RODINIA ASSEMBLY, GRENVILLE PROVINCE, CANADA

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The Grenville Province, located along the southeast margin of the Canadian Precambrian Shield, is the exposed part of the Grenville orogen which remained attached to Laurentia subsequent to break-up of Rodinia. This is also true for Grenvillian inliers that lie on the Laurentian side of the Iapetus suture in the Appalachian orogen, but not for Neoproterozoic terranes (Avalonian) outboard of this suture (Rankin et al. 1993), which have more affinity with Pan-African terranes. The Grenville Province is composed of three, roughly orogen-parallel zones: (1) along its northwest margin (the Grenville Front), a zone in which thoroughly reworked equivalents of older shield provinces to the northwest can be recognized, (2) a central zone of allochthonous terranes which, despite intense Grenvillian (1.2–1.0 Ga) tectonic overprint in many places, record evidence of earlier orogenic events in rocks that cannot be readily correlated with older orogenic events in the exposed Grenville foreland, and (3) a southeastern zone in which are preserved supracrustal and plutonic rocks that have been affected only by the Grenvillian orogeny; plutonic rocks of this category, which includes the well-known 'Grenville anorthosite massifs' (AMCG suite), also intrude the southeastern part of the central zone. The northwestern, central and southeastern zones (Hoffman 1989; Davidson 1998) correspond to the parautochthonous, allochthonous polycyclic, and allochthonous monocyclic belts of Rivers et al. (1989).

The Canadian Shield northwest of the Grenville Front is a mosaic of Archean cratons (Slave, Hearne, Superior, Nain) separated by mid-Paleoproterozoic (2.1–1.8 Ga) orogenic belts (Wopmay, Thelon–Taltson, Penokean, Trans-Hudson–Ungava, New Quebec–Torngat, Ketilidian in Makkovik Province and south Greenland), in part overlain by mid- to late Paleoproterozoic intracratonic sedimentary basins associated with alkaline igneous activity (Thelon, Athabaska) (cf. Hoffman 1989). Late Paleoproterozoic (1.8–1.6 Ga) additions of crust along the southeast margin of this amalgamation are represented by the Yavapai–Mazatzal (Central Plains) orogen in the southwest (Van Schmus et al. 1993) and the Ketilidian–Labradorian in the northeast (Fig. 1). Archean crust is not recorded within or south of these marginal belts, which are regarded as juvenile additions to 'proto-Laurentia', possibly representing the culmination of supercontinent assembly by

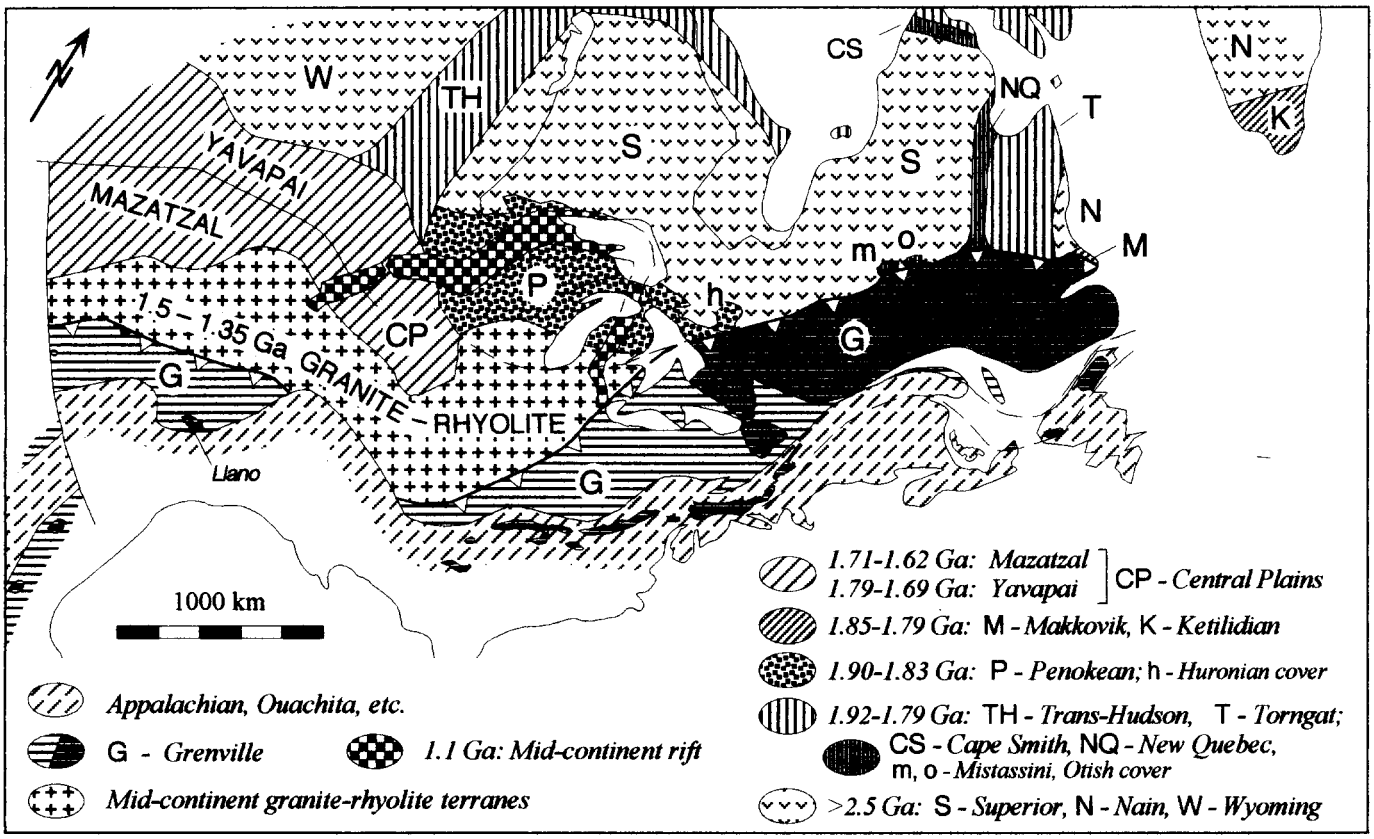

Figure 1. Distribution of pre-Grenvillian structural provinces and orogenic belts adjacent to the Grenville Province in the Canadian Precambrian Shield and midcontinental North America. The dark and light patterns used for the Grenville Province indicate exposed and buried parts respectively.

ca. 1.6 Ga. Within the Grenville Province, these late Paleoproterozoic belts are repesented in the southwest and northeast parts of the parautochthonous northwestern zone, and also in the central zone where they may be present along the whole length of the hanging wall of the allochthon boundary thrust (Fig. 2; cf. Fig. 1 in Karlstrom et al. 1999).

There is no record of events in the interval 1.6–1.5 Ga (geon 15; Hofmann 1990), leaving open the possibility that this was a time of breakup of proto-Laurentia. In early to mid- geon 14, extensive, dominantly felsic plutonic rocks were emplaced within Labradorian crust in the northeastern part of the Grenville Province (Pinware terrane, central zone; Fig. 2). Plutonic rocks of this age are absent from the Labradorian allochthons and northwestern zone to the north, but are present in the southern part of the adjacent foreland where, however, they are typical AMCG-suite rocks and clearly anorogenic in character. In the southwest, coeval plutonic rocks, again mainly granitoid, occur within the central zone and in the foreland (mid-continental granite-rhyolite terranes; Bickford et al. 1986) (Fig. 1), but in addition are present in the northwestern zone where they are associated with coeval high-grade metamorphism and deformation that extend northwest as far as the present position of the Grenville Front. These early Mesoproterozoic igneous rocks appear to represent separate continental plutonic arcs. Also present in the central zone in this region are somewhat younger granitoid plutonic rocks (ca. 1.35 Ga), spatially associated with possible felsic volcanic rocks interpreted as a rift-to-drift association by Culshaw and Dostal (1997); these rocks are age-correlative with the younger midcontinental granite-rhyolite assemblage, but are apparently not present in the intervening northwestern zone.

In the same time interval, rocks indicative of two very different geologic environments are present in the central part of the central zone: (1) the volcanic Montauban Group and calc-alkaline plutonic rocks (ca 1.45–1.37 Ma) forming a deformed arc terrane in central Quebec (Portneuf–St. Maurice domain; Corrigan and van Breemen 1997), and (2) scattered occurrences of slightly younger gabbro-anorthosite and associated charnockite intrusions (ca. 1.35 Ga) in terranes on both sides of, though spatially distant from, the Montauban arc (Fig. 2). The presence in what is now the central Grenville Province of an oceanic basin that had closed by ca. 1.4 Ga implies not only that assembly of Rodinia had begun by this time, but also that, if Labradorian crust had been contiguous along the proto-Laurentian margin, as it seems now to be, then it may have split at the end of Paleoproterozoic time, before reassembly toward the end of the early Mesoproterozoic.

In late geon 13 and in geon 12, paired associations of tholeiitic to calcalkaline volcanism and slightly younger tonalite-granite plutonism appear to represent the formations and closures of marginal basins, successive in time but not necessarily in space, within the southwestern Grenville Province. The oldest tonalitic rocks (ca. 1.35–1.30 Ga) lie in the southeastern Adirondack region and in Appalachian inliers, and may be an extension of the magmatic arc plutonism that followed closure of the Montauban arc (Rivers 1997); the remainder, associated with marine volcanic and sedimentary rocks, are within the Composite Arc Belt of Carr et al. (in press) (Fig. 2); all lie southwest (present coordinates) of the earlier-closed Montauban arc, and none has a known counterpart in proto-Laurentia. The associated metasedimentary rocks, where preserved well enough for interpretation, are derived in large part from marine carbonate and mud, lacking a coarse, continent-derived clastic component; oceanic crust may have developed ephemerally in some basins. There is no firm consensus on the polarity of related subduction; several models call upon attachment of arcs to the margin of a continent approaching Laurentia from the southeast (e.g. Windley 1989), and some require polarity flips during the process of closure (e.g. Carr et al. in press). According to Rivers (1997, p. 146), however, "... subduction was consistently towards the northwest ... underneath Laurentia." East of the Montauban arc, on the other hand, coeval volcanism and plutonism, spatially associated with continental-type sedimentation (quartzite, arkose, red-beds; Wakeham terrane in Fig. 2), are peralkaline in nature and very similar in age and environmental characteristics to the Letitia and Seal Lake groups which lie in the immediate footwall of the Grenville Front to the north. If equated, this may imply that the large part of the Grenville Province east of the Montauban arc was contiguous with proto-Laurentia before closure of the back-arc basin(s) southwest of it.

Final closure of the Composite Arc Belt (Elzevirian orogeny) was accomplished by ca. 1.2 Ga, as manifested by early ductile deformation with thrust sense or oblique transpressional displacement along its northwest margin, and perhaps by extraction of slices of Composite Arc crust and their subsequent emplacement over the Laurentian margin (Martignole and Pouget 1996; Culshaw et al. 1997). Sedimentary rocks of shelf-type affinity (marble-quartzite-pelite) were tectonically emplaced against the east side of the Composite Arc Belt, overriding it. This boundary is stitched by, and is the approximate western limit of a suite of post-collisional, A-type and AMCG plutonic rocks emplaced early in geon 11. Ages of detrital zircon as young as 1.15 Ga in sedimentary rocks deposited on the Composite Arc Belt (Sager-Kinsman and Parrish 1993) imply unroofing of the leading edge of the overriding deck (Frontenac terrane), which itself preserves isotopic evidence of early cooling (Cosca et al. 1992).

This early post-collisional plutonism represents the first of several pulses of similar magmatism within the southeastern and central zones (e.g. Higgins and van Breemen 1996), although such plutonic rocks are absent in the Laurentian margin northwest of the Composite Arc Belt. There is some evidence that plutonism continued longer in the eastern Grenville than in the southwest (Gower 1996; Davidson 1998, Fig. 3.23). Once considered to be 'anorogenic' in nature, Grenvillian post-collisional plutonism, ranging through more than 200 m.y., occurred during a period when the orogen as a whole was still in compression; this is shown not only by syn-emplacement deformation of the plutonic rocks, but also by the record of continuing deformation and high-grade metamorphism in many parts of the province, and by coeval, cratonward ductile thrusting along both major internal boundaries within the province, and between domains within the three zones. Ductile extension occurred in parts of the central and southeastern zones after ca. 1.05 Ga but, as a whole, the Grenville orogen remained in compression and continued to propagate northwestward, cannibalizing its footwall until ca. 980 Ma (Krogh 1994; Jamieson et al. 1995).

It is assumed, because the Grenville Province records compression and crustal thickening, that ocean closure is a necessary precursor, and models have been built on this

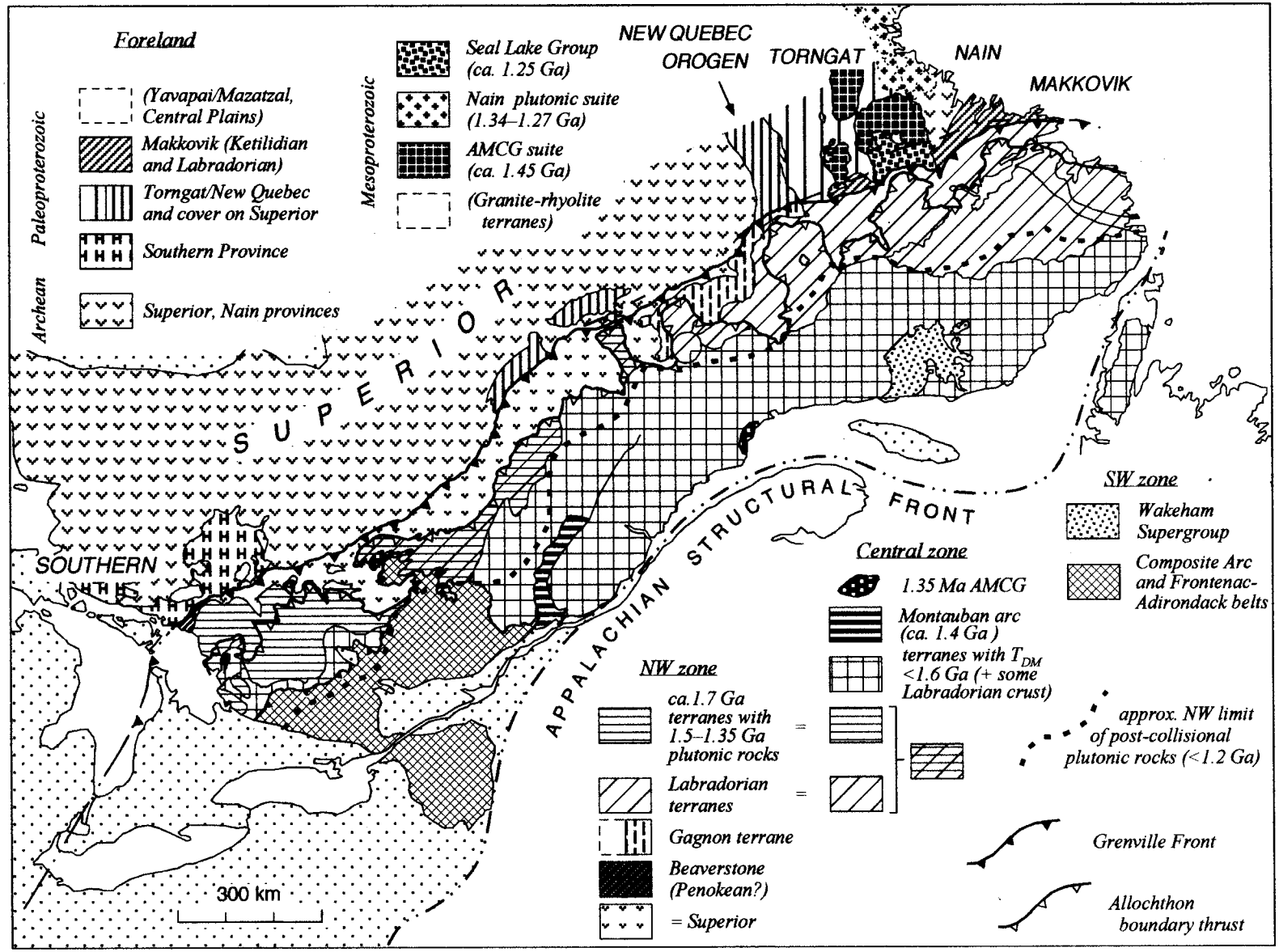

Figure 2. Tectonic divisions of the Grenville Province.

reasonable assumption. However, there is a great deal of speculation concerning the former extent and disposition of a Grenvillian ocean ('Uranus' of Williams et al. 1999) within the present parameters of the province. There has also been a tendency to base models on tectonic classifications of depositional basins and plutonic suites that may not, or cannot, be rigorously constrained; this has led to a considerable diversity of interpretation. Judging by the complexities encountered in more modern orogens (e.g. van Staal et al. 1998), piece-by-piece reconstruction of Meso-proterozoic terrane amalgamation and addition of new crust for the whole Grenville Province requires much speculation. In summary: (1) it seems likely that the break-up of a precursor supercontinent preceded the amalgamation of Rodinia; (2) the Grenville orogen as exposed in the Grenville Province is the result of long-lived, though perhaps sporadic, compressional orogeny against the Laurentian margin during the Meso-proterozoic; (3) the earliest collision occurred at ca. 1.4 Ga, and was followed by final closure of marginal basins at ca. 1.2 Ga; (4) compression continued for another 200 m.y., accompanied by voluminous AMCG- and A-type plutonism in the orogen's core. There is essentially no record of events within the Grenville Province for the 400 m.y. following the terminal thrust-uplift along the Grenville Front at ca. 1.0 Ga. Neoproterozoic sediments preserved in graben in Labrador and locally in the southwest, and small, rift-associated alkaline intrusions and diabase dykes dated at ca. 600 Ma are the earliest recorded evidence of the break-up of Rodinia.

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