Dating ductile deformation using U–Pb geochronology: examples from the Gilbert River Belt, Grenville Province, Labrador, Canada

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The Gilbert River Belt, in the Grenville Province in southeastern Labrador, is a distinctive, west–northwest-trending zone of locally intense deformation and voluminous granitoid plutonism, up to 30 km in width. In an attempt to directly quantify the timing of deformation in ductile shear zones within the belt, rocks interpreted as having been intruded synchronously with ongoing deformation were sampled for U–Pb isotopic analysis. Three of these samples are <2 m wide granitic veins that have sharp intrusive contacts that truncate ductile deformation fabrics, but are themselves deformed at metamorphic conditions similar to their host rocks and are therefore interpreted as having intruded after the initiation of deformation and fabric development, but prior to cessation of this deformation. The first vein is syntectonic with respect to amphibolite-facies deformation and yielded a zircon age of 1664±9 Ma. The second vein intruded synchronously with the development of a zone of amphibolite-facies straight gneisses, which defines the southern limit of the Gilbert River belt at 1509±1 Ma. The third vein is syntectonic with respect to greenschist-facies deformation and yielded a zircon age of 1113±8 Ma and a monazite age of 1078±2 Ma. A sample of the K-feldspar megacrystic granite that underlies much of the belt and is interpreted as having intruded during ongoing amphibolite-facies deformation yielded a zircon age of 1644±6 Ma; a mildly deformed granitic vein that crosscuts the megacrystic granite at the same location contained zircon that indicate a 1062±5 Ma crystallization age. Monazite from a granodioritic gneiss yielded a concordant age of 1077±3 Ma, interpreted as the time of final cooling during gneiss formation. These results indicate that much of the amphibolite-facies deformation (1664–1644 Ma) in the Gilbert River Belt is correlative with the regionally extensive Labradorian orogenic event, whereas greenschist-facies deformation (1113–1062 Ma) and monazite growth (1078 Ma) are the result of renewed tectonomagmatic activity during Grenvillian orogenesis.

La ceinture de Gilbert River est une zone orientée ouest–nord-ouest, pouvant atteindre une largeur de 30 km, caractérisée par une déformation localement intense et par de volumeuse intrusions de composition granitoïde. De façon à quantifier la chronologie de la déformation dans les zones de cisaillement ductile présentes dans la ceinture, des intrusions mises en place pendant les différentes phases de déformation ont été échantillonnées pour fins de datation par la méthode U–Pb. Trois de ces échantillons sont des filons granitiques d’une largeur <2 m, ayant des contacts intrusifs francs et recoupant les structures de déformation ductile. Toutefois, ces échantillons ont été déformés dans des conditions de métamorphisme semblables à celles de leur encaissant et ont donc été mis en place après le début de la période de déformation ductile, mais avant sa cessation. Le premier filon est syntectonique de la déformation au faciès amphibolite et a livré un âge de 1664±9 Ma (zircon). Le second filon fut injecté à 1509±12 Ma, pendant la formation d’une zone de gneiss rectiplanaires métamorphisés au faciès amphibolite qui définit la limite méridionale de la ceinture Gilbert River. Le troisième filon est syntectonique de la déformation au faciès schists verts et a livré un âge de 1113±6 Ma (zircon), et de 1078±2 Ma (monazite). Le granite à phenocrustes de feldspath-K couvrant une grande partie de la ceinture et mis en place pendant la déformation au faciès amphibolite a livré un âge de 1644±8 Ma (zircon); au même site d’échantillonnage, un filon granitique peu déformé et recouvrant le granite à phenocrustes de feldspath-K contient des zircons livrant une âge de cristallisation de 1062±3 Ma. Des monazites extraites d’un gneiss granodioritique ont livré un âge concordant de 1077±3 Ma qui est interprété comme représentant le stade final de refroidissement du gneiss. Ces résultats indiquent que la déformation au faciès amphibolite de la ceinture Gilbert River (1664–1644 Ma) peut être corréllée en grande partie à l’épisode orogénique labradorien, qui est d’extension régionale, alors que la déformation au faciès des schists verts (1113–1062 Ma) et la formation de monazite (1078 Ma) sont liées à une reprise de l’activité tectonomagmatique pendant l’orogénèse grenvillienne.


1Lithoprobe Contribution 439; Geological Survey of Canada Contribution 10593.
Introduction

Our understanding of the role of zones of highly deformed rocks is often hampered by limited knowledge of the absolute timing of their formation. Geologists have long been able to interpret the kinematic significance of such rocks, but a lack of precise age information has hindered attempts to understand crustal-scale deformation processes. It is often difficult to confidently correlate individual phases of deformation away from areas where they are in direct contact. In the following contribution, we present natural examples of how precise U-Pb geochronology, combined with detailed field observations, offers an additional tool that may be used to address these problems.

The Gilbert River Belt (GRB) is located in the eastern part of the Grenville structural province in southeastern Labrador, Canada (Fig. 1). It is a distinctive, west-northwest-trending zone of locally intense deformation and voluminous granitoid plutonism, up to 30 km in width (Gower et al. 1987, 1988; Hanmer and Scott 1990; Scott et al. 1992a, 1992b, 1992c). The belt coincides with a major Bouguer gravity anomaly (Gower et al. 1987) and distinctive regional aeromagnetic patterns (Geological Survey of Canada 1985). The inland, along-strike continuation of the GRB, based on this aeromagnetic signature and geological mapping, appears to be in excess of 300 km, suggesting that the belt is a crustal feature of fundamental importance (Gower et al. 1987; van Nostrand et al. 1992). The belt separates the lithotectonically distinct Hawke River terrane to the north from the Pinware and Mealy Mountains terranes to the south (Gower et al. 1987; Rivers et al. 1989), and is interpreted as the southeastern continuation of the Lake Melville terrane (Gower et al. 1987, 1988).

The GRB is a major structural element in the eastern Grenville Province; detailed knowledge of its evolution is important to our understanding of the geology of this part of eastern North America and to our attempt to correlate these rocks with their European counterparts (e.g., Gower 1992). It also provides an opportunity to explore the possibility of using U-Pb geochronology to directly determine the age of deformation within shear zones developed under a wide range of physical conditions. The timing of magmatism and deformation within the belt, and its overall structural history are discussed in the following sections.

Geological and kinematic framework of the Gilbert River Belt

Recent regional mapping (1:100,000 scale) in the Port Hope Simpson and St. Lewis River map areas (Gower et al. 1987, 1988) provides the foundation for the present topical study (Fig. 2). The GRB transects these two map areas and is composed of metasedimentary gneisses, variably foliated, commonly megacrystic granitoid plutons, and deformed anorthositic and related igneous rocks (Fig. 2). These rocks occur as elongate, interfingering map units that define the pronounced west-northwest structural grain of the belt. The southern margin of the GRB is delineated by a laterally continuous approximately 100 m wide zone of well-banded granoblastic straight gneiss, well exposed in the vicinity of Long Harbour (Fig. 2), which displays well-developed down-dip extension lineations and north-side-up kinematic indicators (Hammer and Scott 1990). Rocks of the belt become less strongly deformed progressively northward; the northern limit of this deformation lies within the White Bear Arm anorthosite complex (Gower et al. 1987). The most northerly deformation examined in the present study is the greenschist-facies mylonite zone south of Occasional Harbour (Fig. 2).

Although the GRB is not well exposed along most of its strike length (e.g., van Nostrand et al. 1992), wave-washed exposures along the southern Labrador coastline provided an excellent opportunity to study a complete, across-strike section of the belt in detail (Hammer and Scott 1990). This structural examination has revealed that within the GRB significant deformation is concentrated in six narrow corridors (<1 km wide) containing discrete bands (<10 m wide) of mylonite (Fig. 2). The mylonitic corridors are arranged in an anastomosing array (Fig. 2), whereas bands within individual corridors are arranged en echelon. Only three of the corridors, Long Harbour, Rexon’s Cove, and Occasional Harbour (Fig. 2), presently show significant (>200–300 m) along-strike continuity of individual bands.

Metamorphic conditions under which the mylonites of the GRB developed range from upper-amphibolite to greenschist facies. The mylonites have been subdivided into high-grade (mid to upper amphibolite facies) and low-grade (greenschist facies) types, and occur in all rock types observed in the GRB (Hammer and Scott 1990). The amphibolite-facies mylonites that were examined are characterized by dominantly shallow to subhorizontal extension lineations and a dextral sense of displacement, as shown by the presence of rotated feldspar por-
Fig. 2. Geological map of the easternmost part of the Gilbert River Belt, southeastern Labrador (after Gower et al. 1987, 1988) showing locations of samples described in text. Locations of mylonitic rocks from Hamer and Scott (1990).
phryoclasts and extensional shear bands. Dip-lineated zones (north side up) and indications of sinistral movement are present but less common (Gower et al. 1987; Hamner and Scott 1990). Greenschist-facies mylonites occur in two laterally continuous zones (Fig. 2), characterized by shallow to moderate east–southwest-plunging extension lineations. Composite C–S fabrics, commonly developed within these zones, consistently indicate a dextral sense of offset.

A relative chronology of deformatonal events has been established from relationships observed in the field (Hamner and Scott 1990). Mineral assemblages within amphibolite-facies mylonite zones and in the foliated host rocks are identical, suggesting that much of the regional fabric development outside the zones and the mylonites themselves may have formed synchronously. Greenschist-facies mylonite zones occur within and rework amphibolite-facies host rocks, suggesting that they postdate the high-grade deformation. The low-grade zones are characteristically narrower than the amphibolite-facies mylonite zones. Greenschist-facies ultralaminites are locally cut by pseudotachylite veins, brittle fractures, and narrow zones of cataclastic rocks. This progression of deformation styles suggests that the history of the area is characterized by a sequence of deformation under conditions of decreasing temperature with time (Hamner and Scott 1990). Whether this deformation is part of a single, continuous event, or is part of a punctuated multistage history characterized by subsequent reactivation and overprinting, will be addressed in the following quantitative geochronologic investigation.

Previous geochronology

Much geochronology has recently been undertaken in the Grenville Province of eastern Labrador and has led to the recognition of two periods of orogenic activity. The older event, referred to as Labradorian orogeny (Nunn et al. 1984), involves deformation, metamorphism, and dominantly felsic magmatism from 1.71 to 1.62 Ga, culminating between 1.68 and 1.64 Ga (Nunn et al. 1988; Gower et al. 1992 and references therein). Tectonomagmatic activity of Grenvillian age (1.15–0.95 Ga) is present to a limited extent in the eastern Grenville Province (Gower et al. 1991 and references therein). A more detailed discussion of these orogenic events follows.

Analytical methods

The analytical methods used are essentially those of Krogh (1973, 1982) as followed at the Centre de recherche en géochimie isotopique et en géochronologie (GEOTOP) U–Pb Laboratory at the Université du Québec à Montréal (Machado et al. 1990), involving magnetic sorting of the bulk heavy mineral concentrate using a Frantz isodynamic separator, handpicking of highest-quality grains, air abrasion (durations stated in text are at ~20 kPa (3 p.s.i.)), and sample dissolution in Teflon digestion vessels with addition of a mixed $^{205}$Pb/$^{233}$U/$^{235}$U tracer solution. Analyses were carried out on a VG Instruments Sector mass spectrometer equipped with a Daly detector. Average 2σ analytical errors are 0.1% for $^{207}$Pb/$^{206}$Pb and 0.5% for U–Pb determinations. All ages are quoted at the 95% confidence level.

The U–Pb results from six rocks analysed in this study are presented in Table 1 and as concordia diagrams in Fig. 3. The samples and their field settings are described from northeast to southwest, across the strike of the GRB, in the following section.

Granitic vein, Rexon’s Cove (S46)

A considerable effort was made during field work to identify intrusive rocks that appear to have been intruded synchronously with ongoing deformation, and which might readily be dated using the U–Pb system in accessory minerals. The principal targets were <2 m wide granitic veins in wave-washed coastal exposures where crosscutting relationships with their deformed host rocks could be unequivocally observed. To determine the age at which greenschist-facies deformation occurred along the Rexon’s Cove mylonite zone (Fig. 2), a granitic vein interpreted as having intruded syntectonically with these mylonites was sampled. The vein has sharp intrusive contacts (i.e., no strain gradient at its margins) that truncate greenschist-facies deformation fabrics, but is itself folded, boudined, and contains a chlorite-bearing foliation that is parallel to the mylonitic fabric in the host rock (Fig. 4). It is therefore thought to have been emplaced after the onset of greenschist-facies deformation, but prior to cessation of this event. Although it cannot be unequivocally demonstrated using field criteria that deformation of the vein did not occur until long after it was intruded during renewed deformation, the strong physical similarity of deformation fabrics and their orientations in both the host rocks and the vein is consistent with the interpretation that the vein was intruded relatively late into an actively deforming zone.

Both zircon and monazite were separated from the sample. Zircon in the diamagnetic fraction consisted of clear, colourless equant prisms euhedral in form. A selection of gem-quality grains was abraded for up to 42 h. Thin (<5 μm) colourless overgrowths were observed on a small proportion of the equant prisms and were removed by abrasion prior to analysis. The upper intercept of the discordia defined by analyses of three fractions indicates an age of 1113±5 Ma (Fig. 3a), interpreted as the age of emplacement of the granitic vein. A single small fragment of a euhedral monazite grain (analysis 4) is concordant at 1078±2 Ma. Whereas the rock may initially have crystallized at 1113 Ma, the 1078 Ma monazite age suggests that approximately 35 Ma may have elapsed prior to final cooling through 725 ± 25°C (Parrish 1990). Attempts to date individual zircon overgrowths were not successful, but we speculate they may be also be ca. 1078 Ma. Alternatively, the 1078 Ma monazite and the zircon overgrowths may represent the crystallization event, the 1113 Ma zircons may therefore be inherited. The Rexon’s Cove greenschist-facies mylonites are at least 1113 Ma, and the zone may have been reactivated at, or remained active until, 1078 Ma. Additional samples with identical relationships to the deformation fabrics were collected elsewhere in this greenschist-facies zone, but trace minerals suitable for U–Pb dating were not recovered.

Granitic vein, Red Point (S60)

On Red Point (Fig. 2), a leucogranitic vein transects amphibolite-facies sinistral strike-slip mylonitic fabrics, but is itself deformed by ductile deformation (Fig. 5). The vein has...
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(a) Rexon's Cove granitic vein (S46)

(b) Red Point granitic vein (S60)

(c) Alexis Bay granodioritic gneiss (S99)

(d) Mecklenburg Hr. megacrustic granite (S23A)

(e) Mecklenburg Hr. granitic vein (S23D)

(f) Long Harbour granitic vein (S401)

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^a zircon; m, monazite.
^b dia, diamagnetic at −0.5° tilt of Frantz magnetic separator at maximum current; M1, magnetic at 1° tilt; IF, nonmagnetic between 1.0 and 1.8 A at 10° side slope.
^c Concentrations are known to 10−20% for sample weights below 20 µg. For sample weights less than 1 µg, the concentrations listed are maximum values.
^d Measured ratio, corrected for fractionation only.
^e Measured ratio, corrected for fractionation only.
^f Total common Pb present corrected for common Pb in spike.
^g Calculated with the two-stage model of Stacey and Kramers (1975). The decay constants are those recommended by the Subcommission on Geochronology of the International Union of Geological Sciences (Steiger and Jager 1977).
sharp intrusive contacts and planar and linear fabric elements in orientations identical to its deformed metsedimentary gneiss host rocks. This is thought to indicate that although the vein intruded after the amphibolite-facies deformation fabric had been developed in the host rocks, ongoing deformation imparted identical fabric elements to the leucogranitic vein, consistent with the interpretation that the vein was intruded relatively late into a continuously deforming zone. The crystallization age of the vein should therefore indicate a minimum age for this high-grade deformation.

Zircon separated from this sample included a variety of variably altered grains, but was dominated by a population of
colourless, euhedral prisms with a stubby habit. As examined using a binocular microscope, these gem-quality grains showed no evidence of overgrowths or internal core structures. A population from the highest quality magnetic fraction, free of visible inclusions and cracks, was selected and given an extended abrasion treatment for up to 100 h. Four populations were analysed and showed a positive correlation between time of abrasion and $^{207}\text{Pb}/^{206}\text{Pb}$ age. The four analyses (Nos. 5–8) define a discordia line (Fig. 3b) with an upper intercept of $1664 \pm 14$ Ma, which is interpreted as the age of emplacement of the vein, and a lower intercept of $1186 \pm 33$ Ma, thought to be the result of Pb loss due to younger tectonothermal activity (discussed below). Although the total probability of fit of the four points is good (74%, Davis 1982), the shallow angle of intersection between the discordia line and concordia results in large uncertainties on the intercepts. As field relationships suggest that this vein was intruded into an active shear zone, 1664 Ma is a minimum age for this deformation.

Granodioritic gneiss, Alexis Bay (S99)

A map unit of polydeformed granodioritic gneiss, intruded by numerous granitic phases and mafic dykes, was recognized by Gower et al. (1987, 1988). In an attempt to characterize the age of this unit, a representative sample was selected from a locality at the west end of Alexis Bay (Fig. 2). The sample contained both zircon and monazite. A wide variety of zircon morphologies was present in each of the magnetically separated fractions. Grains were of low quality, and as a result zircon was not analysed. Two single grains of monazite, a smaller euhedral grain (Fig. 3c, analysis 9) and a larger fragment (analysis 10), were selected (Table 1); they are identical within analytical error. The average $^{207}\text{Pb}/^{206}\text{Pb}$ age of $1077 \pm 3$ Ma is interpreted as the best estimate for the age of the final tectonomagmatic episode experienced by the gneiss at the sample location.

Mecklenburg Harbour (S23)

The potassium feldspar megacrystic granite that underlies an important part of the GRB (Gower et al. 1987, 1988) is well-exposed on the shores of Mecklenburg Harbour in the southeast part of the area (Locality 4, Fig. 2). A representative sample of this magnetite-bearing granite was obtained from an outcrop where a number of crosscutting relationships with other rock types are apparent. A characteristic feature of this map unit is the ubiquitous presence of mafic dykes that are up to several metres wide. The dykes display evidence of two distinct phases of deformation. The dykes are boudined, indicat-
ing an initial period of extension. The dyke boudins are also folded, indicating subsequent compression, and display a distinctive "lobe-and-cusp" fold morphology (Fig. 6), with granitic material filling the rounded lobes or mullions, dyke material filling the tightly pinched cusps (see also Fig. 5 in Hanmer and Scott 1990). A moderate- to well-developed axial planar foliation associated with these folds, observed both in the dykes and the granitic rocks, is parallel to the west-northwest-trending foliation observed throughout the GRB.

The observed response of the dykes to the sequence of deformation (extension followed by compression) suggests that they behaved initially as relatively more competent than the enclosing granite (boudinage) and subsequently as relatively less competent (formation of fold cusps). This apparent reversal in rheological behavior can be explained in terms of strain rate variation and changing thermobarometric conditions associated with either cooling magmatic bodies or regional granulite-facies metamorphism (Hanmer and Scott 1990; Talbot and Sokoutis 1992). The absence of granulite-facies assemblages in these rocks suggests that much of the high-temperature shearing observed in the megacrystic granite may have occurred early in the cooling history of the rock and can essentially be considered as symmagmatic. This relationship implies that the granite and the dykes are comagmatic and that both are syntectonic with respect to the imposed foliation.

Four samples were collected at this location. The oldest magmatic phase in the outcrop is the megacrystic granite (S23A). A ~50 kg sample collected from a weakly foliated part of the outcrop that was free of visible xenoliths or mafic dykes yielded high-quality zircon sufficient for analysis. Two samples of the mafic dykes were collected; no U-bearing minerals suitable for U-Pb dating were recovered from either sample. A ~10 kg sample was collected from a 10-15 cm wide pink aplitic vein (S23D) that intrudes the megacrystic granite and crosses both dyke phases, but is itself mildly deformed and locally foliated. A trace amount of high-quality zircon was recovered from this sample.

Megacrystic granite (S23A)

Much of the zircon throughout the more magnetic fractions consisted of cloudy irregular, altered grains of probable xenocryst origin, or coarse, cracked, faint-pink to colourless square-section prisms. Increasingly common in the less magnetic fractions were euhedral, stubby (~2:1) colourless prisms. In the diamagnetic fraction, the majority of euhedral gem-quality grains is of this type. Four populations of inclusion- and crack-free grains of varying size were selected for analysis (Nos. 11-14, Table 1); they define a discordia line with an upper intercept age of 1644±6 Ma, interpreted as the age of granite emplacement, and a lower intercept age of 890±56 Ma (Fig. 3d). Some of the larger grains in each of the magnetic fractions were overgrown by extremely thin, colourless overgrowths, attempts to analyze individual overgrowths were unsuccessful.

The predominance of the euhedral, stubby prisms in the higher quality magnetic fractions suggests that these are the most likely type to have crystallized magmatically, and 1644±6 Ma can be reasonably interpreted as the age of crystallization of this sample. The lower intercept, and possibly the thin overgrowths, may be related to tectono-thermal activity ca. 0.9 Ga. Although the four analyzed populations lie on a well-defined discordia (78% total probability of fit, Davis 1982), lead loss less than 800 Ma after initial crystallization has resulted in a shallow angle between concordia and the discordia line, leading to rather large uncertainty in the calculated upper intercept age. Based on the interpretation of the relative timing of deformation in the dykes and the megacrystic granite, the crystallization age of this unit is suggested as the age of the deformation fabrics in this sample, and indeed much of the amphibolite-facies shearing observed in the belt.

Granitic vein (S23D)

Zircon separated from this sample consisted almost exclusively of colourless, 3:1 aspect square-section prisms in each of the magnetically separated fractions. Inclusion- and crack-free grains that showed no visible core-overgrowth relationships were selected from the diamagnetic fraction and abraded for up to 42 h. Three populations of these abraded grains were selected for analysis. They define a discordia line (Fig. 3e) with a lower intercept of 1062±6 Ma and an upper intercept of 1790±158 Ma. The three analyses lie near the lower intercept (95-98% discordant), and yield increasingly older 207Pb/206Pb ages with increasing total time of abrasion (Nos. 15-17, Table 1).

The alignment of the three points suggests that air abrasion has successfully removed any effects of recent lead loss (Krogh 1982). With increased abrasion and loss of material from the outer parts of grains, the populations yield increasingly older 207Pb/206Pb ages, suggesting that the zircon crystals contain a ca. 1.8 Ga old component of Pb, interpreted as originating from unobserved xenocrystic cores. The lower intercept, 1062±6 Ma, may therefore correspond to the time of lead-loss and almost complete resetting of the U-Pb chronometer during emplacement of this vein. The analysed zircons have relatively high uranium contents (545-725 ppm) and could readily have lost radiogenic lead during a subsequent tectono-thermal event. Alternatively, small amounts of core material may have been overgrown by new, magmatic zircon at 1062 Ma, varying proportions of core and overgrowth resulting in the range of observed 207Pb/206Pb ages in analyses Nos. 15-17.
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The xenocrysts are known from this region and possibly under-
that the immediate host rocks may not have provided the
xenocrysts. Magmatic rocks that are within the age range of
of the discordia line from the three analyses, and resultant
references therein). However, the extremely long projection
lie the Mecklenburg Harbour area (Gower et al. 1992 and

toward east-southeast, with extensional megashear band indicating

High-quality zircon separated from this sample consists of
small, colourless, elongate, square-section prisms. Core-
overgrowth structures were not observed in any of these
grains. An inclusion- and crack-free selection was abraded for
35 – 46 h. Four populations were analysed; they define a dis-

cordia line with an upper intercept age of 2067 ± 28 Ma and
a lower intercept age of 1509 ± 14 Ma (Fig. 3f). A positive
correlation exists between 207Pb/206Pb age and duration of
abrasion, indicating that an older component of radiogenic
lead is preserved in more internal parts of the grains selected,
despite the absence of visible cores. These observations sug-
gest that these grains contain zircon formed at ca. 2.07 Ga and
that they experienced almost complete lead loss and resetting
of the U–Pb chronometers at 1509 Ma. Alternatively, the
lower intercept may represent the age of zircon overgrowths
not recognized optically on the grains that were analysed. In
either case, the analysed grains are interpreted as in part xeno-
cryptic, and the lower intercept age is interpreted as the mini-
imum age of emplacement of this vein into the actively
deforming shear zone at Long Harbour.

**Discussion**

**Labradorian events**

Gower et al. (1992) have recognized three distinct early- to
mid-Labradorian magmatic pulses in eastern Labrador, which
occur broadly from oldest to youngest from southwest to
northeast, across the structural grain of the eastern Grenville
Province. The oldest, referred to as the Neveisik Island mag-

mantic event, found in the central part of the Lake Melville ter-

tane at ca. 1677 Ma, consists of granitoid plutons intruded by

mafic dykes. The second is recognized in the Hawke River ter-

tane at ca. 1670 Ma (Red Island magmatic event) and involves

voluminous granitic magmatism and mafic dyke emplacement.
Migmatization and deformation of these rocks must have
occurred prior to 1663 Ma, the age of an undeformed discord-
ant granite intrusion (Shoal Bay) that intrudes ca. 1671 Ma

tonalitic gneisses of the Red Island magmatic event. The

youngest pulse, in the Groswater Bay terrane, is the Double

Island event, which consists of tonalite, quartz diorite, and

granodiorite plutons that range in age from 1658 to 1649 Ma.

These rocks are intruded by mafic dykes, which are deformed

and metamorphosed prior to the intrusion of the Michael

Gabbro at 1426 ± 6 Ma (Schärer et al. 1986). Titanite growth

at ca. 1646 Ma observed in samples from the eastern part of

the Hawke River terrane is thought to be linked with the

second deformation event (Gower et al. 1992).

Extensive felsic magmatism has been identified throughout

the northern part of the eastern Grenville Province and north-

ward into the Makkovik Province at ca. 1650 Ma (Trans-

Labrador Batholith of Wardle et al. 1986). A period of

late-Labradorian granitic magmatism, from 1632 to 1622 Ma, is

recognized in the Groswater Bay and Hawke River terranes

(Schärer et al. 1986; Gower et al. 1992).

Intrusion of the leucogranite vein at Red Point (S60, Fig. 8)

into ongoing sinistral strike-slip deformation at 1664 Ma is
coeval with the earlier (pre-Shoal Bay pluton) phase of region-
ally recognized Labradorian deformation in the Hawke River

and Lake Melville terranes (Gower et al. 1992). As Gower

et al. (1992) point out, the extent of magmatic activity at

1663 Ma is not known; the Red Point syntectonic leucogranite

vein, approximately 85 km due south of the Shoal Bay pluton,
is only the second known example of igneous activity of this
age in the eastern Grenville Province. It nonetheless offers
direct evidence justifying correlation of deformation events
from the north and west into the GRB at ca. 1664 Ma.

The 1644 Ma megacrystic granite at Mecklenburg Harbour

(S23A, Fig. 8), which is interpreted as having intruded into

Page dimensions: 595.4x789.8
[Image 0x0 to 595x790]
Grenvillian events

Numerous discrete pulses of Grenvillian-aged tectonomagmatic activity have been identified in the eastern Grenville Province of southern Labrador and eastern Quebec (Gower et al. 1991 and references therein). The volume of Grenvillian-aged rocks that have been identified to date increases across strike toward the southwest.

In the eastern Gros港澳ter Bay terrane, zircons from a 1649 Ma granitic intrusion define a lower discordia intercept of 980 Ma (Scharer and Gower 1988), and titanite ages between 978 and 968 Ma have been reported (Scharer et al. 1986). In the Hawke River terrane, a 1029 Ma monazite and a 977 Ma titanite age have been identified (Scharer et al. 1986; Scharer and Gower 1988). The Southwest Brook granite, along strike from the GRB in the Lake Melville terrane, contains zircons that define an upper intercept of 1079 ± 6 Ma (Scharer and Gower 1988). Discordant titanites with 207Pb/206Pb ages of ca. 1045 Ma and monazite with ages ca. 1030 Ma have been reported from the Lake Melville terrane (Scharer et al. 1986; Scharer and Gower 1988; Gower et al. 1991). Rocks of the Pinware and easternmost Mealy Mountains terranes have been intruded by a series of weakly deformed to nondeformed felsic intrusions (monzonite to granite), which form distinctive, equant plutons and range in age from 966 ± 3 Ma to 956 ± 1 Ma (Gower and Loveridge 1987; Gower et al. 1991).

The granitic vein that intruded the Rexon’s Cove greenschist-facies mylonite zone at 1113−13 Ma (S46, Fig. 8) is less than 3 km from the western end of the Gilbert Bay Pluton, dated at 1132±6 Ma (Gower et al. 1991). This supports the suggestion that the granitic vein, and indeed much of the discordant granitic veining observed in the northeastern part of the GRB, may be related to the Gilbert Bay Pluton (Gower et al. 1987; Hamner and Scott 1990). The lower discordia intercept of the Red Point granitic vein (1186±32 Ma, S60) is similar within error to both of these rocks. The 1078 Ma monazite age from the Rexon’s Cove granitic vein and the 1077 Ma old monazite in the granodioritic gneiss from Alexis Bay (S99, Fig. 8) are identical to the age previously reported further along strike for the Southwest Brook granite (1079 Ma), possibly indicating a distinct tectonomagmatic event within the GRB – eastern Lake Melville terrane at this time. The granitic vein at Mecklenburg Harbour (S23D, 1062 Ma, Fig. 8) is significantly younger than, but possibly related to, the ca. 1078 Ma event. With the possible exception of the lower ongoing dextral strike-slip deformation in the GRB, is coeval with the second period of Labradorian metamorphism and deformation (post-Double Island magmatic event) recognized by Gower et al. (1992). The field relationships observed at Mecklenburg Harbour are representative of much of the high-grade deformation in the GRB. We therefore suggest that the age of this unit, and corresponding synmagmatic deformation, support the interpretation that widespread deformation was occurring throughout the eastern Grenville Province during Labradorian orogeny. As much of this deformation is synmagmatic, we suggest that west–northwest–elongated forms of the megacrystic granite bodies are in fact primary, these rocks having been intruded as sheet-like bodies. Their magnetite-rich compositions and elongate map patterns contribute to the striking regional aeromagnetic features (Geological Survey of Canada 1985).

The age of the granitic dyke (S401) at Long Harbour (1509±11 Ma, Fig. 8), interpreted as syntectonic with the formation of the straight gneiss, at first seems somewhat anomalous, as rocks of ca. 1.5 Ga age are not widely known in southeastern Labrador (Tucker and Gower 1990). Three Grenvillian granitic intrusions have yielded evidence of zircon growth of roughly this age. A garnet–biotite pegmatite on Double Island (Gros港澳ter Bay terrane) was emplaced at 1499±9 Ma (Scherer et al. 1986) and is identical, within analytical uncertainty, to the emplacement age of the granitic dyke at Long Harbour. Zircons from the Rivière Buteault headwaters syenite (Pinware terrane), emplaced at 964 ± 5 Ma, define an upper intercept of 1530 ± 30 Ma (Gower et al. 1991). The banded granodioritic Cuff Island gneiss (Gros港澳ter Bay terrane), metamorphosed at 968±7 Ma, contains inherited zircons dated at 1587±12 Ma (Scherer et al. 1986).

A fourth sample, a 1029 ± 2 Ma microgranite dyke at Beaver Brook (Hawke River terrane) shows evidence of inheritance of 1566 ± 13 Ma zircons (Scherer et al. 1986). Thus, although ca. 1.5 Ga rocks are not common, there is significant evidence in favour of post-Labradorian, pre-Grenvillian magmatism and associated deformation. The 1509 Ma age of the granitic vein from the Long Harbour straight gneisses is thought to provide a reliable minimum age of deformation along the southern margin of the GRB.
intercept of the megacrystic granite from Mecklenburg Harbour (890±50 Ma, S23A, Fig. 8), evidence of thermal disturbance that might correspond to the late granitoid plutonic activity (ca. 966–956 Ma) to the south of the GRB was not observed.

Thus, within the GRB, Grenvillian-aged igneous rocks are of limited extent only and Grenvillian deformation appears to locally overprint Labradorian structures.

Directly dating periods of deformation

Four of the samples for which results are presented here are interpreted as having been intruded into active zones of ductile deformation (S46, S60, S401, and S23A). The first three of these samples are narrow granitic veins, which truncate ductile deformation fabrics in the rocks that they intrude, but are themselves deformed by ductile deformation processes and have developed fabric elements in orientations identical to their host rocks, suggesting that they were intruded synchronously with ongoing ductile deformation. Zircon and monazite separated from samples of these veins provided useful information about the timing of emplacement of these rocks and consequently minimum age information on the timing of deformation at each sample location. In the fourth sample (S23A), it was demonstrated, based on mechanical (i.e., lobe-and-cusp) relationships in the outcrop (Hanmer and Scott 1990), that much of the penetrative deformation fabric was imparted during initial cooling of the rock, and thus the crystallization age of the sample provides a minimum age for this deformation. Two of these deformation ages (S60, 1664 Ma and S23A, 1644 Ma) are coeval with regionally recognized deformation (Gower et al. 1992) indirectly supporting our outcrop-based interpretations. The ages of deformation determined in the Long Harbour area (S401) and Rexon’s Cove greenschist mylonite zone (S46) have not been previously recognized in the eastern Grenville Province; in both cases the ages determined here are consistent with known field relationships and existing geochronological data.

Conclusions

The results presented here indicate that the Gilbert River Belt experienced two distinct episodes of tectonomagmatic activity, separated in time by 500–600 Ma. The older events (1664–1644 Ma) involved voluminous felsic plutonism and deformation at amphibolite-facies conditions that resulted in the formation of dominantly dextral and subordinate sinistral strike-slip mylonite zones and corresponds with Labradorian orogenesis recognized throughout the eastern Grenville Province. The spatial distribution of the majority of amphibolite-facies sheared rocks within the belt (Fig. 2) indicates that they can accommodate only a small amount of total displacement (Hanmer and Scott 1990). The zone of most significant displacement may be the zone of banded, straight gneiss at Long Harbour (Hanmer and Scott 1990). The Long Harbour straight gneiss zone appears to have been active at 1509 Ma, clearly much later than Labradorian events in the eastern Grenville Province. As this age represents a minimum (i.e., it postdates much of the strong deformation in this zone), we cannot determine here if the zone was initiated during the Labradorian or alternatively if it represents subsequent (postcollisional ?) readjustment while these rocks remained at mid-amphibolite facies conditions.

Narrow granitic veins have been identified at 1113 and 1062 Ma, confirming the presence of Grenvillian intrusions across the GRB. The older of these veins is interpreted as hav-


