released) of 429 ±3 Ma, 427 ±3 Ma, 423 ±4 Ma, and 413 ±3 Ma.

[1]GSA Data Repository item 9423, Ar/Ar incremental-heating data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

DISCUSSION

The isotopic age data from the Corner Brook Lake region are remarkably uniform and indicate that regional deformation, metamorphic mineral growth, and cooling within this segment of the eastern Humber zone occurred in the Early Silurian between 435 and 425 Ma. An older age limit on regional deformation in the area is provided by the principal foliation (S_1) that deforms the pegmatite and thus can be no older than 436 Ma. The monazite age of 430 ±2 Ma from the garnet-kyanite-staurolite schist records peak-metamorphic conditions within the area. This assemblage overgrew the principal foliation but was deformed by later penetrative fabrics (S_2 and S_3). A younger age limit on deformation is provided by the muscovite data. The muscovite was partially recrystallized during the D_3 and D_4 events

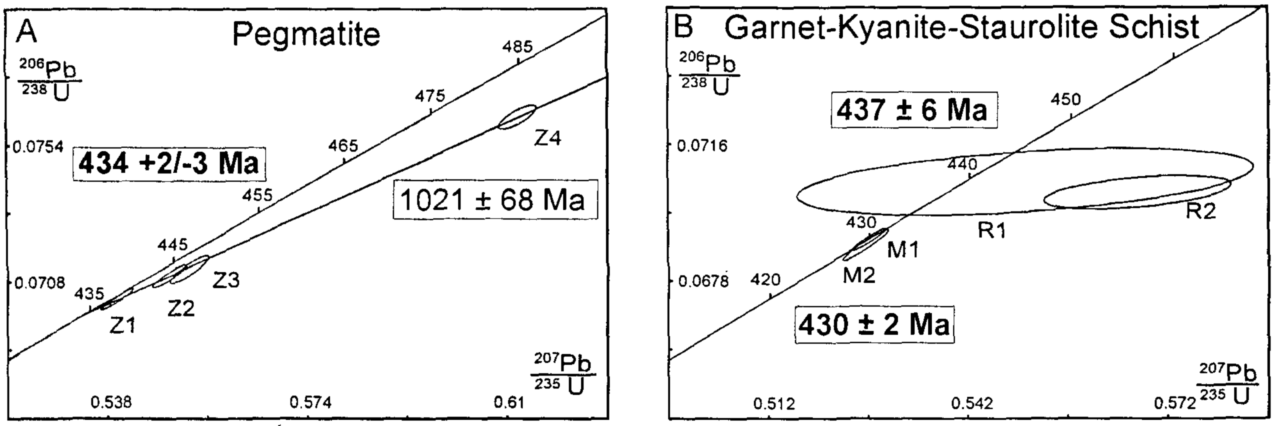

Figure 3. U/Pb concordia plot for zircon from pegmatite (A) and monazite and rutile from garnet-kyanite-staurolite schist (B). Z1–Z4, R1–R2, and M1–M2 refer to zircon, rutile, and monazite analyses, respectively, in Table 1. Ellipses show two-sigma errors, and line is regressed through all points.

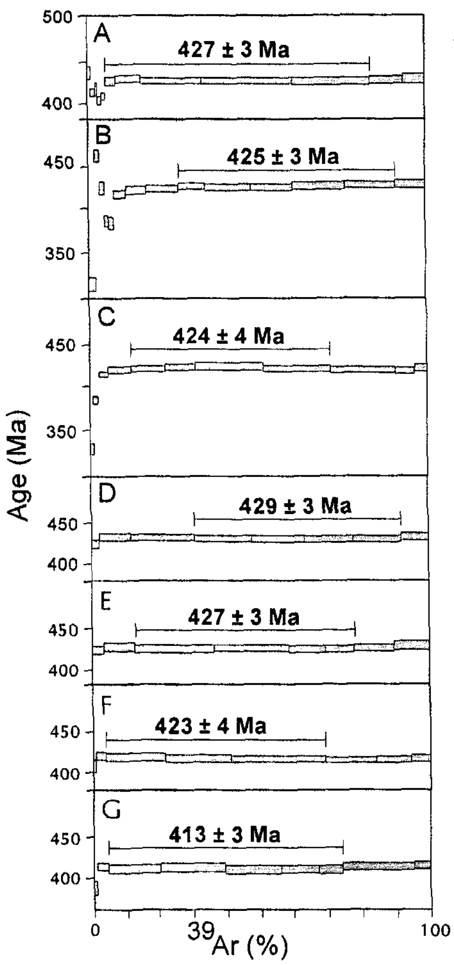

Figure 4. Ar/Ar release spectra for hornblende from amphibolites (A–C) and muscovite from psammitic and pelitic schists (D–G).

and, along with rutile and hornblende, gives a range of cooling ages, most of which are about 430–420 Ma. One muscovite sample from a psammite in the Corner Brook Lake region gave a younger age of ~413 Ma. The reason for this younger age is uncertain, but relative to the other muscovite samples, this one is located in an area of strong dynamic recrystallization during D_4 deformation. An alternative explanation is that this sample is located at the site of highest metamorphic grade and its younger age may reflect the longer time to cool from peak-metamorphic temperature to the muscovite blocking temperature.

The Corner Brook Lake region lies along strike from and contains rock units similar to the Baie Verte Peninsula (Fig. 1). Recent U/Pb data from this region (Cawood and Dunning, 1993) give an age range for peak metamorphism and deformation similar to that of the Corner Brook area. Monazite from a syntectonic leucogranite melt within a psammite from the Fleur de Lys Supergroup yielded a precise concordant U/Pb age of 427 ±2 Ma. Monazite from the muscovite-garnet–bearing syntectonic S-type phase of the Wild Cove igneous suite gave an identical age (427 ±2 Ma). Zircon and titanite from a K-feldspar, megacrystic, posttectonic I-type pluton of the suite indicate an age of crystallization of 423 ±3 Ma. Ar/Ar data from the Fleur de Lys Supergroup give ages as old as 429 ±10 Ma for hornblende and 421 ±10 Ma for muscovite (Dallmeyer, 1977; recalculated to new constants).

U/Pb and Ar/Ar age data on a selection of metamorphic minerals covering an along-strike distance of ~150 km between Corner Brook Lake and Baie Verte restrict the time of peak amphibolite-facies metamorphism and associated regional deformation to a relatively narrow time frame of ~435–425 Ma.

IMPLICATIONS

U/Pb and Ar/Ar isotopic data indicate that orogenic activity in the eastern Humber zone is of Silurian age. Recognition of a phase of Early to Middle Silurian deformation, metamorphism, and plutonism and its clear temporal separation from either the Ordovician Taconian orogeny or the Devonian Acadian orogeny suggests that this is a distinct orogenic pulse and should not be grouped with either of these other two events.

Our data suggest that any orogenic effects associated with westward emplacement of the west Newfoundland Taconian allochthons must have been limited to high crustal levels and must not have left a significant thermal or deformational imprint in the rock record. Cawood and Williams (1988) pointed out that deformational effects associated with ophiolite obduction and emplacement are largely confined to the Taconian allochthons. A similar situation likely prevailed in the eastern Humber zone.

The similarity of the bulk of the mineral age data over a range of blocking temperatures extending from 700 °C for monazite (Parrish, 1990) to 400 °C for rutile and muscovite (Mezger et al., 1989) suggests rapid cooling of the metamorphic pile between 430 and 425 Ma. These data suggest that peak metamorphism was followed by rapid exhumation of this segment of the orogenic belt. Extensional collapse features recognized in the western external domain of the Humber zone which postdate regional deformation and include late-stage remobilization of the ophiolite massifs (Cawood, 1989, 1993) may be a response to rapid uplift and a cause of exhumation of the eastern internal domain.

Combined field mapping and U/Pb dating within Gander zone and Avalon zone sequences from southern and eastern Newfoundland (Dunning et al., 1990; O'Brien et al., 1991; Holdsworth, 1991; Dunning, unpublished data) indicate that these rocks were involved in a widespread and major pulse of magmatism, deformation, and metamorphism during the Early to Middle Silurian. The rocks of these zones belong to the Gondwanan margin of the Appalachian orogen. The Humber zone, where we have

TABLE 1. U/Pb DATA

Fraction description	Weight	Concentration: U	Concentration: Pb rad	Measured: Total common Pb	Measured: $^{206}Pb/^{204}Pb$	Corrected Atomic Ratios*: $^{208}Pb/^{206}Pb$	Corrected Atomic Ratios*: $^{206}Pb/^{238}U$	Corrected Atomic Ratios*: $^{207}Pb/^{235}U$	Corrected Atomic Ratios*: $^{207}Pb/^{206}Pb$	Age (Ma): $^{206}Pb/^{238}U$	Age (Ma): $^{207}Pb/^{235}U$	Age (Ma): $^{207}Pb/^{206}Pb$
	(mg)	(ppm)	(ppm)	(pg)								
PEGMATITE (39330532)†												
Z1 8 clear euh grns abr	0.051	1212	77.3	44	6262	0.0002	0.07022 ± 0.00030	0.5397 ± 0.0024	0.05574 ± 0.00006	437	438	442
Z2 clear euh abr	0.139	136	8.8	28	2976	0.0027	0.07100 ± 0.00032	0.5491 ± 0.0026	0.05609 ± 0.00008	442	444	456
Z3 clear needles abr	0.085	127	8.2	8	6220	0.0033	0.07123 ± 0.00038	0.5527 ± 0.0030	0.05628 ± 0.00012	444	447	464
Z4 clear euh abr	0.088	113	8.0	17	2805	0.0150	0.07635 ± 0.00032	0.6119 ± 0.0028	0.05813 ± 0.00016	474	485	535
GARNET-KYANITE-STAUROLITE SCHIST (39121051)												
M1 clear yellow frags abr	0.057	1473	278.9	50	7355	2.1212	0.06896 ± 0.00026	0.5271 ± 0.0020	0.05544 ± 0.00006	430	430	430
M2 clear yellow frags abr	0.039	1923	367.9	63	5158	2.1609	0.06881 ± 0.00036	0.5267 ± 0.0028	0.05552 ± 0.00008	429	430	433
R1 red needles abr	0.083	3	0.4	24	64	nd	0.07056 ± 0.00076	0.5506 ± 0.0280	0.05659 ± 0.00266	440	445	476
R2 blocky red frags abr	0.413	4	0.3	106	84	0.0342	0.07026 ± 0.00038	0.5674 ± 0.0114	0.05858 ± 0.00106	437	456	551

Note: euh = euhedral; frags = fragments; grn = grain(s); abr = abraded; nd = not determined.
* Ratios corrected for fractionation, spike, 5-10 pg laboratory blank and initial common Pb, calculated by the model of Stacey and Kramers (1975) for the age of the sample and 1 pg U blank. Uncertainties are 2σ.
†Abbreviated Universal Transverse Mercator grid references in parentheses refer to Corner Brook map sheet (12 A/13).

documented Silurian peak orogenesis, lies on the ancient Laurentian margin. The coincidence of Silurian orogenesis across the island indicates that the Iapetus ocean had closed by this time and that orogenic activity was taking place within a Himalayan-style continent-continent collisional environment between the Laurentian and Gondwanan plates. In the New England Appalachians, the time of continent-continent collision is typically ascribed to the Devonian Acadian orogeny. We speculate that if collision was truly earlier in Newfoundland it may have resulted from the interaction of promontories along the colliding continental edges. In Newfoundland, the Devonian Period is represented primarily by late movement on shear zones, and plutonism is confined to posttectonic high-level potassic granites. This record contrasts with that in Nova Scotia where Devonian deformation and magmatism are widespread. The timing of Silurian orogenesis in the Newfoundland Appalachians corresponds with the Salinic disturbance in New England (cf. Boucot, 1962), and following Dunning et al. (1990), we refer to this event as the Salinian orogeny.

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