Crustal architecture and tectonic assembly of the Central Gneiss Belt, southwestern Grenville Province, Canada: a new interpretation[1]

J.W.F. Ketchum and A. Davidson

Abstract: The Central Gneiss Belt, southwestern Grenville Province, is characterized by parautochthonous crust in the north and allochthonous lithotectonic domains in the south. Despite nearly two decades of study, the basal décollement to allochthonous domains transported from the southeast, known as the allochthon boundary thrust, has not been precisely located throughout much of the belt. Between Lake Nipissing and Georgian Bay where its surface trace is known, it separates 1.24 Ga Sudbury metadiabase in the footwall from eclogite remnants and 1.17–1.15 Ga coronitic olivine metagabbro confined to its hanging wall. On the premise that this relationship can be used to trace the allochthon boundary thrust elsewhere in the Central Gneiss Belt, we have sought to extend the known distribution of these mafic rock types, making use of field, petrographic, and geochemical criteria to identify them. New occurrences of all three mafic types are identified in a region extending from south of Lake Nipissing to western Quebec, and the mutually exclusive pattern of occurrence is maintained within this region. Structural trends and reconnaissance mapping of high-strain zones that appear to represent a structural barrier to the mafic suites suggest that the allochthon boundary thrust lies well to the north of its previously suggested location. Our preferred surface trace for it passes around the southern end of the Powassan batholith and through the town of North Bay before turning east to join up with the Lac Watson shear zone in western Quebec. This suggests that a large segment of "parautochthonous" crust lying north of, and including, the Algonquin domain is in fact allochthonous. The mutually exclusive distribution of the mafic suites points to significant separation of allochthonous and parautochthonous components prior to the Grenvillian orogeny, in accord with models of pre-Grenvillian continental rifting proposed by others. Despite a relative abundance of geological and geochronological data for the Central Gneiss Belt and a mafic rock distribution that appears to successfully locate a major tectonic boundary, we emphasize the need for additional field and laboratory work aimed at testing our structural model.

Résumé : La Zone de gneiss centrale dans le sud-ouest de la Province de Grenville est caractérisée par une croûte parauthochtone dans le nord et par des domaines lithotectoniques allochtones dans le sud. Même après presque deux décennies d'études, le décollement basal des domaines allochtones transportés du sud-est, reconnu comme étant la limite de charriage des allochtones, n'a pas encore été localisé avec précision à travers la majeure partie de la Zone. On peut suivre sa trace en surface entre le lac Nipissing et la baie Georgienne, elle sépare la métadiabase de Sudbury âgée de 1,24 Ga dans la lèvre inférieure d'avec les vestiges d'éclogite et le métagabbro à olivine coronitique âgé de 1,17–1,15 Ga confinés à la lèvre supérieure. En supposant qu'on puisse utiliser cette relation pour tracer la limite de charriage des domaines allochtones ailleurs dans la Zone de gneiss centrale, nous avons cherché à extensionner la distribution qui était connue de ces types de roches mafiques, en utilisant comme guide d'identification les critères de terrain et les compositions pétrographique et géochimique. Ainsi, on a été capable d'identifier de nouvelles expositions de ces trois types de roches mafiques dans la région s'étendant du sud du lac Nipissing jusque dans l'Ouest du Québec, et la distribution exclusivement particulière des expositions est constante dans cette région. Les directions structurales et la carte de reconnaissance des zones de contraintes intenses qui semblent représenter une barrière structurale aux suites mafiques, suggèrent que la limite du charriage des domaines allochtones se trouve loin au nord de la localisation suggérée antérieurement. Notre préférence porte sur une trace en surface passant près de l'extrémité sud du batholite de Powassan et traversant la ville de North Bay avant de tourner vers l'est pour se fusionner avec la zone de cisaillement du lac Watson dans l'Ouest du Québec. Ce qui suggère que le grand segment de la croûte «parauthochtone» qui apparaît au nord du domaine Algonquin, incluant même celui-ci, aurait vraisemblablement une origine allochtone. La distribution essentiellement particulière des suites mafiques indique qu'il y a eu une séparation majeure des composantes allochtone et parauthochtone avant l'orogenèse du Grenville, en accord avec les modèles de rifting continental anté-grenvillien qui ont été proposés par d'autres auteurs. En dépit du nombre relativement important de données géologiques et

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géochronologiques pour la Zone de gneiss centrale, et de la distribution des roches mafiques qui semble localiser avec succès une limite tectonique majeure, il y a néanmoins nécessité d'effectuer des travaux supplémentaires sur le terrain et en laboratoire pour tester la validité de notre modèle structural.

[Traduit par la Rédaction]

Introduction

First-order tectonic belts, typically consisting of smaller, structurally bounded lithotectonic terranes with shared characteristics, form the largest building blocks in collisional orogens (e.g., Rivers et al. 1989). Recognition of the origin and geological history of these belts can provide considerable insight on the large-scale tectonic processes that shape collisional orogens. In deeply eroded orogens, first-order belts are generally difficult to identify, because of the absence of fossil evidence, and difficulties in identifying precursor lithologies and stratigraphy in crust that has undergone ductile deformation and high-grade metamorphism. However, where first-order belts can be outlined in the middle to lower orogenic crust, they are potentially useful for determining pre-orogenic crustal architecture, the large-scale tectonic response of the ductile crust to collision, and differences between upper and lower crustal processes during orogenesis.

The Grenville Province of the Canadian Shield is an example of a deeply eroded orogen with laterally continuous, first-order tectonic belts (Rivers et al. 1989). From orogenic front to orogenic interior, these authors recognized a Parautochthonous Belt (PB), an Allochthonous Polycyclic Belt (APB), and an Allochthonous Monocyclic Belt (AMB; Fig. 1, inset). The PB lies southeast of the Grenville Front (the northwestern limit of major Grenvillian deformation) and contains rocks that can be correlated with less deformed and metamorphosed precursors in the foreland. A history of both pre-Grenvillian and Grenvillian orogenesis is evident throughout much of the PB, distinguishing it as a polycyclic unit (Rivers et al. 1989). To the southeast, the APB consists of allochthonous[3] lithotectonic domains, many of which also display evidence of both pre-Grenvillian and Grenvillian orogenesis. Direct linkage of rock units in the APB with those in the parautochthon and foreland, however, is speculative at best. The APB is separated from the PB by a first-order tectonic boundary termed the allochthon boundary thrust (ABT) (Rivers et al. 1989), on which northwest-directed transport, where not proven, is generally inferred. Southeast of the APB, the AMB consists of two areally distinct regions dominated by supracrustal rocks that were first deformed during the ~1300–950 Ma Grenvillian orogeny (hence the monocyclic designation) and are in tectonic contact with the underlying APB.

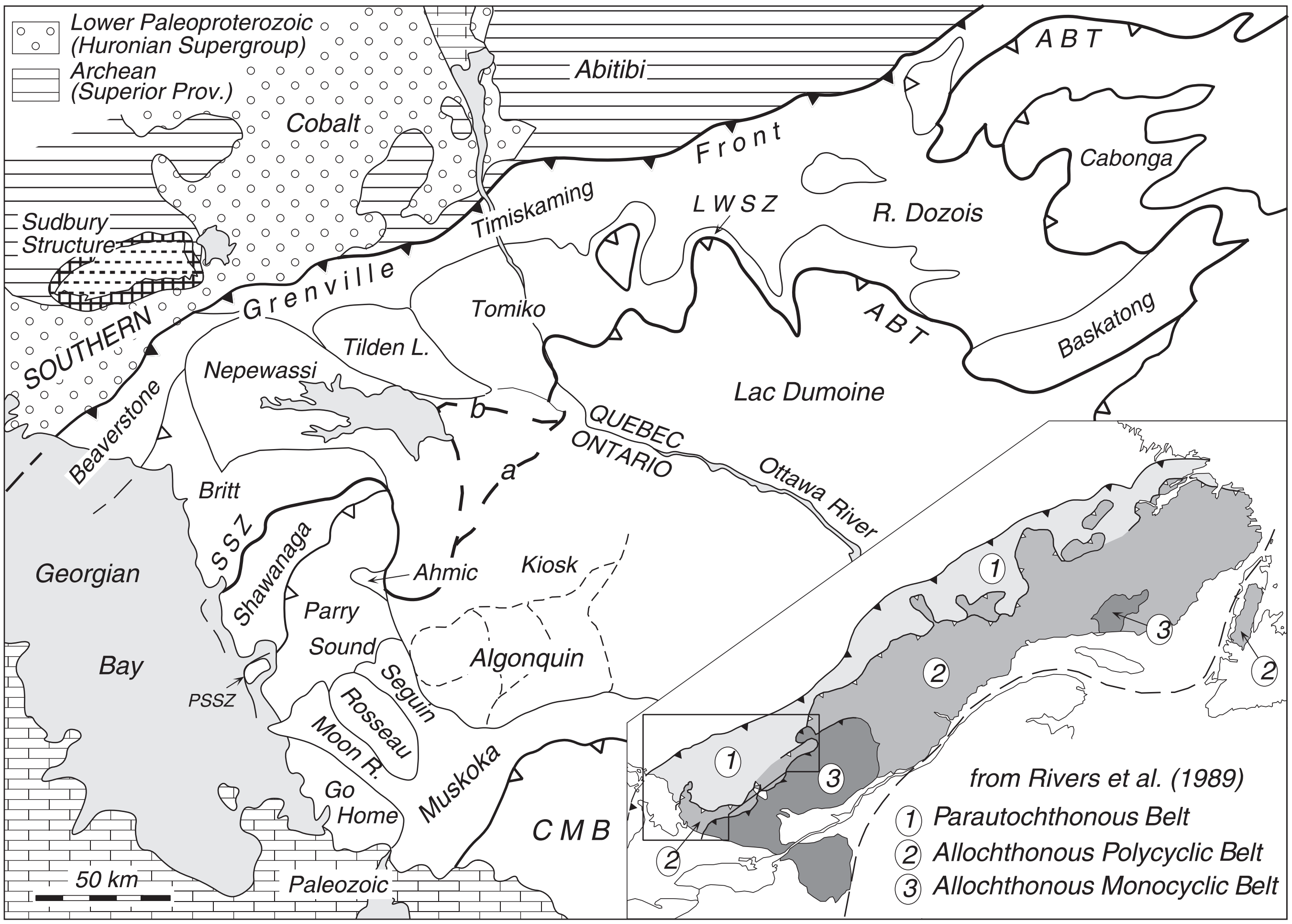
Rivers et al. (1989) suggested that future work might result in modifications to the location and extent of these first-order belts, and this has indeed been the case in some regions. For example, in central Ontario, detailed work (Culshaw et al. 1988, 1989, 1994, 1997; Jamieson et al. 1992; Ketchum 1994) has shown that the westernmost extent of the ABT coincides with the Shawanaga shear zone (formerly the Central Britt shear zone; Davidson 1991; Culshaw et al. 1994) and not with the Parry Sound shear zone as originally proposed (Fig. 1). Although this does not radically alter the position of the ABT in this region, it does provide a new framework for evaluating the position of this boundary elsewhere in Ontario and western Quebec, where its original placement (Fig. 1, inset) was regarded as tentative (Rivers et al. 1989). The purpose of this paper is to use this framework to propose a new location for the ABT in parts of Ontario and western Quebec. Our modification of the Rivers et al. model leads to a reinterpreted crustal architecture for the PB and APB (collectively making up the Central Gneiss Belt of Wynne-Edwards 1972) which has important implications for Grenvillian tectonic models. We expand on the crustal model proposed by Culshaw et al. (1997) by extending it eastward from Georgian Bay and incorporate data from western Quebec (e.g., Kellett et al. 1994; Currie and van Breemen 1996; Indares and Dunning 1997) where the ABT is situated closer to the orogen boundary (Fig. 1). Debates on Grenvillian orogenic history in the western Central Gneiss Belt are currently hampered by uncertainty over the position of the ABT and emphasize the need to locate this boundary more accurately.

The Central Gneiss Belt

The Central Gneiss Belt underlies a significant portion of the Grenville Province in Ontario and western Quebec (Fig. 1). It lies structurally above northeast-striking gneisses of the Grenville Front tectonic zone (Fig. 2) and is structurally overlain by Grenville Supergroup rocks and high-grade gneisses of the Central Metasedimentary Belt and Central Granulite Terrane, respectively (Wynne-Edwards 1972). Although much of the Central Gneiss Belt is composed of gently dipping, upper-amphibolite- and granulite-facies orthogneiss, units of unambiguous supracrustal origin are also present. Igneous protoliths within the Central Gneiss Belt range from ~2680 Ma trondhjemitic gneiss near the Grenville Front tectonic zone (Chen et al. 1995) to late-tectonic, ~990 Ma pegmatite dykes found in a number of locations (e.g., Corrigan et al. 1994; Chen et al. 1995; Ketchum et al. 1998). However, much of the Central Gneiss Belt was formed during two major magmatic episodes at 1750–1600 and 1470–1340 Ma. Plutonic units intruded dur-

[3] Following Rivers et al. (1989) and Culshaw et al. (1997), the term allochthonous is used here to describe a crustal unit that has undergone significant tectonic transport, without reference to the source or parentage of this unit. This usage contrasts with that of some Grenville workers (e.g., Corrigan and van Breemen 1997; Indares and Dunning 1997) who consider only those transported elements which were not originally part of pre-Grenvillian Laurentia to be allochthonous. Although both definitions are acceptable, we suggest that allochthonous is best employed in a nongenetic sense in the Grenville Province (similar to the common usage of "terrane" in Grenville literature; e.g., Davidson 1995), and should serve to highlight differences in *Grenvillian* tectonic, metamorphic, and plutonic characteristics between crustal units.

Fig. 1. Lithotectonic subdivision of the Central Gneiss Belt, Grenville Province of Ontario and western Quebec, compiled from Davidson (1986), Easton (1988), Rivers et al. (1989), Ketchum (1994), and Martignole and Calvert (1996). ABT, allochthon boundary thrust; CMB, Central Metasedimentary Belt; LWSZ, Lac Watson shear zone; SSZ, Shawanaga shear zone; PSSZ, Parry Sound shear zone. The positions of ABT represented by broken lines north of Algonquin domain correspond to that of Davidson (1996) (segment *a*) and the position proposed here (segment *b*). The inset shows the major belts of the Grenville Province; note the more southeasterly position of the allochthon boundary thrust (between 1 and 2) originally assigned by Rivers et al. (1989) than in the main figure.

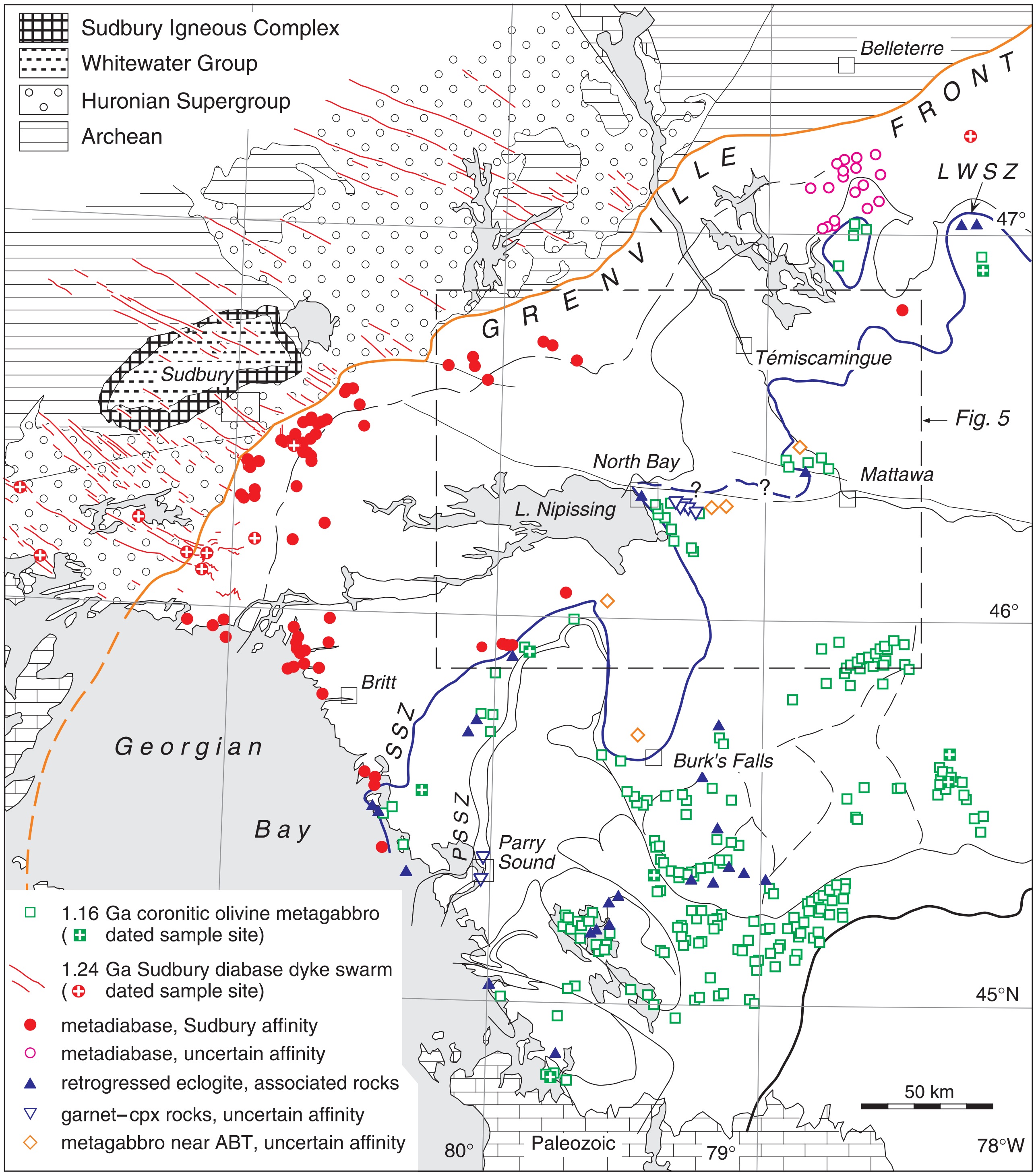


ing the Grenvillian orogeny constitute only a small percentage of exposed crust.

The tectonic evolution of Central Gneiss Belt is generally described in terms of northwest-directed thrust emplacement of discrete lithotectonic domains on laterally continuous gneissic tectonite zones (e.g., Davidson and Morgan 1981; Davidson et al. 1982; Culshaw et al. 1983; Davidson 1984). The lithotectonic domains are characterized by distinctive combinations of lithological, structural, metamorphic, and in some cases geophysical properties, and the gneissic tectonite zones are interpreted by most workers as deep-seated Grenvillian shear zones. Reconnaissance mapping by Davidson et al. (1982), Culshaw et al. (1983), and Davidson (1984) forms the basis for the current lithotectonic subdivision of the Central Gneiss Belt (Fig. 1). Rivers et al. (1989) incorporated these findings into their tectonic model by assigning structurally lowest domains of the Central Gneiss Belt (level 1 of Culshaw et al. 1983) to the PB and structurally higher domains to the APB (Fig. 1, inset).

Two contrasting views of the tectonothermal evolution of the Central Gneiss Belt have recently been proposed, based mainly on the findings of detailed, field-based studies. In the Huntsville area, Nadeau and Hanmer (1992) used structural relationships to document a break-back (i.e., out of sequence) thrust assembly of Seguin subdomain and underlying subdomains of the Algonquin domain (Fig. 1). Based on existing structural and U–Pb age data, these authors also suggested that break-back thrusting occurred on a regional scale during Grenvillian tectonic assembly. Nadeau and Hanmer attributed apparent slow orogenic cooling of the Central Gneiss Belt to an extended period of regional break-back thrusting that slowed the rates of exhumation and cooling due to thrust loading at higher levels. In contrast, field and geochronological data from Georgian Bay (e.g., Jamieson et al. 1992; Wodicka et al. 1996; Culshaw et al. 1997) have indicated a dominantly forward propagating, piggyback thrust sequence during regional tectonic assembly, with metamorphic assemblages and tectonic fabrics in some domains being transported on younger, coplanar structures. An important finding of this work is that the absolute ages of metamorphic and structural events, mainly determined by U–Pb geochronology, in some cases date events that did not

Fig. 2. Distribution of 1.24 Ga Sudbury diabase and metadiabase, ~1.17–1.15 Ga coronitic olivine metagabbro, and eclogitic rocks in the Central Gneiss Belt, Ontario and westernmost Quebec. The broken line near the Grenville Front is the southeast margin of the Grenville Front tectonic zone (Wynne-Edwards 1972). Domain outlines as in Fig. 1. Area of Fig. 5 is shown by broken-line box.



occur in situ. Although these findings question the validity of out-of-sequence thrusting on a regional scale, they do not address the break-back thrust sequence documented in the Huntsville area by Nadeau and Hanmer (1992). Workers are therefore faced with two major questions stemming from these contrasting views of Central Gneiss Belt orogenesis: (*i*) why is there an apparent contrast in structural style in adjacent regions; and (*ii*) what is the relationship between Grenvillian tectonic stacking and thermal relaxation?

Below we attempt to provide insight on these questions by proposing a tentative new location for the ABT in Ontario and western Quebec. Our crustal model for the Central Gneiss Belt suggests that the tectonothermal evolution of the Huntsville and Georgian Bay areas cannot be directly compared because these regions are underlain by unique combinations of crustal slices, each possessing its own distinctive tectonothermal history.

Position of the allochthon boundary thrust (ABT)

The position of the ABT is relatively well established in two regions of the western Central Gneiss Belt. In central Ontario, the ABT is marked by the Shawanaga shear zone, a ductile tectonite zone separating the Britt and Shawanaga domains that extends northeast from Georgian Bay toward Lake Nipissing (Figs. 1, 2). Kinematic indicators along this boundary near Georgian Bay consistently infer top-side-southeast normal displacement, but the shear zone originated as a northwest-directed thrust décollement that transported overlying allochthonous domains (Jamieson et al. 1992; Culshaw et al. 1994, 1997).

In westernmost Quebec, Kellett et al. (1994) identified an aeromagnetically distinct boundary between regionally extensive quartzofeldspathic gneiss and overlying paragneiss in the northern Grenville Province as the likely position of the ABT. In the same region, Davidson (1995, 1996) and (although not explicitly stated) Indares and Dunning (1997) placed it at a higher structural position coinciding with the Lac Watson shear zone, across which granulite-facies gneisses structurally overlie amphibolite-facies granitoid rocks and paragneiss.

The position of the ABT between these distant locations (Fig. 1) has not been firmly established. Rivers et al. (1989) originally placed the boundary along the southern and eastern margins of Algonquin domain, but more recently Ketchum (1994), Davidson (1995), and Culshaw et al. (1997) have postulated more northerly locations. Ketchum regarded the observed distribution of three distinctive mafic rock suites across the Shawanaga shear zone to be potentially significant in tracing the ABT. The restriction of (*i*) coronitic olivine metadiabase derived from the 1.24 Ga Sudbury dyke swarm to the Shawanaga shear zone footwall, and (*ii*) regionally extensive, 1.17–1.15 Ga coronitic olivine metagabbro, and retrogressed eclogite associated with metamorphosed anorthositic and ultramafic rocks to its hanging wall, led to the suggestion (Ketchum 1994) that these suites could be used as tectonic discriminators to trace the ABT elsewhere in Ontario. In this regard, the known distribution of 1.17–1.15 Ga coronitic metagabbro bodies in the Algonquin domain (Fig. 2) (Davidson and Grant 1986; Grant 1987) would indicate that this boundary lies to the west and north of its original placement. This implies that the Algonquin domain may be entirely allochthonous.

To investigate the hypothesis that the ABT can be traced using the distribution of the three mafic suites outlined above, we conducted reconnaissance fieldwork and sampled mafic plutonic bodies within a broad region centred on the town of North Bay, Ontario (Fig. 2). Our goals were to (*i*) identify and extend the known occurrences of the three mafic rock suites and confirm their identity using petrographic and (or) geochemical criteria, (*ii*) determine whether their spatial distribution conforms to the pattern observed across the Shawanaga shear zone, and, if so, (*iii*) identify high-strain zones between the mutually exclusive suites which could potentially mark the position of the ABT. As outlined below, identification of all three suites among both previously mapped and newly found bodies significantly extends the known distribution of these mafic rock types.

Identification and previously established distribution of the three mafic rock suites

Sudbury diabase and metadiabase

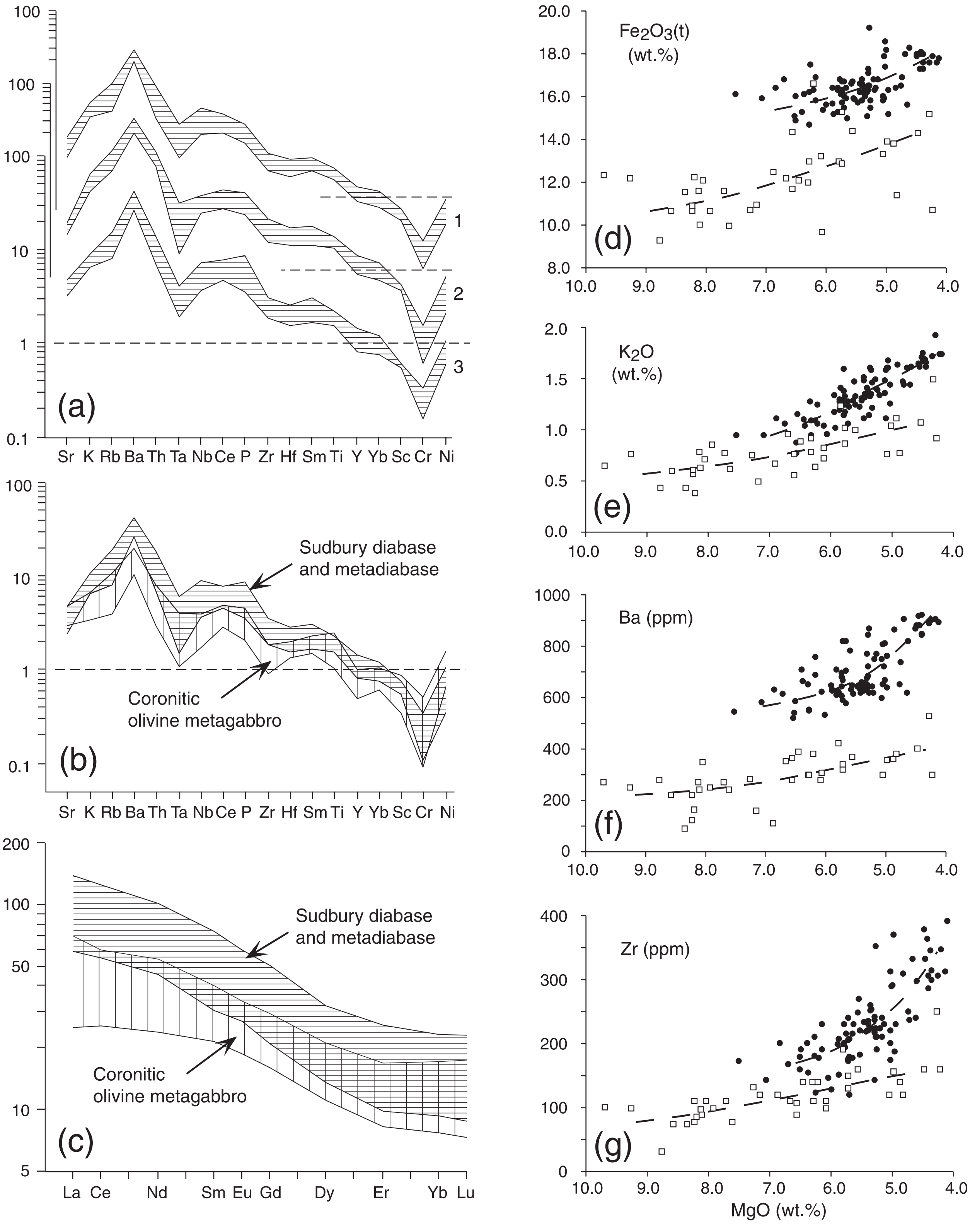
Dykes of the Sudbury swarm in the Southern and Superior province foreland of the Grenville orogen strike southeastward, orthogonally to the Grenville Front (Fig. 2). They are composed of fresh, medium- to fine-grained olivine diabase, and some carry large xenocrysts of plagioclase near their margins. Sudbury diabase has a distinctly alkaline chemistry, characterized in particular by relative enrichment in Fe, K, P, Zr, Ba, and light rare earth elements (LREE), and impoverishment in Mg, Ni, and Cr with respect to most other dyke swarms in the Canadian Shield (Fahrig et al. 1965; Condie et al. 1987). The dykes were intruded over a short period at ~1.24 Ga (Krogh et al. 1987; Dudás et al. 1994).

In the Grenville Province, folded dykes of olivine metadiabase within a few kilometres of the Grenville Front between Sudbury and Georgian Bay (Fig. 2) are confidently correlated with the Sudbury swarm on the basis of chemistry (Fig. 3*a*) and age (Palmer et al. 1977; Bethune and Davidson 1988, 1997; Bethune 1993, 1997; Dudás et al. 1994). Progressive Grenvillian metamorphism (~1.00 Ga; Dudás et al. 1994) has produced typical two-pyroxene–garnet coronas between olivine and plagioclase, and biotite–amphibole–garnet coronas between Fe–Ti oxide and plagioclase within 3 km of the Grenville Front; primary plagioclase laths characteristically are intensely clouded with submicroscopic spinel. East and northeast of Sudbury (Davidson and Ketchum 1993; Davidson 1998), and also in northern Britt domain farther from the Grenville Front (Davidson and Bethune 1988), undeformed coronitic metadiabase in the resistant cores of marginally amphibolitized pods and discontinuous dyke segments has the same chemical signature as Sudbury diabase (Fig. 3*a*) and, like Sudbury diabase, commonly carries large plagioclase xenocrysts. Along the coast of Georgian Bay, examples of this type of occurrence are known as far south as the Shawanaga shear zone, where they lie in its immediate footwall but have not been identified anywhere in its hanging wall (Fig. 2).

Coronitic olivine metagabbro

Generally equant masses of coronitic olivine metagabbro, ranging in diameter from a few metres to one kilometre, are common south and east of the Shawanaga shear zone (e.g., Fig. 88.3 of Davidson and Grant 1986) and are present in the immediate hanging wall of this zone (Fig. 2). Massive, coarse-grained to very coarse grained olivine metagabbro with minimally developed corona texture is preserved in the cores of many of the larger bodies, some of which are internally layered. Coronite in such occurrences, like Sudbury metadiabase, contains original olivine, augite, plagioclase, and Fe–Ti oxide and lacks primary orthopyroxene. Unlike Sudbury metadiabase, however, it does not carry plagioclase xenocrysts and is typically much coarser grained. All stages of recrystallization to amphibolite or two-pyroxene–garnet

Fig. 3. (*a*) Rock/mid-ocean-ridge basalt (MORB) spidergrams (Pearce 1983) comparing (1) Sudbury diabase northwest of the Grenville Front; (2) Sudbury metadiabase, Grenville Front tectonic zone south of Sudbury; and (3) metadiabase, Grenville Province east of Sudbury and Britt domain. Ranges are ±1σ of the mean of 56, 42, and 38 analyses, respectively. (*b*) Rock/MORB spidergrams comparing Sudbury diabase and metadiabase, and ~1.16 Ga coronitic olivine metagabbro from the Central Gneiss Belt; the extent of overlap is shown where the two patterns coincide. Ranges are ±1σ of the mean of 136 and 37 analyses, respectively. (*c*) Rare earth element profiles (Nakamura 1974) comparing Sudbury diabase and metadiabase and coronitic olivine metagabbro. Ranges are maximum and minimum values from 75 and 13 analyses, respectively. (*d–g*) Total Fe (as Fe_2O_3), K_2O, Ba, and Zr contents plotted against MgO serve to distinguish Sudbury diabase (solid circles) from coronitic olivine metagabbro (open squares).



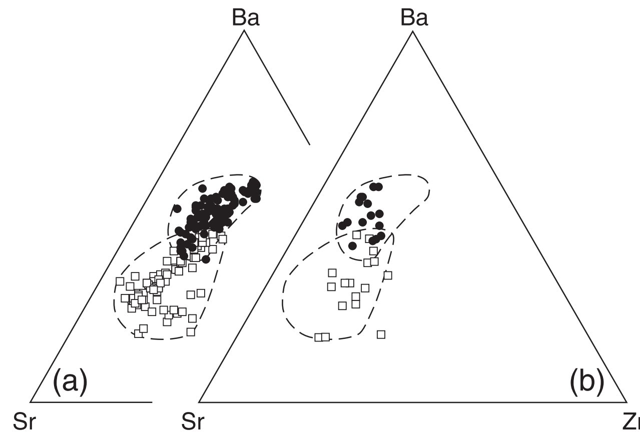
granulite, either massive or foliated, have been observed. Contact relationships with enclosing gneiss or granulite are for the most part tectonic. In a few places, however, fine-grained metagabbro is present at contacts which cut across older layering and leucosomes in the adjacent country rocks; such primary intrusive relationships are limited to one side or opposing sides of bodies whose contacts are otherwise tectonic, and appear to be preserved in large-scale strain shadows.

Coronitic olivine metagabbro from well-preserved cores has been dated at 1.17 and 1.15 Ga in several widely separated localities (Fig. 2) (Davidson and van Breemen 1988; van Breemen and Davidson 1990; Heaman and LeCheminant 1993). Whole rock chemistry (Grant 1987) of least-altered coronite (i.e., preserving relict primary olivine) varies more widely than that of Sudbury diabase and metadiabase, but overall it tends to be more "primitive," with higher Mg/(Mg + Fe), higher contents of Ca, Al, Cr, and Ni, and lower contents of Fe, alkalis, LREE, and notably Ba and Zr. These chemical characteristics can be used to distinguish the two types of coronite (Figs. 3*b*–3*g*). Bodies of coronitic olivine metagabbro are locally concentrated in clusters, implying that they are tectonically detached fragments of formerly larger intrusions. This interpretation is borne out by the fact that individual bodies in any one cluster have similar chemistry, whereas the average chemistry of different clusters may be quite distinct. Even where relatively enriched in Fe, K, Ti, and Zr, however, 1.17–1.15 Ga coronitic olivine metagabbro (referred to as Algonquin metagabbro throughout the rest of this paper; Rivers 1997) does not acquire the high level of Ba and LREE attained by Sudbury diabase. It is thus reasonable to use whole-rock chemistry, along with the physical attributes of grain size and presence or absence of plagioclase xenocrysts, to distinguish 1.24 Ga Sudbury metadiabase from Algonquin metagabbro for the vast majority of coronite occurrences that have not been dated.

Retrogressed eclogite and associated rocks

Rocks composed predominantly of garnet and clinopyroxene, having the appearance of eclogite, occur either as isolated pods and lenses or as a component of larger, variably deformed basic complexes that may include both ultramafic and anorthositic rocks. Both modes of occurrence are typically associated with highly strained quartzofeldspathic host rocks marking the structural boundaries between lithotectonic domains (Fig. 2). Unlike either Sudbury metadiabase or Algonquin metagabbro, relict primary plagioclase is rarely present in these eclogite-like rocks and is entirely absent in associated and more common garnet-studded amphibolite. Despite the fact that the clinopyroxene in these rocks is not omphacitic, it is usually intimately intergrown with sodic plagioclase in the form of fine, feathery symplectite (Davidson 1990, 1991), known elsewhere to be the breakdown product of omphacite (e.g., Dunn and Medaris 1988). In addition, some garnet–clinopyroxene rocks contain aggregates of fine-grained corundum, spinel, and sapphirine which locally enclose cores of embayed kyanite. Both these features attest to the rocks having once attained eclogite facies. Pods of retrogressed eclogite are present locally throughout much of the Central Gneiss Belt southeast of the Shawanaga shear zone, including in its immediate hanging wall (Needham 1992), but have yet to be identified structurally beneath it.

Fig. 4. Ba–Sr–Zr plot comparing (*a*) Sudbury diabase northwest of the Grenville Front and metadiabase in the Grenville Front tectonic zone (solid circles) and coronitic olivine metagabbro in the Central Gneiss Belt (open squares), and (*b*) coronitic metadiabase and metagabbro sampled during this study to the northwest (solid circles) and southeast (open squares) of the suggested trace of the allochthon boundary thrust between Georgian Bay and Lake Kipawa.

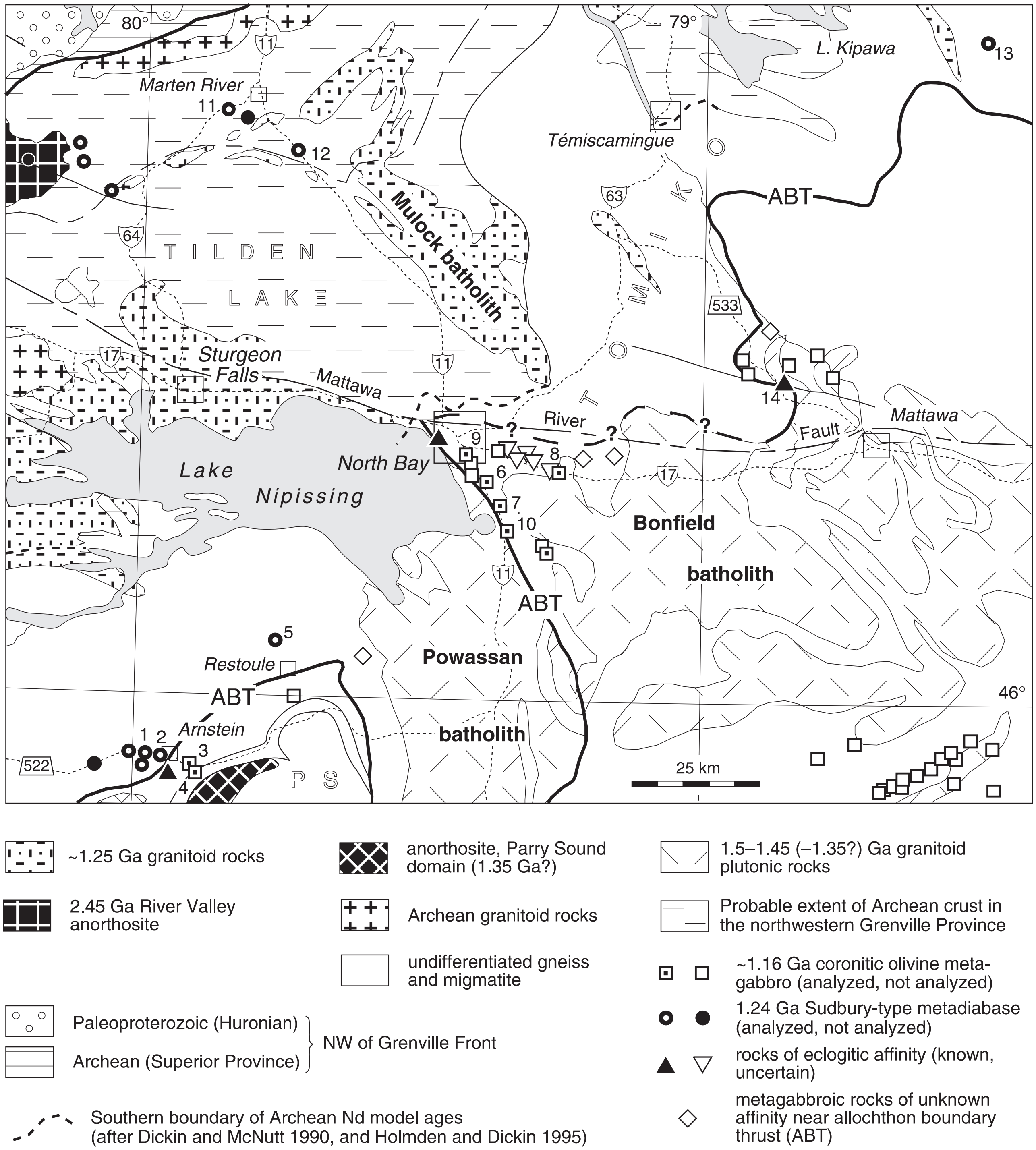


Two eclogitic bodies from the Central Gneiss Belt have well-constrained ages of ~1.4 Ga for primary crystallization of their gabbroic protoliths, with a third yielding an older protolith age of 1.47 Ga (U–Pb zircon; Indares and Dunning 1997; Ketchum and Krogh 1997, 1998). The complete age range for primary crystallization of these rocks is currently unknown. Close spatial association with Algonquin metagabbro, which lacks obvious mineralogical evidence of high-pressure metamorphism, suggests that eclogite-facies metamorphism occurred before 1.17 Ga (e.g., Davidson 1991). However, Ketchum and Krogh (1997, 1998) report U–Pb ages of ~1.09 Ga for secondary zircon growth in several eclogitic bodies which they link to this high-pressure event. This discrepancy is currently the subject of ongoing study. Judging by the fact that the olivine metagabbro was subjected to high-grade metamorphism at ~1.05 Ga (Davidson and van Breemen 1988; Heaman and LeCheminant 1993), it is not surprising that former eclogite-facies assemblages have been thoroughly retrograded.

New mafic rock occurrences and postulated position of the allochthon boundary thrust

In extending the known distribution of the three mafic suites, we used published geological maps of the Lake Nipissing – western Quebec region (Lumbers 1971*a*, 1971*b*, 1971*c*, 1973, 1976; Card and Lumbers 1977; Avramtchev and Lebel-Drolet 1980) to locate mafic rock occurrences. Many of these have physical and chemical attributes that allow them to be confidently assigned to one of the three mafic suites outlined above. For example, Ba–Sr–Zr ratios of Sudbury-type metadiabase and coronitic olivine metagabbro collected in the North Bay area lie in the same fields as

Fig. 5. Schematic geology of the area centred on North Bay, Ontario, showing locations of metamorphosed mafic igneous rocks and the suggested trace of the allochthon boundary thrust (ABT) between its known position in the Lake Kipawa area and the Shawanaga shear zone (see Fig. 1). Numbers identify localities of analyzed samples whose rare earth element profiles are given in Fig. 6. PS, Parry Sound domain.



Sudbury diabase northwest of the Grenville Front and Algonquin metagabbro, respectively (Fig. 4).

Based on the findings of our mafic rock study, evaluation of mapped regional structural trends and aeromagnetic data (Gupta 1991), and reconnaissance mapping of high-strain zones, we outline in the following sections a tentative new location for the ABT in the western Central Gneiss Belt (Figs. 2, 5).

South of Lake Nipissing

The northeastern segment of the Shawanaga shear zone is placed along a southeasterly dipping high-strain zone passing through the village of Arnstein (Davidson et al. 1982) (Fig. 5), just south of which retrograded eclogite with relict kyanite (Fig. 7*b* of Davidson 1991) occurs as isolated pods in straight gneiss. Fine-grained coronitic metadiabase along Highway 522 west of Arnstein has the chemical attributes of Sudbury diabase (Fig. 6, samples 1 and 2; locations are shown in Fig. 5), whereas coarse-grained coronitic metagabbro east of Arnstein does not (Fig. 6, samples 3 and 4), and at one locality has been dated at ~1170 Ma (van Breemen and Davidson 1990).

Five kilometres northwest of Restoule (Fig. 5), a single occurrence of fine-grained metadiabase with black plagioclase xenocrysts has Sudbury chemistry (Fig. 6, sample 5), whereas coarse-grained coronitic metagabbro (not analyzed) is present 4 km south-southeast of Restoule. A zone of augen mylonite and straight gneiss lies between these two occurrences, but to the east is folded and cannot be traced northeast toward Lake Nipissing. Rather, it appears to turn south, passing west of the Powassan batholith, and then east around its southern margin (Figs. 2, 5). This potential extension of the Shawanaga shear zone and ABT has not yet been traced out. However, coronitic olivine metagabbro pods are distributed within straight gneiss near the south end of this batholith, and both coronite and retrogressed eclogite have been identified east of this location at higher structural levels (Fig. 2). Mafic bodies examined within the deformed Powassan batholith have none of the physical attributes of either Sudbury metadiabase or Algonquin metagabbro, being predominantly massive or foliated amphibolite.

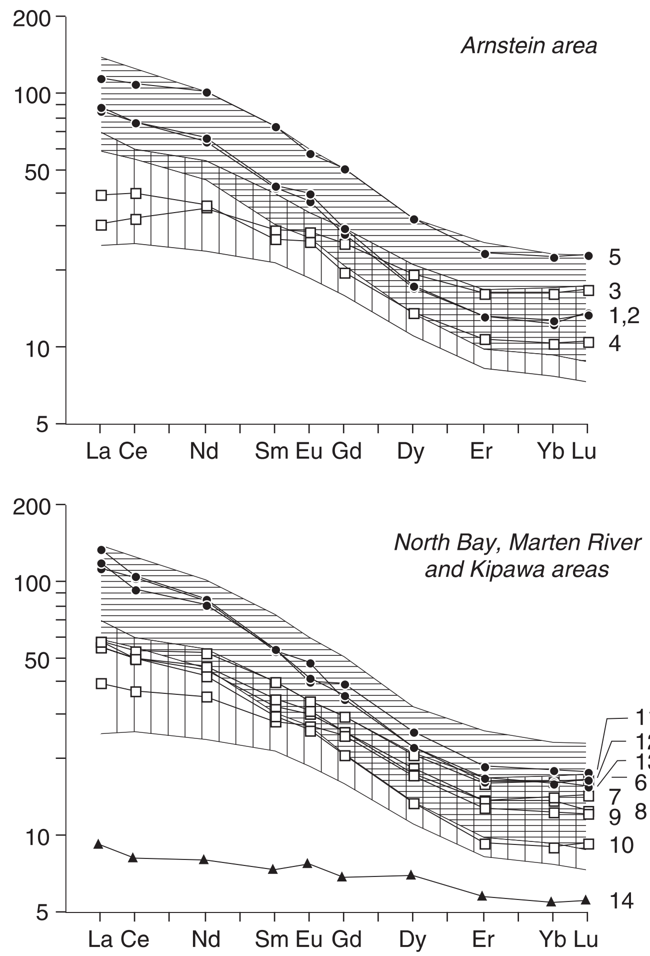
We speculate on the basis of mafic rock distribution and mapped structural trends in this region (Davidson et al. 1982; Culshaw et al. 1983; Davidson and Grant 1986) that the ABT wraps around the southern end of the Powassan batholith and then turns northward to parallel its eastern margin. The poorly exposed eastern margin coincides with a prominent aeromagnetic low (vertical magnetic gradient map of Ontario; Gupta 1991) which extends from the southern tip of the batholith to North Bay. This aeromagnetic anomaly, which is similar to those observed for other shear zones in the Central Gneiss Belt, could alternatively mark a distinctive paragneiss unit bordering the southeastern margin of the batholith (Davidson and Grant 1986), but given the regional continuity of the aeromagnetic low, we consider this option to be less likely.

If the ABT lies within the east-striking zone of straight gneiss wrapping the south end of the Powassan batholith, its presence may account for a 0.24 Ga difference in Nd model age for two gneiss samples collected in this region. A sample from near the town of Burk's Falls (Fig. 2) has a model age of 1.90 Ga, whereas one from 10 km to the south yields a model age of 1.66 Ga (Dickin and McNutt 1990).

North Bay area

At the east end of Lake Nipissing (Fig. 5), the eastern contact of the Powassan batholith is marked by a south-southeast-striking, near-vertical zone of highly strained gneiss with a gently south-plunging stretching lineation. Asymmetric feldspar porphyroclasts suggesting dextral shear are observed in at least one location within this zone. Immediately to the east along Highway 11, several large masses of coarse coronite and derived amphibolite are exposed in road

Fig. 6. Comparison of rare earth element profiles of Sudbury metadiabase and coronitic olivine metagabbro sampled closest to the suggested trace of the allochthon boundary thrust between Georgian Bay and Lake Kipawa. Numbers correspond to sample locations given in Fig. 5. Ranges from Fig. 3*c* are shown for reference.



cuts. Similar occurrences are present to the southeast and along Highway 17 east of North Bay (Fig. 5). Analyses of samples from five localities in this cluster are all typical of Algonquin metagabbro (Fig. 6, samples 6–10). Mafic rock occurrences (not shown in Fig. 5) examined in several localities west of the high-strain zone mainly consist of foliated and (or) migmatitic garnet amphibolite.

The high-strain zone passes northwestward through North Bay, close to the shore of Lake Nipissing. It is well exposed at the western city limit (Highway 17B) where straight and porphyroclastic gneiss encloses small pods of garnet–clinopyroxene rock resembling eclogite. This steep zone does not continue north of the Mattawa River Fault (Lumbers 1971*a*) (Fig. 5), a major east-striking brittle structure marking the edge of the Neoproterozoic graben in which Lake Nipissing lies. However, if shallowly south-dipping straight gneisses with extensional kinematics exposed along Highway 11 immediately north of this fault are part of the same zone, then the shear zone turns abruptly eastward in this area. It is noteworthy that normal displacement on this tectonite zone is kinematically consistent with the dextral shear sense noted for the subvertical high-strain zone to the south. It is perhaps also significant that the shallowly dipping straight gneiss includes a unit of highly attenuated and recrystallized anorthosite, an association common to many shear zones within allochthonous terranes of the Central Gneiss Belt in Ontario.

Garnet–clinopyroxene rocks are also present as pods and discontinuous layers within chaotically folded, but generally south-dipping straight and mylonitic gneiss near Highway 17 east of North Bay (Fig. 5). Associated with garnet amphibolite and with metagabbro which locally retains relict primary texture, these occurrences were originally mapped as gneiss derived from calcareous sedimentary rocks (unit 5 of Lumbers 1971*a*). However, thin sections show that, other than clinopyroxene, these rocks lack minerals such as scapolite, clinozoisite, and titanite which are characteristic of calcareous metasedimentary gneiss in this region. Preliminary microprobe analyses show that the clinopyroxene is aluminous (~5 wt.%) and somewhat sodic (~1.7 wt.%) and that the garnet (~$Grs_{26}Pyr_{23}Alm_{51}$) and plagioclase (~An_{25}) are no more Ca rich than commonly found in high-grade metagabbroic rocks. Although these rocks resemble eclogite, they do not contain omphacitic pyroxene. That they constitute retrogressed eclogite is suggested by symplectitic clinopyroxene-sodic plagioclase intergrowths in several occurrences. Their highly strained host rocks may potentially link with the straight gneiss zone with extensional kinematic indicators north of North Bay (Fig. 5), an association that Easton (1992) appears to have made also (i.e., the southeastern structural boundary of his Tilden Lake domain) (see Fig. 1). Whether these tectonites coincide with the location of the ABT is currently not known, but the retrogressed eclogite – gneissic tectonite association with structurally overlying Algonquin metagabbro is reminiscent of the situation south of North Bay (Fig. 5). Sudbury metadiabase has not been documented nearby, limiting the usefulness of the metabasites for more precise location of the ABT in this region.

The postulated position of the ABT at North Bay lies immediately south of a Nd model age (T_{DM}) boundary identified by Holmden and Dickin (1995) (Fig. 5). An average T_{DM} of 2.69 ± 0.03 Ga was obtained for seven samples north of the model age boundary, whereas a 1.84 ± 0.12 Ga average model age was obtained from 20 samples to the south. These authors, and Easton (1992, p. 759), suggested that the model age break coincides with the edge of a Proterozoic allochthon (Tomiko domain) that was thrust northward onto Archean crust during the Grenvillian orogeny or an earlier event. However, we note that a structural control on Nd model age variations generally cannot be presumed without substantiating field evidence. At North Bay, identification of a south-dipping gneissic tectonite zone with anorthosite slivers near the position of this model age boundary may constitute the necessary evidence. We have not examined rocks along the model age boundary between North Bay and the Mulock granitic orthogneiss batholith (1244 Ma; Lumbers et al. 1991) (Fig. 5), but its position appears to coincide with both a lithological boundary between Archean and Proterozoic paragneiss and a structural boundary between orthogonal foliation trends (Lumbers 1971*a*). Although our data do not specifically address the nature of Tomiko domain, the presence of Sudbury-type metadiabase within the equivalent structural level in neighbouring Quebec (Fig. 5, sample 13) argues against placement of the ABT at the base of this domain.

Marten River area

The region north and west of North Bay is underlain by gneissic rocks that include those with Archean protoliths (Chen et al. 1995) (Fig. 5). Several mafic rock occurrences near and west of Marten River have both the physical and chemical attributes of Sudbury diabase (Fig. 6, samples 11 and 12). One occurrence that does not is composed of coarse noritic metagabbro that is cryptically layered. Another is a disrupted dyke with white plagioclase phenocrysts in an amphibolitic matrix; it has the chemistry of quartz tholeiite and may represent a deformed and metamorphosed dyke derived from the Early Paleoproterozoic Matachewan swarm in the neighbouring Superior Province. All other examined occurrences (not shown in Fig. 5) are nondescript amphibolite. The occurrences of Sudbury metadiabase near Marten River, although demonstrating the presence of this dyke swarm many kilometres southeast of the Grenville Front, are too far from the coronite masses near North Bay to be of much help in precisely locating the ABT.

Northwest of Mattawa

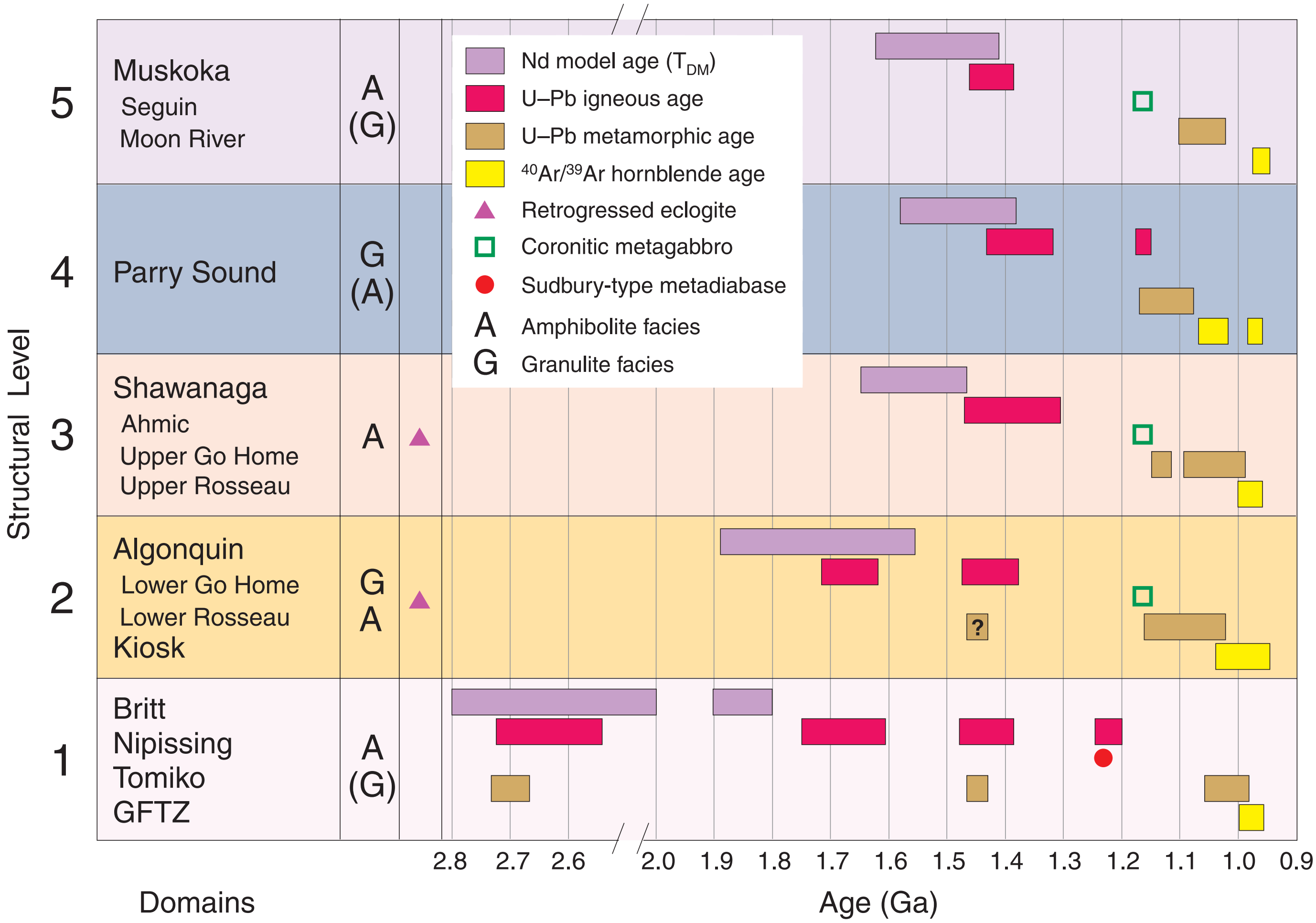
Most of Tomiko domain between North Bay and Témiscamingue is underlain by Proterozoic metasedimentary gneiss which extends into Quebec south of reworked Archean rocks of the Grenville Front tectonic zone (Fig. 5). The supracrustal package and the Mulock batholith to the west are both indicated (Lumbers 1971*a*; Card and Lumbers 1977) and observed by us to be largely devoid of mafic rock occurrences. Northwest of Mattawa, however, gneisses mapped as part of a metaplutonic complex (units 9 and 11 of Lumbers 1976) contain several small bodies of metagabbro. Photomicrographs in Moore (1976) allow some of these to be confidently assigned to the ~1.16 Ga coronitic metagabbro suite, and one body examined during our reconnaissance is a "classic" coronite with centimetric grain size. Another, mapped by Moore (1976) as an ultramafic body, is a lenticular layer composed chiefly of garnet–clinopyroxene amphibolite, associated with metamorphosed olivine-rich noritic gabbro with relict plagioclase laths replaced largely by garnet, spinel, and clinopyroxene. A thin section of this rock shows unaltered olivine in contact with garnet, a relationship indicative of high pressure. This last rock type is very similar in appearance and composition to that of a component of the eclogitic metagabbro bodies exposed along the Shawanaga shear zone on Georgian Bay (Needham 1992; illustrated in Fig. 7*a* of Davidson 1991). Its rare-earth pattern (Fig. 6, sample 14) is primitive and quite unlike those of the Sudbury (meta)diabase and Algonquin metagabbro suites.

The ABT is tentatively placed west of these mafic rock occurrences as a moderately folded, north-trending structure that conforms to the regional structural trend (Fig. 5).

Lake Kipawa area, western Quebec

Along a corridor extending into the Grenville Province southeast of Belleterre, Indares and Dunning (1997) have identified Sudbury-type metadiabase within the Archean parautochthon (dated by these authors at 1217^{+15}_{-10} Ma), omphacite-bearing eclogitic rocks within the Lac Watson shear zone, and coronitic olivine metagabbro in a structurally

Fig. 7. Schematic representation of chronological, metamorphic, and mafic rock characteristics of the five structural levels of the Central Gneiss Belt defined in this study. The diagram serves to highlight important similarities and differences between structural levels. Sources of Nd and $^{40}Ar/^{39}Ar$ age data are given in the text. U–Pb age data are from a large number of sources that cannot be listed here but are available from the authors as a compilation of all U–Pb age data from the Central Gneiss Belt in Ontario and adjacent Quebec. GFTZ, Grenville Front tectonic zone.



higher block (Fig. 2). Farther southwest, a remnant metadiabase dyke with Sudbury chemistry (Fig. 6, sample 13) (Currie and van Breemen 1996; analysis courtesy of K.L. Currie, Geological Survey of Canada) is hosted by Proterozoic metasedimentary gneiss that is structurally sandwiched between the Archean parautochthon and the Lac Watson shear zone (Figs. 2, 5). The location of this metadiabase suggests that the Lac Watson shear zone likely marks the position of the ABT, and not the structurally lower aeromagnetic anomaly described by Kellett et al. (1994). Closer to the Grenville Front (Fig. 2), a number of metadiabase remnants mapped by Sabourin (1960) but not examined during the present study may be relics of Sudbury dykes. In this region, a klippe of the allochthonous terrane contains unequivocal pods of Algonquin metagabbro (Fig. 2).

Tectonic subdivision of the Central Gneiss Belt

In light of the new location for the ABT suggested here, a new tectonic subdivision of the Central Gneiss Belt in Ontario and western Quebec is clearly warranted. Following Culshaw et al. (1997), we divide the Central Gneiss Belt into five structural levels defined on the basis of distinctive combinations of Grenvillian and pre-Grenvillian characteristics. These features are described below and are schematically summarized in Fig. 7. We focus our discussion on U–Pb ages of primary crystallization and metamorphism, Nd model ages, hornblende $^{40}Ar/^{39}Ar$ cooling ages, grade of metamorphism, and metabasite suites because these attributes best exhibit the similarities and differences between structural levels. Of these, most emphasis is placed on Grenvillian attributes (e.g., metabasites, age of metamorphism, and hornblende cooling ages) because variations in these between structural levels cannot be ascribed to pre-Grenvillian events. We place less emphasis on quantitative pressure and temperature (*P–T*) estimates of Grenvillian metamorphism because high-temperature reequilibration may have followed the attainment of peak *P* and *T* conditions, but we note these estimates where relevant.

Structural level 1

Level 1 is the structurally lowest tectonic unit (Fig. 8) and is conceptually equivalent to the parautochthonous belt of

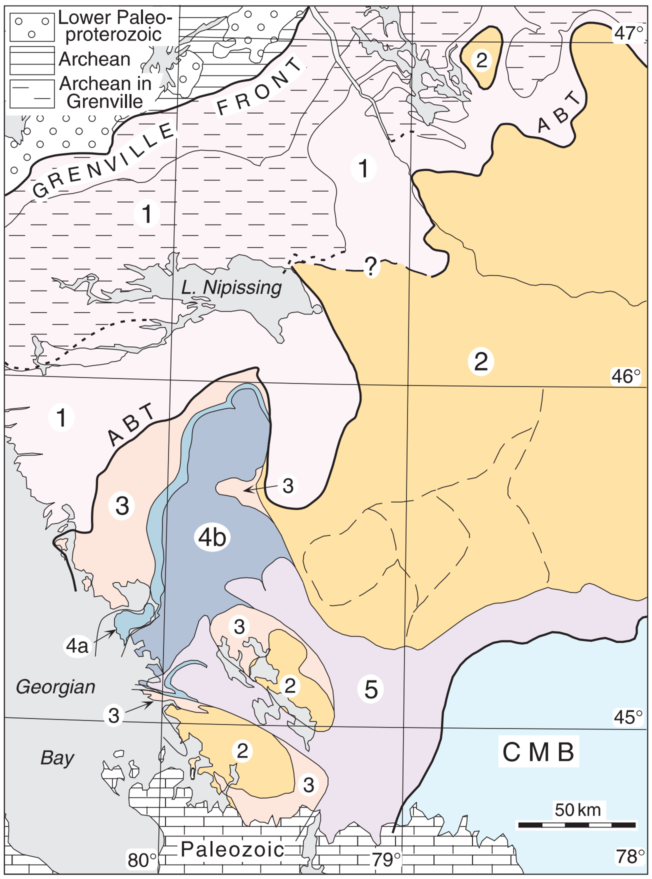


Fig. 8. Summary of structural superposition in the western Central Gneiss Belt. 1, Parauthochthonous Belt, including reworked Archean crust and Paleoproterozoic rocks in Britt, Nepewassi, and Tomiko domains; 2, Algonquin – Lac Dumoine and structurally lower parts of Rosseau and Go Home domains; 3, Shawanaga, Ahmic, and structurally higher parts of Rosseau and Go Home domains; 4*a*, Parry Sound shear zone and basal Parry Sound and Twelve Mile Bay assemblages of Wodicka et al. (1996); 4*b*, granulite-facies interior of Parry Sound domain; 5, Muskoka domain, including contiguous Seguin and Moon River subdomains.

Rivers et al. (1989). In Ontario and western Quebec, it comprises both Archean and Proterozoic crust (U–Pb primary crystallization ages of 2680–2560, 1750–1605, and 1470–1380; see Fig. 7 for information on these and other age references). Archean units can be linked in places with those in the Superior Province north of the Grenville Front. Younger ages, between 1250 and 1200 Ma, have been obtained for the Mulock (Lumbers et al. 1991) and West Bay (Sturgeon Falls) batholiths (L.M. Heaman, personal communication, 1993) and the St. Charles and Mercer anorthosites (Prevec 1992). Level 1 has been the subject of several Nd-isotope studies (Dickin and McNutt 1989, 1990; Dickin et al. 1990; Holmden and Dickin 1995) which indicate that Archean rocks and those with a significant Archean component (e.g., some paragneisses and younger plutonic units) have depleted mantle model ages of 2.8–2.0 Ga, whereas Proterozoic rocks lacking a significant Archean influence have model ages of 1.9–1.8 Ga. The position of the ABT does not coincide with this model age boundary, except perhaps in the vicinity of North Bay (see above; Fig. 5).

Major Grenvillian metamorphism in level 1 occurred at 1060–980 Ma, with youngest ages documented near the Grenville Front. This northward decrease in the age of oldest recorded Grenvillian metamorphism is consistent with the model of a forward-propagating orogen (Jamieson et al. 1992; Culshaw et al. 1997; Indares and Dunning 1997). Hornblende $^{40}Ar/^{39}Ar$ cooling ages throughout level 1 range from ~1000 to ~950 Ma (Culshaw et al. 1991; York et al. 1991; Haggart et al. 1993; Reynolds et al. 1995).

Linking all the lithologically diverse units of level 1 are tectonically modified and metamorphosed diabase dykes correlated with the 1235 Ma Sudbury swarm. Quantitative *P–T* estimates for these dykes, which unequivocally record Grenvillian metamorphic conditions, indicate equilibration at 640–720°C and 600–1080 MPa within the Grenville Front tectonic zone (Bethune 1993; Currie and van Breemen 1996; Indares and Dunning 1997; Bethune and Davidson 1997) and at 600–870°C and 400–1420 MPa elsewhere in level 1 (Ketchum 1994; Jamieson et al. 1995). The large variability in the latter pressure range can be attributed to near-isothermal decompression during tectonic unroofing (Jamieson et al. 1995). Despite paleopressure estimates as high as ~1400 MPa, there is no petrologic or mineral chemical evidence for eclogite-facies metamorphism in level 1. Jamieson et al. (1995) have suggested that this likely reflects relatively high temperature conditions at the time of maximum burial (i.e., outside of the eclogite stability field).

Structural level 2

Level 2 is the lowest allochthonous unit and forms the hanging wall to the ABT, except in the west where it is occluded by level 3. It consists of Algonquin, lower Go Home, and lower Rosseau domains (Fig. 8) (Culshaw et al. 1997), as well as a large region lying north of Algonquin domain (Lac Dumoine terrane in Quebec; Fig. 1) (Indares and Martignole 1990). All these crustal segments were previously grouped within the parautochthon on the basis of lithologic and structural similarity with Britt domain (e.g., Culshaw et al. 1983; Rivers et al. 1989), but here we consider them to be allochthonous because they lack Sudbury metadiabase and contain retrogressed eclogite and Algonquin metagabbro.

Orthogneiss protolith ages in level 2 range from 1715 to 1610 Ma and 1470 to 1375 Ma, almost identical to those in level 1 (Fig. 7). Archean rocks have not been reported in level 2 and may be entirely absent based on widespread Nd model ages of 1.87–1.56 Ga (nearly all are <1.77 Ga; Dickin and McNutt 1989, 1990; Holmden and Dickin 1995). In the North Bay area, the trace of the ABT as identified here separates Nd model ages of 1.72–1.56 Ga in level 2 from those greater than 1.8 Ga in level 1 (see Dickin and McNutt 1990; Holmden and Dickin 1995). A ~200 MPa paleopressure difference (~1000–1100 MPa in level 2, 850–950 MPa in level 1) was documented across this potential segment of the ABT by Anovitz and Essene (1990), but was attributed by them to post-Grenvillian displacement on the Mattawa River Fault (Fig. 5).

U–Pb metamorphic ages throughout level 2 range from 1145 to 1020 Ma and include a ~1090 Ma estimate for high-pressure metamorphism in lower Go Home domain (Ketchum and Krogh 1997, 1998). In contrast to structurally lower (1) and higher (3, 4*a*, 5) levels which are dominated by amphibolite-facies assemblages, level 2 contains a significant component of granulite-facies rock (Culshaw et al. 1983; Davidson 1991). Some granulite-facies units in Algonquin domain have U–Pb metamorphic ages of >1100 Ma, significantly older than metamorphic ages throughout much of the Central Gneiss Belt with the exception of level 4*b* of Parry Sound domain (Fig. 7). Hornblende cooling ages for level 2 define a 1025–930 Ma interval (Cosca et al. 1991). The 1025 Ma hornblende cooling age is significant in that the sample location, a few kilometres west of Mattawa, is only 60 km southeast of the Grenville Front tectonic zone, within which U–Pb metamorphic ages are ~1000 Ma. This supports the interpretation of an important structural boundary lying somewhere between the Grenville Front tectonic zone and Mattawa (as suggested by the mafic rock distribution in this area). In general, level 2 is poorly known, and there may be internal subdivisions that are not yet recognized, particularly in the eastern half of the region.

Structural level 3

Level 3 consists of the allochthonous Shawanaga, Ahmic, upper Go Home, and upper Rosseau domains (Fig. 8), all of which mainly differ from underlying allochthonous domains in that (*i*) U–Pb igneous crystallization ages are entirely Mesoproterozoic (1465–1300 Ma), (*ii*) amphibolite-facies migmatite is dominant (Culshaw et al. 1997), and (*iii*) depleted mantle model ages of 1.64–1.46 Ga are somewhat younger than those reported from level 2. U–Pb metamorphic ages range from 1120 to 990 Ma but the data are relatively sparse. Oldest metamorphic ages are from eclogitic bodies in the Shawanaga (1120 and 1090 Ma) and upper Go Home domains (1090 Ma; Ketchum and Krogh 1997, 1998). All other reported ages (≤1080 Ma) appear to record thermal peak or near-thermal peak conditions (e.g., Bussy et al. 1995). Relatively few hornblende cooling ages have been reported from level 3. A single ~1000 Ma cooling age has been determined from the Ahmic domain (Cosca et al. 1991), and four hornblende ages of ~960–970 Ma characterize Shawanaga domain near its contacts with the underlying Britt and overlying Parry Sound domains (Culshaw et al. 1991, 1997; Wodicka 1994).

Level 3 contains Algonquin metagabbro bodies and eclogite remnants; the latter mainly occur near or at the structural base of level 3, which in places forms the hanging wall to the ABT.

Structural level 4

Level 4 consists of the composite Parry Sound domain, interpreted by some authors (e.g., Wodicka et al. 1996) as an allochthonous slice sourced from the Central Metasedimentary Belt or Adirondack Highlands. This linkage is based on lithologic similarity and comparable U–Pb ages of plutonism, sedimentation, metamorphism, and deformation recorded in the lower level (unit 4*a* in Fig. 8). The upper, thrust-bounded segment of Parry Sound domain (unit 4*b*; interior Parry Sound assemblage of Wodicka et al. 1996) is lithologically less comparable to the Central Metasedimentary Belt or Adirondack Highlands and may have a different, but similarly exotic source region (Culshaw et al. 1989; Easton 1992).

Granitoid and anorthositic plutonism is dated at ~1425–1315 and 1163 Ma, and Nd model ages are 1.57–1.38 Ga (most fall within a narrow 1.42–1.40 Ga interval; Dickin and McNutt 1990). U–Pb metamorphic and $^{40}Ar/^{39}Ar$ hornblende age ranges (1160–1080 and 1070–1020 Ma, respectively) from interior regions of the Parry Sound domain are somewhat anomalous with respect to the rest of the Central Gneiss Belt (Fig. 7). This domain clearly experienced a unique Grenvillian metamorphic history, part of which occurred at a location southeast of its present position (Wodicka et al. 1996; Culshaw et al. 1997). Hornblende cooling ages of ~985–970 Ma (Dallmeyer and Sutter 1980; Cosca et al. 1991; Wodicka 1994) near the boundary with level 3 demonstrate that the Parry Sound domain margin experienced a cooling history similar to that of adjacent rocks in other levels.

Level 4 lacks Sudbury metadiabase, Algonquin metagabbro, and retrogressed eclogite, supporting the hypotheses that it is exotic with respect to other Central Gneiss Belt domains. Level 4*b* was tectonically emplaced onto its level 4*a* substrate at ~1160 Ma (van Breemen et al. 1986), somewhat earlier than the final emplacement of level 4 onto Shawanaga domain (estimated at ~1080 Ma; Wodicka et al. 1996).

Structural level 5

This is the highest structural level in the Central Gneiss Belt, consisting of Muskoka domain and the contiguous Seguin and Moon River subdomains (Fig. 8). U–Pb primary crystallization ages fall in the interval 1455–1395 Ma, and Nd model ages range from 1.62 to 1.41 Ga. U–Pb zircon and titanite analyses indicate metamorphism at 1095–1025 Ma, but metamorphism may predate ~1100 Ma in at least part of Seguin subdomain (Nadeau 1990). However, U–Pb evidence for metamorphic zircon growth or isotopic resetting before 1080 Ma is absent from southeastern Muskoka domain (Timmermann et al. 1997). A single hornblende cooling age of ~950 Ma is reported for level 5 from a location immediately beneath the Central Metasedimentary Belt boundary thrust zone (Cosca et al. 1992).

Level 5 contains Algonquin metagabbro, but retrogressed eclogite has not been documented within this unit or along its tectonic boundaries. The absence of high-pressure metamorphism has been explained by out-of-sequence thrust emplacement of level 5 (Culshaw et al. 1997).

Discussion

Allochthon boundary thrust

In conjunction with published maps and earlier studies, we have used the distribution of distinctive metabasite types to define a tentative new position for the ABT in Ontario and western Quebec. The presence or absence of distinctive plutonic suites, in particular mafic dykes, has been used for decades as a tool for recognizing tectono-stratigraphic terranes and appears to have merit in the present study. Although our model is admittedly speculative, it nevertheless has so far withstood an important test, namely that bodies of Sudbury metadiabase and one or both of retrogressed eclogite and Algonquin metagabbro have not yet been found together in structurally coherent crust (Fig. 2).

Along Georgian Bay, the ABT (Shawanaga shear zone) separates Grenvillian high-pressure metamorphic assemblages as old as 1090 Ma (and possibly 1120 Ma) in level 3 from level 1 rocks that were not metamorphosed until –1060 Ma. Although there are fewer data, this age disparity is also evident to the east where level 2 domains with metamorphic ages as old as ~1130–1145 Ma (Carr and Berman 1997) overlie level 1. This marked contrast in the age of earliest Grenvillian metamorphism requires further documentation throughout Ontario and western Quebec, but is consistent with U–Pb data from elsewhere in the orogen demonstrating an older Grenvillian metamorphic history in the allochthons (e.g., Friedman and Martignole 1995). We suggest that as more U–Pb data are obtained from the southwestern Grenville Province, this metamorphic age disparity may provide an additional means of corroborating or independently tracing the allochthon boundary. The presence of Grenvillian granulite-facies assemblages in level 2 and their absence from level 1 are potentially related to this metamorphic age contrast and might also assist in locating the ABT, as it does elsewhere in the Grenville Province (Rivers et al. 1989; Davidson 1995). However, local occurrences of pre-Grenvillian granulite in level 1 (Ketchum et al. 1994) may hinder this approach.

As suggested by data from the Burk's Falls and North Bay areas, Nd model ages vary by ~0.1–0.2 Ga across the proposed ABT. However, it is currently uncertain if Nd model ages can be used to unambiguously locate the boundary. This is because large tracts of Proterozoic orthogneiss throughout levels 1 and 2 have similar primary crystallization ages and may also have similar source characteristics. It is likely that locating the ABT in this region will depend mainly on further identification of candidate shear zones, distinctive metabasite bodies, and Grenvillian metamorphic age contrasts. Rock characteristics not directly related to Grenvillian orogenesis (e.g., lithology, primary crystallization age, Nd model age, pre-Grenvillian metamorphic history) are of secondary importance in locating the ABT as there is no a priori reason why these features should vary significantly across it. A case in point is provided by the Britt and Algonquin domains which share a number of pre-Grenvillian characteristics (Fig. 7). However, contrasting pre-Grenvillian features are regularly and in fact commonly observed across major Grenvillian structures (e.g., between Parry Sound and adjacent domains). Although such features can be used to establish tectonic boundaries, they cannot be relied upon in isolation, as the Britt–Algonquin example illustrates. Regardless of which method is used to trace the ABT, its position as shown in Fig. 8 may require modification as additional work is carried out.

Further work in the present study area should attempt to trace the continuity of highly strained rocks along the suggested trace of the ABT between the Shawanaga and Lac Watson shear zones, addressing whether the ABT is represented by a single shear zone or comprises two or more structures. Evidence that may favour a composite allochthon boundary east of Parry Sound domain is provided by Lithoprobe seismic reflection data. The data for line 30 of the Abitibi–Grenville Lithoprobe transect (White et al. 1994), which crosses the central part of Parry Sound domain, suggest a deep subsurface position for the Shawanaga shear zone beneath western Ahmic domain (Fig. 7*c* of White et al. 1994). This makes it geometrically difficult, but not impossible, to link this shear zone with the proposed surface trace of the ABT west of the Powassan batholith, and raises the possibility that this north-trending segment is a steeply dipping structure that either intersects the Shawanaga shear zone or joins it as a lateral ramp. A similar structural complication may also exist at the southern end of the Powassan batholith where the proposed ABT turns abruptly east. These speculations warrant further field study. It should be noted that tectonites marking the eastern boundaries of the Parry Sound and Ahmic domains border a distinctive promontory of allochthonous thrust sheets overlying structural levels 1 and 2 (Fig. 8). It remains possible that northwestward transport of this allochthonous thrust stack may not have entirely coincided with emplacement of level 2 rocks over level 1.

Tectonic assembly

As documented by earlier workers, Central Gneiss Belt domains were largely assembled during deep-seated, northwest-directed Grenvillian thrusting on broad ductile shear zones, and can be grouped into larger tectonic units (structural levels) on the basis of structural position and shared lithologic and tectono-metamorphic characteristics (Davidson et al. 1982; Culshaw et al. 1983, 1997; Davidson 1984; Nadeau and Hanmer 1992). Tectonic assembly of the Central Gneiss Belt is generally considered in terms of transport of structural levels rather than of individual domains. Although much work remains to be done to assess the coherency of each level during tectonic assembly, the pattern of Grenvillian and pre-Grenvillian characteristics shared among constituent domains broadly suggests that each level behaved more or less as a single tectonic entity, at least on a regional scale.

Culshaw et al. (1997) concluded that forward-propagating tectonic transport punctuated by minor out-of-sequence thrusting characterized orogenic development of the Central Gneiss Belt. Their tectonic model involves (*i*) early deformation and metamorphism within the Central Metasedimentary Belt and Parry Sound domain (1190–1160 Ma); (*ii*) initial encounter of these units with the Central Gneiss Belt (–1120 Ma); (*iii*) thrusting of the Parry Sound domain and underlying Shawanaga, upper Go Home, and upper Rosseau domains onto the Laurentian craton (~1080 Ma); (*iv*) out-of-sequence thrusting of the Moon River lobe over Parry Sound domain (1080–1040 Ma); and (*v*) thrusting of Algonquin, lower Go Home, and lower Rosseau domains over the parautochthon (1080–1040 Ma). Although this scenario appears to conflict with break-back thrusting in Algonquin domain (Nadeau and Hanmer 1992), much of the assembly of Algonquin domain likely took place before 1100 Ma (Nadeau 1990; Nadeau and Hanmer 1992), prior to major thrusting in the Central Gneiss Belt at 1080–1040 Ma. We suggest that break-back thrusting in Algonquin domain reflects an earlier period of orogenic construction within structural level 2 that cannot be directly compared to the larger scale, forward-propagating sequence described by Culshaw et al. (1997). Break-back emplacement of Seguin subdomain over Algonquin domain is, however, compatible with out-of-sequence thrust emplacement of Moon River subdomain, although the timing of these potentially correlative events is disputed. Granulite-facies mineral assemblages older than 1100 Ma in level 2 (e.g., Carr and Berman 1997) are therefore unlikely to reflect the main period of tectono-metamorphic activity in the Central Gneiss Belt. The metamorphic history of the Central Gneiss Belt appears to include a number of structural level specific events that occurred at various times during orogenic construction, and prior to final tectonic transport of some of these levels. This represents a somewhat different view of tectonic–metamorphic relationships than that of Nadeau and Hanmer (1992), who attributed prolonged metamorphic activity and apparent slow cooling to a lengthy period of break-back thrust loading at higher crustal levels.

An important implication of our model is that a large segment of the Central Gneiss Belt (level 2) is allochthonous rather than parautochthonous. Incorporation of level 2 into the advancing thrust wedge represents a process of basal accretion, which predictably yields a lowermost allochthonous block with preorogenic properties similar to those of the adjacent parautochthon (as observed in this study). Levels 2 and 3 may have been deeply buried at ~1090 Ma, the proposed metamorphic age of eclogite remnants found within them (Ketchum and Krogh 1997, 1998). This suggests that these structural levels were overridden by higher levels and the Central Metasedimentary Belt at ~1090 Ma before being accreted to the base of the allochthonous thrust stack and partly exhumed on the ABT, most likely at ~1080 Ma (Culshaw et al. 1994, 1997; Ketchum and Krogh 1997, 1998; Wodicka et al. 1999; cf. Indares and Dunning 1997). An initial outboard position for levels 2 and 3 would shed light on Central Gneiss Belt metamorphic ages of >1100 Ma, which potentially record an even earlier interaction with the Central Metasedimentary Belt (e.g., Nadeau and Hanmer 1992; McEachern and van Breemen 1993; Culshaw et al. 1997; Ketchum and Krogh 1997, 1998).

Significant Grenvillian displacement is inferred on the ABT because it separates the regionally extensive Sudbury metadiabase and Algonquin metagabbro suites, and because it juxtaposes structural levels with very different Grenvillian metamorphic histories. The mutually exclusive distribution of the mafic suites suggests that level 2 may have been either detached or, more likely, incompletely rifted away from Laurentia after ~1450 Ma but prior to intrusion of Algonquin gabbro at 1170 Ma (cf. Easton 1992; Gower and Tucker 1994; Rivers 1997; Rivers and Corrigan 2000). The northwest propagation direction proposed for Sudbury dyke emplacement (Fahrig 1987; Ernst 1994) is consistent with rifting at a location within the present-day Central Gneiss Belt and provides a mechanism to account for the restriction of these dykes to the parautochthon and foreland. Level 3 crust, in particular Shawanaga domain, is interpreted as a passive-margin sequence that formed along a post-1450 Ma rifted Laurentian margin or within a basin inboard from this margin (Culshaw et al. 1997; Culshaw and Dostal 1997; Rivers and Corrigan 2000). One or more episodes of continental rifting represents one way to explain enigmatic ~1400–1200 Ma ages of magmatism and volcanism in the Central Gneiss Belt (e.g., retrogressed eclogite precursors, ~1400 Ma (Indares and Dunning 1997; Ketchum and Krogh 1997, 1998); Shawanaga domain volcanic rocks, <1390 Ma (T.E. Krogh, unpublished data); Mulock Batholith, ~1244 Ma (Lumbers et al. 1991); Mercer and St. Charles anorthosites, 1222–1206 Ma (Prevec 1992)). This period of pre-Grenvillian activity remains poorly understood and awaits further study.

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