An 1161 Ma suture in the Frontenac terrane, Ontario segment of the Grenville orogen

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ABSTRACT

In the Central Metasedimentary belt of the Grenville orogen, we recognize two contrasting packages of rocks within what traditionally has been interpreted as a continuous, intact stratigraphic sequence metamorphosed under upper amphibolite–facies to granulite-facies conditions. The two packages are separated by a thrust fault, the hanging wall of which was transported northwestward relative to rocks of the footwall. Upper greenschist– to lower amphibolite–grade marbles make up the footwall, whereas the allochthon contains granulites, metamorphosed prior to deposition of an unconformably overlying quartzite and intrusion of a compositionally diverse suite of 1179–1162 Ma plutons. Emplacement of the pluton-saturated allochthon occurred at ~1161 Ma and metamorphosed platformal carbonates into the marbles of the footwall. We interpret this thrust as part of a fundamental suture within the Grenville orogen.

INTRODUCTION

Despite its proximity to major cities, its immense size, and abundant well-mapped areas, the Grenville orogen remains one of the most poorly understood orogenic belts in North America. Since the pioneering work of Davidson (1984), who recognized deep- to middle-crustal shear zones that juxtapose rocks of contrasting metamorphic grades in the Central Gneiss belt of Ontario, Canada, and Moore (1982), who recognized four fundamental lithological assemblages that he called terranes, most syntheses have tried to blend the terrane concept, found so useful in the North American Cordillera, with the shear-zone concept. Despite this marriage, and many suggestions as to the locations of sutures, the accretionary evolution of the orogen is still poorly understood.

In this paper we reexamine the geology of the Frontenac terrane and suggest that contrasting supracrustal sequences, metamorphic grades, plutonism, basements, and marble melange delineate a major thrust fault, active at 1161 Ma, that placed what we interpret as hot, pluton-saturated, arc basement on top of cool platformal carbonates. This testable model—derived mostly from a preexisting database of detailed maps, abundant geochronology, and numerous metamorphic studies, but also from our own field observations—rationalizes formerly conflicting relations and links the geologic history across the entire southwestern Grenville orogen.

REGIONAL SETTING

Rocks of the Grenville orogen crop out from the coast of Labrador to the shores of Lake Huron in Ontario, where the widest transect of the orogen is exposed southeastward through Ontario and New York to the Appalachian orogen (Fig. 1). Within this transect, the rocks are traditionally separated into three major domains: the Central Gneiss belt, the Central Metasedimentary belt, and the Adirondack Highlands terrane (Easton, 1992). The Central Gneiss belt comprises a wide variety of deformed and metamorphosed pre-Grenvillian rocks of Archean to Mesoproterozoic age that were thrust northwestward at ~1160 Ma and possibly earlier (van Breemen et al., 1986). To the southeast, the high-grade gneisses are separated from rocks of the Central Metasedimentary belt by the Central metasedimentary belt boundary zone, a complex and long-lived zone of northwest-directed thrusts, which may be as old as 1189 Ma and as young as 1060 Ma (McEachern and van Breemen, 1993).

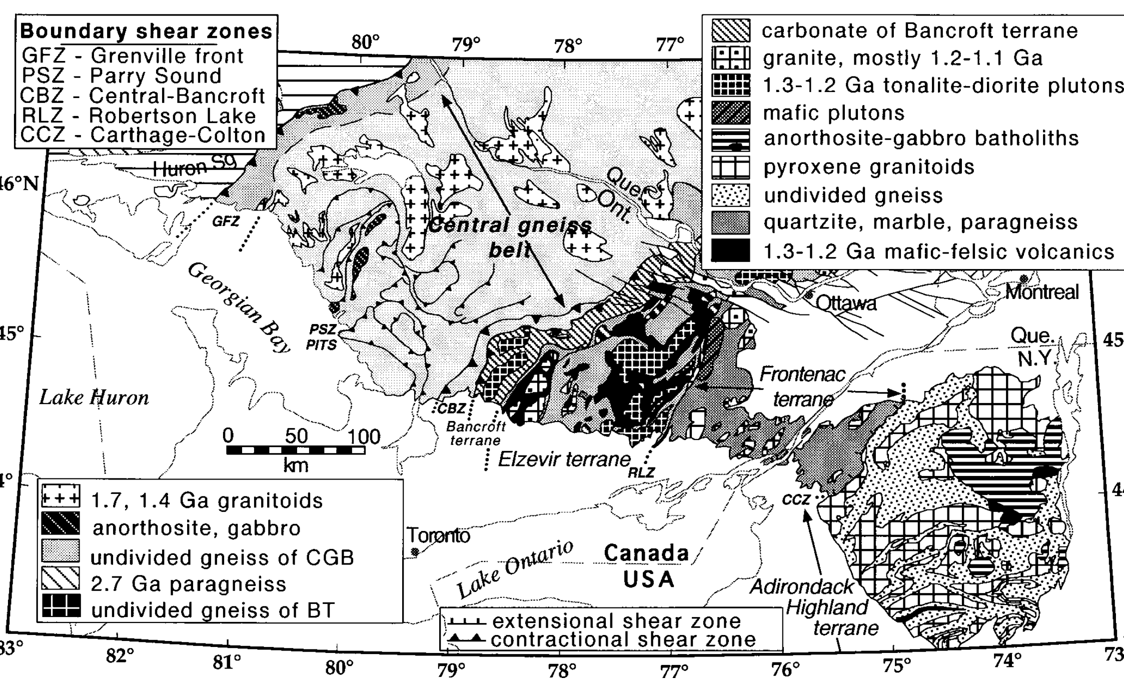

Figure 1. Extent of various domains within Ontario–New York transect through Grenville orogen (modified after Hoffman, 1989). PITS indicates location of Parry Island thrust sheet. CGB = Central Gneiss belt; BT = Bancroft terrane.

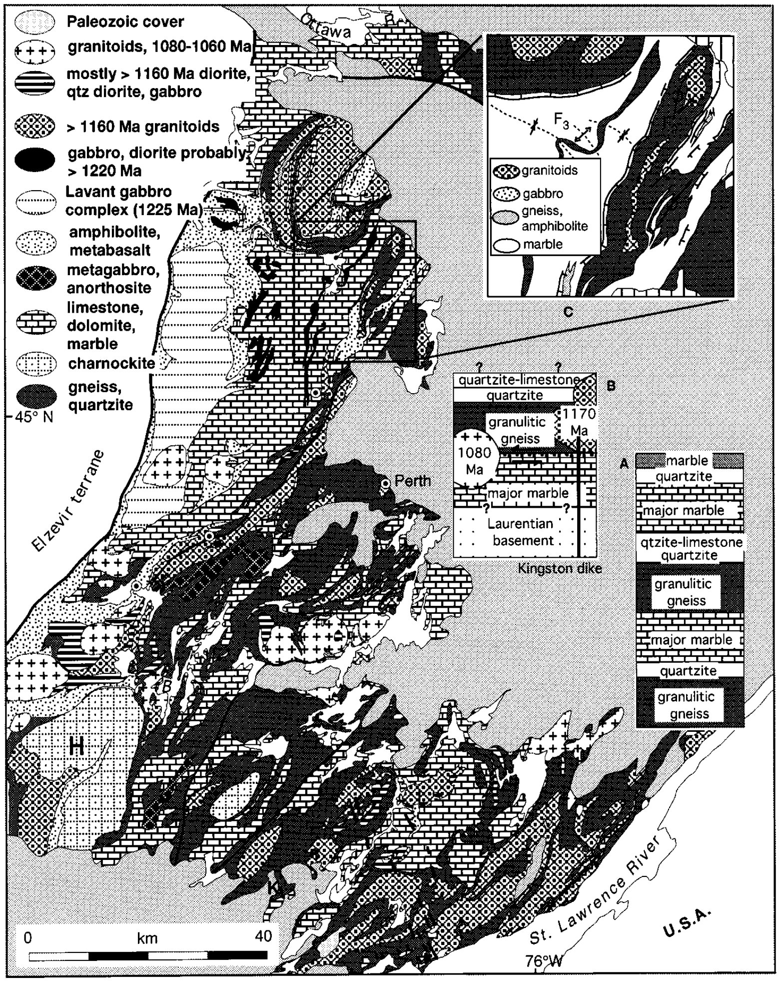

Figure 2. Geologic sketch map of Frontenac terrane between St. Lawrence and Ottawa rivers showing distribution of major rock units (modified after Wilson and Dugas, 1961; Wynne-Edwards, 1962, 1963, 1965, 1967; Reinhardt et al., 1973). H indicates 1.25 Ga charnockite, and heavy lines in southern part of area represent Kingston dikes. A: Wynne-Edwards (1967) hypothetical stratigraphy. B: Relations proposed in this paper. C: Simplified geologic map showing relations between marble and gneiss contact and metamorphism in northern part of Frontenac terrane. Line with ticks marks trace of isobaric reaction assemblage tremolite + diopside + calcite + dolomite + quartz; ticks on high-*T* side (after Ewert, 1977, and Kornik, 1986). L marks Lyndhurst pluton, which, on basis of map of Wynne-Edwards (1967), is likely a pluton-dominated klippe.

Rocks of the Central Metasedimentary belt are divided into various terranes and domains but overall constitute a diverse amalgamation of volcanic and platformal sedimentary rocks metamorphosed under greenschist to granulite conditions and intruded by a temporal and compositional spectrum of plutons (Easton, 1992). Basement to the supracrustal rocks is unrecognized, and volcanism is in the 1300–1225 Ma range, as is much of the plutonism. Rocks of the Adirondack Highlands terrane (Fig. 1) consist of complexly folded granulite facies igneous and sedimentary rocks as well as a variety of 1.3 to 1.0 Ga plutonic rocks (McLelland and Isachsen, 1986).

The Frontenac terrane is the southeasternmost domain within the Central Metasedimentary belt in Ontario. For the most part, the terrane is well mapped (Wilson and Dugas, 1961; Wynne-Edwards, 1962, 1963, 1965, 1967; Reinhardt et al., 1973), and the maps provide a significant, but underutilized, database from which much of the geologic history of the area can be unraveled. Traditionally, the geology of the area has been viewed as a multiply deformed sedimentary succession metamorphosed to granulite grade and intruded by plutons (Wynne-Edwards, 1967; Carmichael et al., 1987).

When Wynne-Edwards (1967) erected his hypothetical stratigraphy in the region, he proposed basically that there are two stacked sets of tripartite units consisting of, from bottom to top, gneiss, quartzite, and marble (Fig. 2A). In erecting the stratigraphy, he made several assumptions, of which two are fundamental: (1) that continuous contacts represent single stratigraphic boundaries and (2) that there are two major marble horizons. However, review of mapped geologic relations in the area indicates that assumption 1 can be used to show that assumption 2 is erroneous. Except for small inliers of marble within gneiss and small inliers of gneiss and quartzite surrounded by marble, and where displaced by younger faults, one highly folded marble contact can be traced throughout the entire terrane (Fig. 2). Thus, there can be only one major marble unit (Fig. 2B). We turn now to describe the major rock units on either side of the contact.

GNEISS, QUARTZITE, AND PLUTONS: ROCKS OF THE HANGING WALL

Gneisses of various types are among the major rock assemblages in the area (Wynne-Edwards, 1967). Most common are pelitic gneisses the protoliths of which were metamorphosed under upper amphibolite to granulite facies conditions. Regionally, rocks of the garnet-cordierite and cordierite-orthopyroxene zones are common and provide evidence of metamorphism near 700 °C at ~5 kbar; additionally, the local occurrence of the assemblage sillimanite + orthopyroxene + potassium feldspar + melt suggests that pressures were locally above 7 kbar (Lonker, 1980; Carmichael et al., 1987). At several localities there is mineralogical, chemical, and textural evidence for an overprinting amphibolite-facies event (Lonker, 1980; Carmichael, 1978; Easton and Hildebrand, 1994). The minimum age of the gneiss is 1310 ± 47 Ma, based on Rb-Sr whole-rock data (Spooner, 1969), but Nd model ages in the range 1.6–2.0 Ga (Marcantonio et al., 1990) allow that they might be much older.

The gneisses are unconformably overlain along a surface of low relief by quartzite and minor arkose containing sparse feldspar granulestone. The quartzite overlies two-pyroxene migmatitic gneiss and is overlain by beds of psammite and semipelite with pelitic tops, which are now biotite-muscovite schists. Semipelites contain the assemblage biotite + epidote + microcline + albite + quartz. Although the pelites and semipelites are <10 m from extremely migmatitic gneisses with two pyroxenes, there are no pyroxenes, melt pods, or aluminum silicate minerals within these rocks. Thus, we conclude that deposition of the quartzite postdates high-grade metamorphism in the underlying gneisses but predates another metamorphic event, likely the overprinting metamorphism found in the gneisses. The age of the quartzite has been determined from one detrital zircon to be younger than 1306 ± 16 Ma (Sager-Kinsman and Parrish, 1993).

The granulitic gneiss and quartzite package is cut by a suite of sheetlike to tabular plutons that range in composition from gabbro, diorite, quartz diorite, quartz monzonite, and monzonite to syenite and granite (Wynne-Edwards, 1962). Biotite, hornblende, and clinopyroxene are the dominant ferromagnesian constituents of the rocks. A typical feature of the larger plutons is a concordant to semiconcordant sheath of injection migmatite and granitic veins that intrude the older granulitic rocks. Because the plutons intrude the younger siliciclastic sequence, and as there is only one recognized metamorphism in that sequence, we infer that the metamorphism affecting the younger sequence and the overprinting metamorphism observed in the gneisses were caused mainly by cooling of the plutons.

The plutons range in age from 1179 to 1162 Ma (van Breemen and Davidson, 1988; Marcantonio et al., 1990; O. van Breemen, 1994, personal commun.). Nd model ages for rocks of the suite range between 1.34 and 1.48 Ga (Marcantonio et al., 1990), indicating that the rocks are most likely mixtures of 1170 Ma basalt and older continental crust. Also present within the gneisses is a suite of hypersthene-bearing plutons, only one of which is dated (Wallach, 1974), but its 1.25 Ga age may provide a maximum age for the granulite-facies metamorphism. It may also link the Frontenac terrane with the rest of the Central Metasedimentary belt, where magmatism of similar age dominates (Easton, 1992).

MARBLES: ROCKS OF THE FOOTWALL

The fourth dominant lithology of the region is marble. It is a regionally extensive unit and was likely deposited on a stable platform. The marble is a medium- to coarse-grained rock composed of calcite or dolomite with varying proportions of graphite, serpentine, and calc-silicate minerals that define a faint layering. Wynne-Edwards (1967) considered this layering as original bedding. Locally, the carbonates contain blocks and disrupted layers of rusty paragneiss comprising variable proportions of quartz, diopside, scapolite, phlogopite, potassium feldspar, graphite, sphene, and pyrite. The contact between marble and gneiss is marked by marble melange containing peculiar megaperthite blocks and locally pyroxenite and other crystalline blocks. Furthermore, a review of the geologic maps of the region cited previously reveals that the marble is in contact with virtually every other rock type known to be present in the area and that most contacts are truncated, in many places at high angle, by the marble contact.

The metamorphism of the marbles throughout the area was studied by Ewert (1977) and by Kornik (1986). Metamorphic lows with unreacted quartz + dolomite assemblages preserve sedimentary features, and the assemblage potassium feldspar + dolomite, in places with unequivocal textures indicating prograde reaction to the assemblage phlogopite + calcite (G. Skippen, 1994, personal commun.), occurs throughout the region. Such features document that the marbles are regionally at greenschist grade, they have undergone only one metamorphism, and it is prograde. The metamorphic grade increases progressively through diopside + quartz + calcite assemblages to forsterite-bearing assemblages adjacent to the gneiss-quartzite-pluton package. Where mapped in detail, the isograds parallel the contact and are folded by at least two sets of folds (Fig. 2C). Therefore, the isograds must dip in the same direction as the contact, and as the high-temperature side is toward the overlying gneisses, the isograds are hot-side up.

Although the gneiss and quartzite package is riddled with 1179–1162 Ma plutons, intrusions of this age apparently do not cut the marble succession (Fig. 2). In the few places where plutons of the suite abut marble melange ($\ll$5% of total), we could find no evidence such as dikes, sills, or chilled margins to indicate that the plutons are intrusive, although such relations are common where the plutons cut gneisses and also adjacent to a suite of 1080–1060 Ma plutons that intrude both marbles and gneisses. The 1179–1162 Ma plutons intrude the overlying gneisses; thus, how could so much magma have risen through the marbles and leave no trace? We suggest that it didn't.

INTERPRETATION

The metamorphic contrasts, the different metamorphic and plutonic histories, the truncation of contacts, and the marble melange indicate to us that, rather than being a normal stratigraphic contact, the top of the marble is a fault that places a wide variety of rocks above the main marble unit. Because higher-grade rocks are placed on top of lower-grade platformal marbles and because reclined folds, which are coaxial with earlier recumbent isoclines and are interpreted to be part of the same progressive deformation (Wynne-Edwards, 1967), verge northwest when viewed in sections perpendicular to the strike of the orogen (Easton and Davidson, 1994b), we interpret the contact as a northwest-directed thrust fault. Furthermore, we suggest that the hanging wall was hot because of the intrusion of the 1179–1162 Ma plutons when it was emplaced over the platformal carbonates; that is, metamorphism of the carbonates is dynamothermal metamorphism related to the emplacement of a hot allochthon. The distribution of sphene ages from marbles within the Frontenac terrane (Mezger et al., 1993) supports this interpretation because they range from 1178 to 1157 Ma, which overlaps the plutonic ages.

The age of movement on the proposed fault is tightly determined. It must be younger than the transported plutons, the youngest of which is 1162 ± 3 Ma (van Breemen and Davidson, 1988) and older than a set of northwest-striking diabase dikes, known as Kingston dikes, which cut the proposed thrust yet are unmetamorphosed (Easton and Davidson, 1994a). Several unpublished U-Pb baddleyite ages from the dikes are 1160 Ma (cited in Easton and Davidson, 1994a, p. 74–75) and establish that emplacement of the allochthon took place at ~1161 Ma.

BASEMENT TO THE MARBLES

Within the Frontenac terrane we know of no rocks that can be shown to lie stratigraphically beneath the marble; in fact, no crystalline basement is recognized anywhere within the Central Metasedimentary belt. To the southwest within the Adirondacks, a similar stratigraphic sequence has long been recognized, and the Gouverneur marble, with its tectonically overlying major gneiss unit (Foose and Brown, 1976), is likely correlative with marble in the Frontenac terrane, but again we know of no basement to the marble.

Some data on the basement to the marbles, and addional support for our hypothesis, come from a suite of 1080–1060 Ma plutons that clearly crosscut the thrust plane in the Frontenac terrane (Fig. 2) and presumably sample the basement beneath the carbonates. Nd model ages determined from some of these younger plutons by Marcantonio et al. (1990) cluster between 1239 and 1256 Ma, which is consistent with their generation by mixing of a juvenile component and older continental crust. We suggest that this may be >1400 Ma crystalline basement similar to that extensively exposed within the northwestern part of the Central Gneiss belt of Ontario (van Breemen et al., 1986; Easton, 1992).

SIGNIFICANCE OF THE THRUST AND REGIONAL IMPLICATIONS

In this contribution we propose a regionally extensive thrust fault that places hot, pluton-riddled metamorphic rocks over cool platformal carbonates. Similar relations are common to many orogenic belts where hot, arc-basement rocks or oceanic lithosphere of the upper plate are thrust over cold, passive-margin sedimentary rocks of the lower plate. Thus, we envision the thrust as part of the fundamental contact between upper and lower plates developed during collision.

If our interpretation is correct, then on the basis of comparison with the geology of the Adirondacks (McLelland and Isachsen, 1986), we suggest that part of the upper-plate hinterland involved in the collision lies in the Adirondacks, whereas the area of the Central Metasedimentary belt lying to the northwest of the Frontenac terrane contains mostly lower-plate basement and cover overridden by upper-plate rocks. We do not know the southeastern extent of basement to the marbles but isotopic studies of plutons younger than 1160 Ma should delineate it as long as it is not southeast of the Adirondacks.

Rocks of the upper plate may extend well to the northwest, primarily on the basis of recently acquired data from rocks of the Parry Island thrust sheet, located midway into the Central Gneiss belt (Fig. 1). The thrust sheet is composed of mostly upper amphibolite facies rocks with intrusions ranging in age from 1312 to 1163 Ma, slivers of marble melange, a quartzite containing detrital zircons with ages ranging from 1385 to 2675 Ma, shear-sense indicators and dated syntectonic pegmatites documenting northwest-directed thrusting at ~1160 Ma, and mafic dikes emplaced at ~1160 Ma (Wodicka, 1994; van Breemen et al., 1986). Overall, the similarities between rocks and events in the allochthon of the Frontenac terrane and their counterparts within the Parry Island thrust sheet are too numerous to be mere coincidence; therefore, we suggest that both packages are part of the same plate, which was thrust over the southwestern margin of Laurentia at ~1160 Ma.

This interpretation, if correct, raises the obvious question, What is the tectonic setting of rocks lying between Parry Island and the Frontenac terrane? The rocks between the two regions comprise extensive tracts of poorly dated gneiss of the southeastern Central Gneiss belt; platformal carbonates and metaevaporites of the Bancroft terrane, which are perhaps correlative with marbles of the Frontenac terrane; varied sequences of tholeiitic and calc-alkalic volcanic rocks, associated metasedimentary rocks; and a compositional spectrum of plutonic rocks of the Elzevir terrane (Easton, 1992). Ages for the volcanic rocks and the plutons are in the range 1300–1200 Ma, the same age as both the older plutons in the Parry Island thrust sheet and the hypersthene-bearing plutons in the allochthon. We hypothesize that the majority of rocks between the Bancroft and Frontenac terranes are also upper-plate rocks, but there the upper plate is dominated by remnants of the supracrustal part of the overriding magmatic-arc system or possibly an earlier arc accreted to the overriding plate prior to collision with Laurentia.

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