PEREGRINATION OF MIDDLE PROTEROZOIC MASSIFS AND TERRANES WITHIN THE APPALACHIAN OROGEN, EASTERN U.S.A.

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TRABAJOS DE GEOLOGIA

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En la parte oriental de los Estados Unidos de América, las rocas del Grenvilliense se pueden agrupar en tres categorías litotectónicas principales. La primera pertenece al interior del margen cratónico ancestral del Proterozoico superior de América del Norte e incluye a los macizos de los Adirondacks y Nueva Inglaterra, así como la mayoría de los macizos de Blue Ridge de los Apalaches. El segundo es un grupo de transición que contiene rocas del Grenvilliense tanto interiores como exteriores respecto al margen continental ancestral de Norteamérica reconstruido en base a los macizos internos. En este grupo hay terrenos, macizos y «domos» anómalos con afinidades claramente internas pero que poseen diferencias suficientes para cuestionar un origen «in situ» con respecto al margen adyacente del Grenvilliense. El tercero contiene terrenos que debieron de originarse fuera del craton norteamericano adyacente. La restauración palinspástica de los macizos del Grenvilliense que comprenden el margen de Norteamérica, sugieren que existía un terreno volcánico del Blue Ridge Grenvilliense bordeando a un terreno constituido por una secuencia cratónica metasedimentaria con rocas metaígneas asociadas del Proterozoico medio. Al sudeste del terreno volcánico de Blue Ridge, se encuentran rocas metasedimentarias que pueden ser parte de un cratón de 1.2 a 1.8 Ga acrecionado a Norteamérica durante la Orogénesis Grenvilliense.

Palabras clave: Norteamérica, Apalaches, Proterozoico, Grenvilliense, Basamento, Macizos, Terrenos.

[Traducido por la revista]

In the eastern U.S.A., Grenvillian rocks are divisible into three major lithotectonic categories. The first belongs inboard of the late Proterozoic ancestral cratonic margin of North America and includes the Adirondacks and the New England massifs, as well as the majority of Blue Ridge massifs of the Appalachian orogen. The second is a transitional group which contains Grenvillian rocks both inboard and outboard relative to the ancestral North American continental margin reconstructed from the inboard massifs. Among these are anomalous terranes, massifs and «domes» with clearly inboard affinities but which possess differences significant enough to question an in situ origin relative to the adjacent Grenvillian margin. The third contains terranes which must originate outboard of the adjacent North American craton. Palinspastic restoration of Grenvillian massifs which comprised the margin of North America suggest that a Grenvillian Blue Ridge volcanic terrane bordered a terrane consisting of a Grenvillian metasedimentary platform sequence associated with middle Proterozoic metaigneous rocks. Southeast of the Blue Ridge volcanic terrane are metasedimentary rocks which may part of a 1.2-1.8 Ga craton accreted to North America during the Grenville event.

Key words: North America, Appalachians, Proterozoic, Grenville, Basement, Massifs, Terranes.

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In the Eastern United States of America, Grenvillian and older rocks are exposed both as relatively isolated massifs and terranes along the length of the Appalachian orogen and over a significantly larger area in the Adirondack Mountains of New York state (Figure 1). The base map was modified after King (1969) with data on lithology, geochronology, faults, and geophysics compiled from Bird and Dewey (1970), Fullagar *et al.* (1979), Hatcher and Zietz (1980), Williams and Hatcher (1983), Monrad and Gulley (1983), Rankin *et al.* (1983), Bartholomew and Lewis (1984), Crawford and Hoersch (1984), Drake (1984), Helenek and Mose (1984), McConnell and Costello (1984), Herz and Force (1984), Muller and Chapin (1984), Sinha and Bartholomew (1984), Wiener *et al.* (1984), Farrar (1984, 1985), Keppie (1985), Gulley (1985), Stanley and Ratcliffe (1985), McLelland (1986).

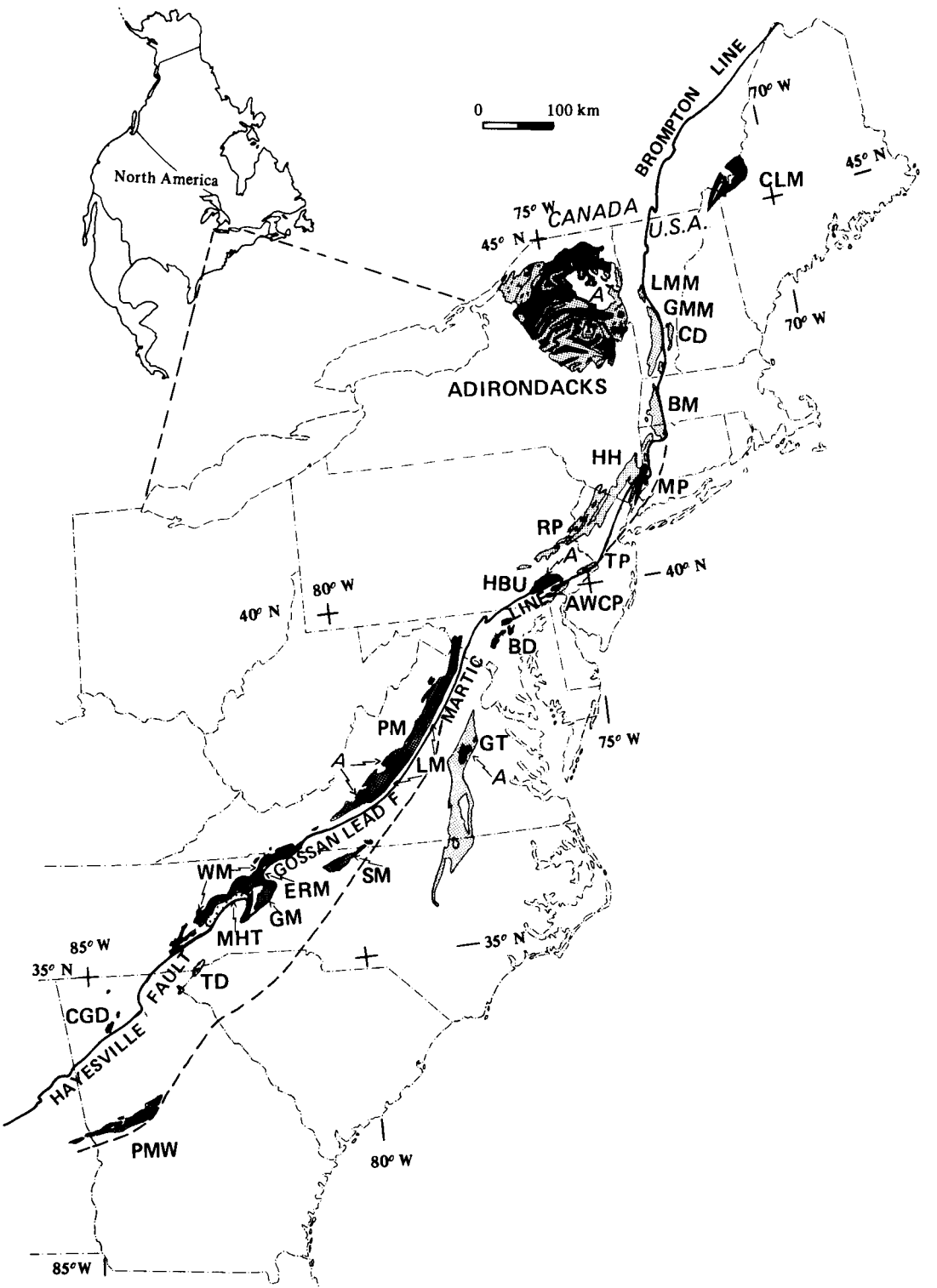
In the Adirondacks recent work (Wiener *et al.,* 1984; McLelland 1986) has resulted in recognition of two distinct Proterozoic lithologic assemblages consisting of a middle Proterozoic (> 1.15 + Ga) plutonic suite associated with a Grenvillian (1.0 – 1.2(?) Ga) supracrustal sequence. As described by Wiener *et al.* (1984), the supracrustal rocks can be interpreted as a metasedimentary platform sequence probably deposited on a continental margin; whereas, the middle Proterozoic metaigneous rocks are interpreted as a possible anorogenic caldera complex (McLelland, 1986). This work on the supracrustal sequence in the Adirondacks provides a framework for developing a tectonic model for Grenvillian rocks found within the Appalachian orogenic belt. By comparing the Adirondack lithotectonic assemblage with the massifs of the Appalachian orogen, distinct zones of related massifs can be distinguished. These Grenvillian zones are analogous to the provinces and terranes now recognized throughout the younger Appalachian orogen.

DISTRIBUTION OF GRENVILLIAN ROCKS IN THE APPALACHIAN OROGEN

Grenvillian rocks in the Appalachians occur in a large number of massifs, «domes», and terranes that are presently separable into three lithotectonic belts by their respective probable relationships to the pre-Appalachian late Proterozoic margin of eastern North America. First, and westernmost, is the belt of Grenvillian rocks which show the strongest affinities to the North American craton either because of lithologic similarities to the Adirondacks (e.g. the New England massifs) or because cover rock sequences clearly belong to the Appalachian sequence of North America (e.g. the massifs of the Virginia Blue Ridge). All of these Grenvillian rocks lie west of the «Piedmont terrane» of Williams and Hatcher (1983), a major tectonic boundary defined approximately by the Hayesville-Gossan Lead fault in the South, the Martic Line and Huntingdon Valley fault continuing roughly northeast, and the Bromptom Line in the North (Fig. 1). These westernmost Grenvillian lithologies are virtually all contained in thrust sheets having considerable horizontal displacement over the North American craton during Appalachian orogenesis. Nevertheless, all of these rocks appear to be derived from the pre-Appalachian post-Grenvillian margin of North America, hence are considered to lie inboard of the old (Late Proterozoic) North American cratonic margin.

FIGURE CAPTIONS

Fig. 1.–Distribution of middle Proterozoic rocks in the Appalachian orogen and the Adirondacks. Black – 1.15+ Ga metaigenous protolith; Dark shading – 1.0 – 1.15 Ga metaigenous protolith; Light shading – 1.0 – 1.15+ Ga metasedimentary protolith; Dotted – 1.2 – 1.8 Ga metasedimentary protolith; A or Δ – anorthosites and related rocks. Heavy solid line is tectonic boundary separating internal from external massifs. Heavy dashed line is approximate trace of Palaeozoic cratonic margin inferred from geophysical data.
CLM – Chain Lakes massif; LMM – Lincoln Mountain massif; GMM – Green Mountain massif; CD – Chester dome; BM – Berkshire massif; HH – Hudson Highlands; MP – Manhattan Prong; RP – Reading Prong; TP – Trenton Prong; HBU – Honey Brook Upland; AWCP – Avondale-West Chester Prong; BD – Baltimore «domes»; GT – Goochland terrane; PM – Pedlar massif; LM – Lovingston massif; SM – Sauras massif; WM – Watauga massif; ERM – Elk River massif; GM – Globe massif; MHT – Mars Hill terrane; TD – Toxaway dome; CGD – Corbin Gneiss «domes»; PMW – Pine Mountain window.


North America
0 100 km
BROMPTON LINE
CANADA
U.S.A.
75° W
45° N
70° W
45° N
CLM
LMM
GMM
CD
ADIRONDACKS
BM
HH
MP
RP
TP
HBU
AWCP
40° N
80° W
40° N
BD
MARTIC
PM
LM
GT
75° W
GOSSAN LEAD F
WM
ERM
SM
GM
MHT
85° W
35° N
35° N
TD
CGD
HAYESVILLE FAULT
PMW
80° W
85° W

The second belt of Grenvillian rocks is a commingled group of diverse terranes which either lie along the aforementioned «Piedmont terrane» tectonic boundary (e.g. Mars Hill terrane), which divides the external and internal massifs of Hatcher (1984); or are situated between that boundary and the prominent gravity gradient (Figure 1) farther east interpreted as the eastern edge of the Palaeozoic North American craton by Hatcher and Zietz (1980). Some of the basement rocks within this belt are similar to those in the more westerly belt (e.g. Baltimore «domes»; Sauras massif) and, hence, likely represent originally inboard parts of the Grenvillian continental margin. A few (e.g. Pine Mountain window) may be parautochthonous parts of the craton over which the inboard rocks were thrust. However, this belt also contains rocks (e.g. Avondale-West Chester Prong) distinctly different from the adjacent parts of the Grenvillian margin of North America which may have originated outboard relative to that adjacent portion of North America. Thus a few of the «domes», massifs, and terranes of this second belt show varying degrees of evidence that not only were they thrust westward over the North American craton, but also they may have experienced large translational movement prior to thrusting associated with Palaeozoic deformation of the Appalachian orogen.

Finally, Middle Proterozoic rocks (e.g. Goochland terrane; Chain Lakes massif) that presently lie east (outboard) of the interpreted margin of the post-Grenvillian North American craton clearly must be viewed as exotic relative to the other exposed Grenvillian rocks of eastern North America. Rocks in this third belt are most likely to have experienced both large translational and/or contractional displacements, and indeed could represent fragments of other cratons amalgamated to North America during Appalachian orogenesis.

By 1) comparing protolithic assemblages for Grenvillian rocks of each of these belts, 2) palinspastically restoring the external massifs of the western belt, and 3) judiciously approximating pre-thrust locations for internal massifs and terranes of the eastern two belts, the major lithotectonic zones of the Grenvillian orogenic belt can be differentiated. Individual massifs and terranes which either experienced large post-Grenvillian translations and/or were originally parts of other cratons may also be delineated.

Inboard Belt of Grenvillian Rocks

Although not as well described as the Adirondacks, the major Grenvillian massifs of New England (Green Mountains and Berkshire massifs) are generally considered to be an eastward extension of the Adirondack lithologies (Stanley and Ratcliffe, 1985). Farther south in the Reading Prong, a Grenvillian metasedimentary sequence (Drake, 1984) is associated with only limited exposures of rocks which can be interpreted as part of the 1.15 + Ga plutonic associations. Thus, beneath western New England, New York, and northeastern Pennsylvania, 1.15+ Ga plutonic suites can be inferred to underlie (McLelland, 1986) or be intruded into (Silver, 1969) a Grenvillian metasedimentary platform sequence.

In the central and southern Appalachians, Grenvillian metavolcanic rocks are ubiquitous within the massifs of the Blue Ridge (Bartholomew and Lewis, 1984; Sinha and Bartholomew, 1984; Lewis *et al.,* 1986). These metavolcanic rocks and most of the associated charnockitic igneous plutons yield ages of 1.0 – 1.13 Ga (summarized in Bartholomew and Lewis, 1984; Pettingill *et al.,* 1984), significantly younger than the 1.15 + Ga plutonic rocks of the Adirondacks.

Lithologic character and known age constraints are consistent with an interpretation that the Blue Ridge massifs (Pedlar, Lovingston, Watauga, Globe, Elk River, and Sauras) are largely a volcanic province of Grenvillian age (1.0 – 1.13+ Ga) which locally contain older Middle Proterozoic (1.15 + Ga) plutonic Rocks (Figure 1). Moreover, the Pedlar River Charnockite Suite appears to have evolved from Middle Proterozoic (1.48 Ga) crustal material (Pettingill *et al.,* 1984).

Northeast of the Blue Ridge, the Honeybrook Upland is considered (Crawford and Hoersch, 1984) to have a volcanic protolith; geochemical comparison with both Blue Ridge rocks (Lewis *et al.,* 1986) and probable charnockitic basement in the Reading Prong (Drake, 1984) suggest a closer lithologic affinity of the Upland with the Grenvillian volcan-

ic rocks of the Blue Ridge rather than the charnockitic rocks to the north. Age control in the Honey Brook Upland is minimal, and indicates only that the Upland experienced Grenvillian metamorphism (Sutter *et al.,* 1980); it neither supports nor denies tentative correlation of the Honey Brook Upland as the northern extension of the Blue Ridge Grenvillian rocks, and does not preclude possible correlation with older metaigneous rocks to the north.

The southern Appalachians appear to share involvement of a middle Proterozoic igneous basement with the Grenville Province and the Adirondack region, but differ in that the Grenvillian supracrustal rocks are more of a volcanic, rather than a sedimentary, sequence as in the Adirondacks (Wiener *et al.,* 1984) and adjacent Canada (Moore and Thompson, 1980).

Grenvillian Rocks of the Middle Belt

At the southern end of the Appalachians (Pine Mountain window) are other charnockitic rocks which resemble the Grenvillian charnockites of the external Blue Ridge massifs (Schamel and Bauer, 1980). These rocks have been viewed as a structurally complex window exposing parautochthonous cratonic rocks (Clarke, 1952; Cook, *et al.,* 1979; Sears and Cook, 1984). To the north within the central and southern Appalachians, are several anomalous massifs and terranes which do not bear much similarity to nearby Grenvillian massifs. The southernmost of these is the Mars Hill terrane which lies structurally above the Blue Ridge massifs in northwestern North Carolina. The Mars Hill terrane is largely a metasedimentary sequence (Merschat, 1977; Gulley, 1985; N.C.G.S., 1985) which limited age constraints suggest is 1.2 – 1.8 Ga (Fullagar *et. al.,* 1979; Monrad and Gulley, 1983). The structural juxtaposition of the Mars Hill terrane over the Elk River massif is a consequence of Palaeozoic thrusting (Gulley, 1985; Goldberg *et. al.,* 1986). However, respective contrasting Grenvillian lithologies suggest that a pre-Appalachian tectonic boundary probably separated these rocks as well. Because of its age, we consider the basement of the Toxaway dome correlative with the Mars Hill terrane.

Farther north the Sauras massif lies within another structurally complex window. Peralkaline granitoids of the late Proterozoic Crossnore plutonic suite intrude the Sauras massif as well as all of the other Blue Ridge massifs; the Sauras lithologies resemble some of those in the Blue Ridge massifs as well. Thus, the Sauras massif is interpreted as proximal to the Blue Ridge massifs throughout Appalachian orogenesis. Similar to the Sauras massif, the structurally complex (Muller and Chapin, 1984) Baltimore «domes» of Maryland contain rocks that are lithologically similar to the layered gneisses of the nearby Lovingston massif, the «domes» also have been interpreted as having volcanic protoliths (Crowley, 1976; Drake, 1984).

In the eastern portions of the Reading Prong, Hudson Highlands, and Manhattan Prong, the Grenvillian metasedimentary cover interfingers with rocks believed to be volcanic origin (Helenek and Mose, 1984; Drake, pers. comm., 1986). Thus, thease massifs appear to be proximal to the New England massifs during Grenvillian orogenesis.

Outboard Grenvillian Basement

In eastern Virginia and North Carolina, the internal Goochland terrane contains a sedimentary sequence above some mafic volcanic rocks which appear to nonconformably overlie plutonic basement (Farrar, 1984; 1985). A single age determination only verifies that the basement metamorphism (and presumably that of the sedimentary cover) is of Grenvillian age (Glover *et al.,* 1982). Nevertheless, apparent intrusion of the basement and cover sequence by an anorthosite coupled with the granulite facies metamorphism imply a probable Grenvillian age for all these rocks in the Goochland terrane (Farrar, 1984, 1985).

Lastly, the Chain Lakes massif in Maine contains Middle Proterozoic (pre-Grenvillian) rocks, (Naylor *et al.,* 1973; Keppie, 1985), and thus owes its present location to Palaeozoic orogenesis and not Grenvillian orogenesis. Keppie (1985) suggests a possible derivation of the Chain Lakes massif from the Svecokarelian orogen of the Baltic Shield. With additional work, outboard Grenvillian rocks may be found in other terranes of the Appalachian orogen as more geochronological data on su-

spected basament becomes available. Keppie (pers. comm., 1986) indicates that possible Grenvillian rocks have now been found in the Avalonian terrane of Newfoundland.

RECONSTRUCTION OF THE PRE-APPALACHIAN GRENVILLIAN MARGIN

In order to unravel the nature of the Grenvillian orogenic belt, it is essential to palinspastically restore those external and internal massifs believed to have been contiguous (inboard) parts of the North American craton, but subsequently juxtaposed by thrusting during Palaeozoic orogenesis.

Once the contiguous Grenvillian massifs have been restored, then the other terranes and massifs may be examined to ascertain their compatibility with Grenvillian rocks of the nearby margin of North America. Based on the degree of compatibility, their probable locations during Grenvillian orogenesis and subsequent peregrination during development of the Appalachian orogen may be reconstituted.

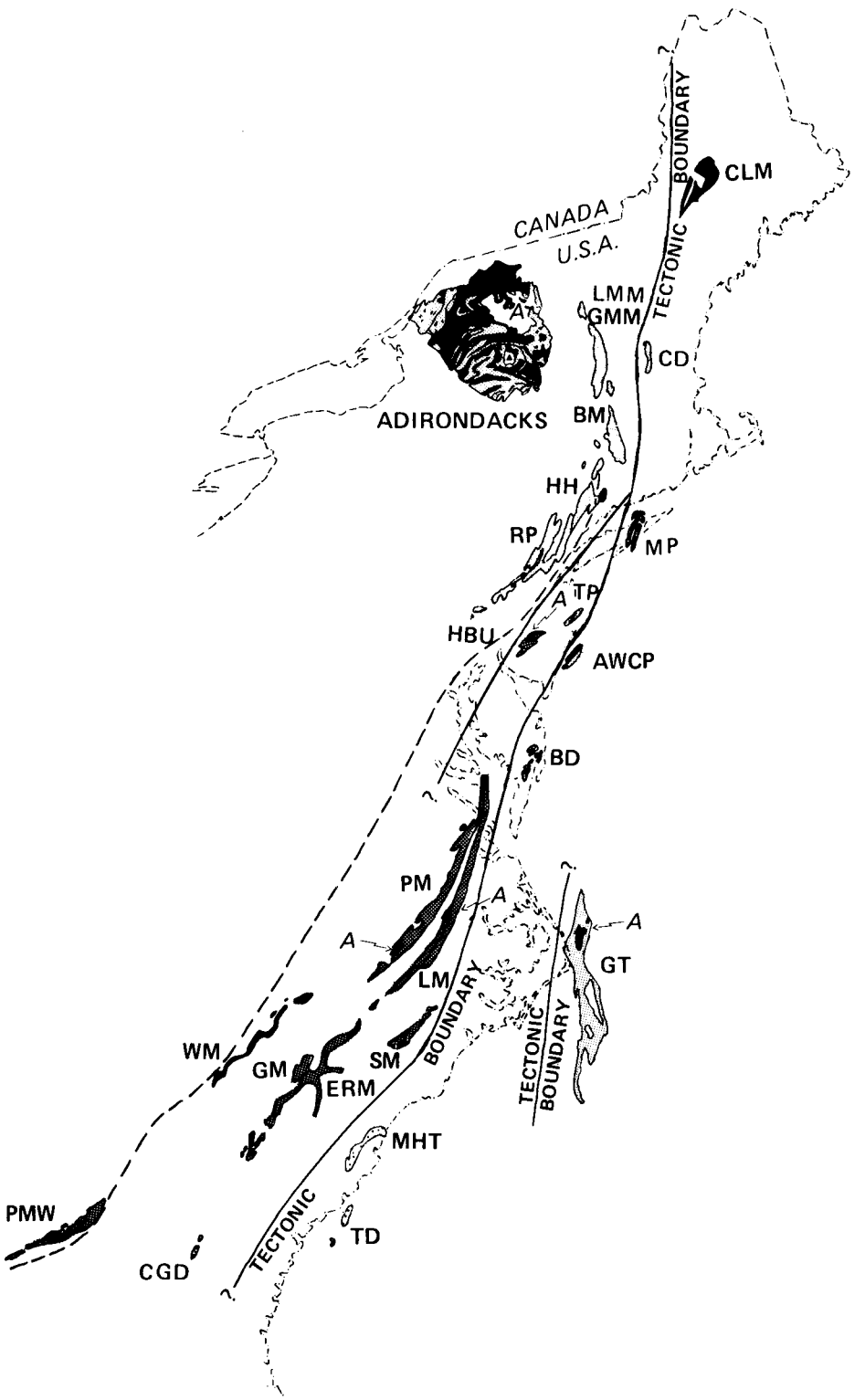
Stanley and Ratcliffe (1985) recently constructed balanced and restored cross sections in a reconstruction for the New England region. They link the Adirondacks and the Grenvillian massifs of New England as a continuous «basement» beneath the Appalachian cover. In our reconstructed map (Fig. 2), we have used their palinspastic locations for the New England massifs. We placed each massif at the center of their reconstructed position for that massif.

Bartholomew (1983) presented a palinspastic map for the Grenvillian rocks of the Blue Ridge in North Carolina and Virginia. We have modified his reconstruction somewhat based on new information on both metamorphism in North Carolina and the Mars Hill terrane (Monrad and Gulley, 1983; Gulley, 1985; N.C.G.S., 1985). This pre-Grenvillian metasedimentary terrane likely had a pre-thrusting location eastward of the Grenvillian volcanic rocks of the Blue Ridge. Moreover, the entire Blue Ridge was thrust over the Pine Mountain window (Cook *et al.,* 1979) during Palaeozoic orogenesis, and thus, originated near the interpreted Palaeozoic edge (Hatcher and Zietz, 1980) of the North American craton.

When the New England massifs are restored and Blue Ridge massifs are approximately relocated relative to both the Pine Mountain window and the Palaeozoic cratonic margin, as well as restored (Fig. 2) in their pre-Appalachian relative positions (Bartholomew, 1983); then locations for the Reading Prong, Trenton Prong, and Honeybrook Upland can be approximated as lying in between the New England and Blue Ridge massifs (Fig. 2). A possible tectonic boundary (heavy solid line) separates the Grenvillian volcanic belt of the Blue Ridge from the Grenvillian platform sequence of the Adirondacks and New England. Possible pre-Appalachian tectonic boundaries also separate outboard terranes, massifs, and «domes» which are likely to have either experienced large-scale dextral translation and/or to be parts of other cratons.

The anomalous massifs and terranes which lie east of the Blue Ridge region are (1) the Mars Hill terrane and Toxaway «dome»; and (2) the Goochland terrane. These areas are all moved a corresponding distance eastward to maintain their relative positions to the restored massifs once the Mars Hill terrane is placed in a position east of the Blue Ridge massifs. These terranes are considered exotic to the Grenvillian Blue Ridge and thus they likely represent either: 1) Grenvillian rocks translated large distances along strike-slip faults during Late Proterozoic-Palaeozoic time, 2) other cratonic areas accreted to North America during the Grenville event, or 3) fragments of other cratonic areas which experienced a temporally equivalent event to the Grenvillie and were subsequently sutured to

Fig. 2.–Distribution of middle Proterozoic terranes, massifs, and «domes» in the eastern U.S.A. based on palinspastic restoration (partially from Stanley and Ratcliffe, 1985; Bartholomew, 1983) of the late Proterozoic margin of the North American craton.
Patterns and symbols are the same as other Figures.


CANADA
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CLM
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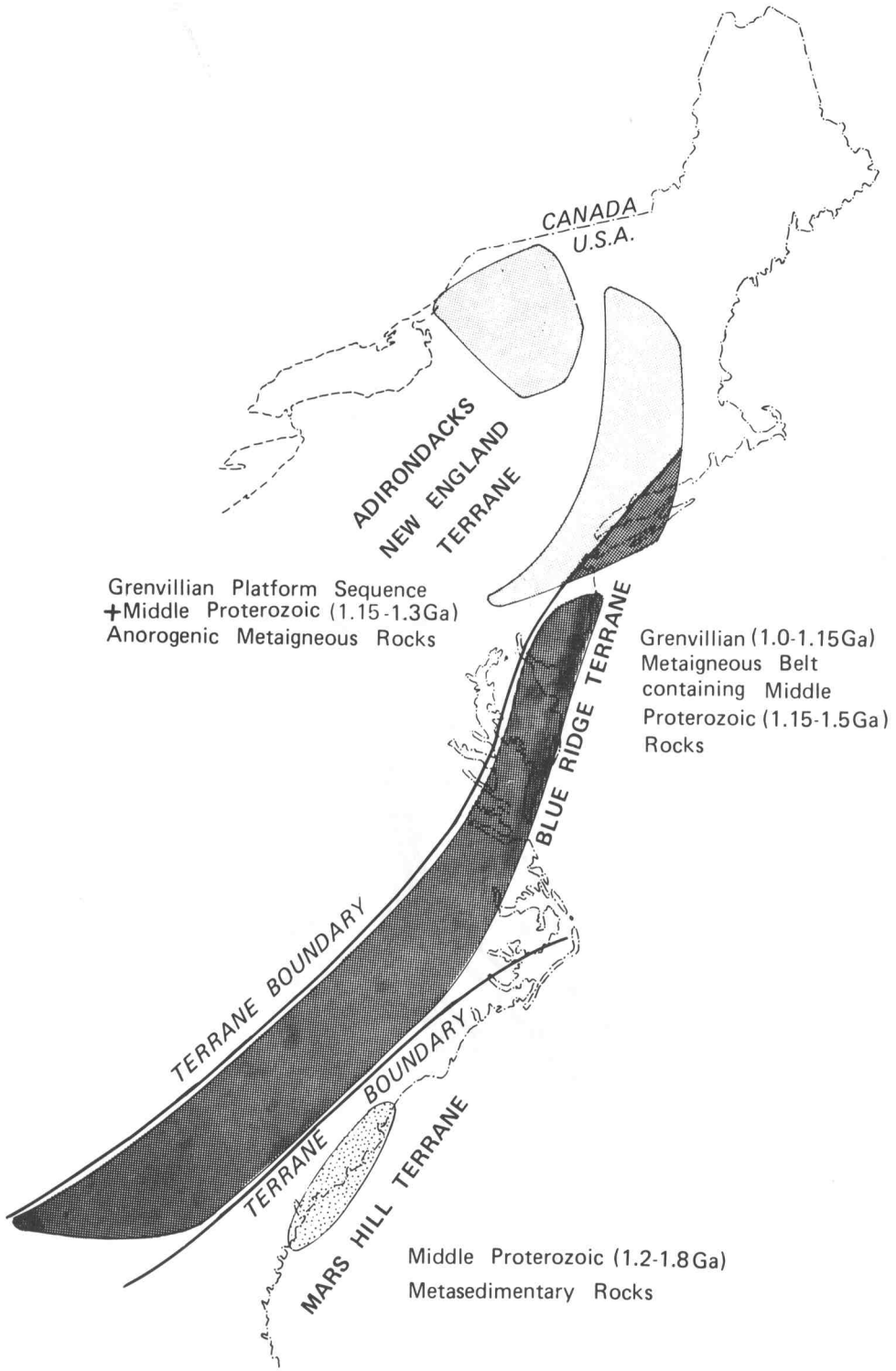
CANADA
U.S.A.
ADIRONDACKS
NEW ENGLAND
TERRANE
Grenvillian Platform Sequence
+Middle Proterozoic (1.15-1.3Ga)
Anorogenic Metaigneous Rocks
Grenvillian (1.0-1.15Ga)
Metaigneous Belt
containing Middle
Proterozoic (1.15-1.5Ga)
Rocks
BLUE RIDGE TERRANE
TERRANE BOUNDARY
TERRANE BOUNDARY
MARS HILL TERRANE
Middle Proterozoic (1.2-1.8Ga)
Metasedimentary Rocks

North America during the Palaeozoic. The Chain Lakes massif of Maine also represents another exotic region which has greater similarity to the Balto-Scandinavian region (Keppie, 1985) than to the nearby Adirondack region. In restoring the New England massifs, the outboard Chain Lakes massif must also be moved a corresponding distance eastward.

Major tectonic boundaries must exist between all of these exotic terranes and the Adirondacks, New England and Blue Ridge portions of the Grenvillie orogenic belt (Fig. 2). There are, however, other massifs, notably the Avondale-West Chester Prong and Baltimore «domes» which may have experienced some strike slip translation, but have not been translated beyond proximity to other related rocks of the Grenvillian orogen. The Sauras massif, like the nearby Blue Ridge massifs, contains the Crossnore plutonic suite, so it cannot have experienced a significant amount of translation.

If the peregrination of the Goochland terrane, and possibly the Manhattan Prong, Avondale-West Chester Prong, and Baltimore «domes» all followed similar paths, then they have originated from Grenvillian positions east of the New England massifs which they resemble more than the Blue Ridge massifs. Moreover, restoring dextral translation (relative to North America) of the Chain Lakes massif would place it in closer proximity to Scandinavia with which Keppie (1985) has correlated it, although he suggested sinistral translation (relative to Scandinavia).

SUBDIVISIONS OF THE GRENVILLIAN OROGENIC BELT

Regardless of the methods used to explain the exotic massifs and terranes found east (outboard) of the restored late Proterozoic margin of North America, it is still apparent that a major Grenvillian boundary separated the Adirondack/New England region from the Blue Ridge region (Bartholomew and Lewis, 1986). The Adirondack/New England region represents a Grenvillian metasedimentary platform sequence associated with the 1.15 + Ga plutonic rocks, whereas, the Blue Ridge region represents a volcanic belt developed along or on an older 1.2 + Ga basement (Fig. 3). At this stage, it is difficult to determine if the Blue Ridge volcanic belt developed along the margin of the Adirondack/New England terrane, or if the Blue Ridge region is itself a Grenvillian terrane accreted to North America during the Grenville event.

To the southeast of the Blue Ridge terrane lie remnants of another possible terrane. The Mars Hill terrane experienced Grenvillian metamorphism, but appears to be a 1.2−1.8 Ga sequence of metasedimentary rocks. Of course, it is possible that the Mars Hill terrane could represent emergent (North American) cratonic rocks (a «two-sided» orogen), but because the older rocks of the Adirondacks/New England terrane are primarily metaigenous this alternative seems less likely than the hypothesis that the Mars Hill terrane is part of another craton accreted to North America during the Grenville event.

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Fig. 3.—Possible Grenvillian terranes of the palinspastically-restored late Proterozoic margin of the North American (eastern U.S.A.) craton. Patterns are the same as on other Figures. CLM, AWCP, and GT are excluded in this diagram.

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