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# *Linking the Pinware, Baraboo, and Picuris orogens: Recognition of a trans-Laurentian ca. 1520–1340 Ma orogenic belt*

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## ABSTRACT

**It is proposed that the Pinware orogen of eastern Canada, the Baraboo orogen of the midcontinent, and the Picuris orogen of the southwestern United States delineate a previously unrecognized, ~5000-km-long, ca. 1520–1340 Ma trans-Laurentian orogenic belt. All three orogenic provinces are characterized by Mesoproterozoic sedimentation, magmatism, metamorphism, and deformation—the hallmarks of a tectonically active plate margin. Tectonism was diachronous, with the earliest stages beginning ca. 1520 Ma in eastern Canada and ca. 1500 Ma in the southwest United States. Magmatic zircon age distributions are dominated by Mesoproterozoic, unimodal to multimodal age peaks between ca. 1500 and 1340 Ma. The onset of magmatism in the Pinware and Baraboo orogens was ca. 1520 Ma, and onset for the Picuris orogen was ca. 1485 Ma. Detrital zircon age distributions within each orogenic province yield maximum depositional ages between ca. 1570 and 1450 Ma. Minimum depositional ages generally fall between ca. 1500 and 1435 Ma, as constrained by crosscutting intrusions, metatuff layers, or the age of subsequent metamorphism. Metamorphic mineral growth ages from zircon, garnet, and monazite yield peak ages between ca. 1500 and 1350 Ma and tend to be older in the Pinware and Baraboo**

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**orogens than in the Picuris orogen. The $^{40}Ar/^{39}Ar$ cooling ages for hornblende, muscovite, and biotite yield significant peak ages between ca. 1500 and 1350 Ma in the Baraboo and Picuris orogens. We propose that the Pinware-Baraboo-Picuris orogen formed in a complex, diachronous, convergent margin setting along the southern edge of Laurentia from ca. 1520 to 1340 Ma.**

## INTRODUCTION

The Mesoproterozoic ca. 1500–1340 Ma tectonic setting for southern Laurentia has long been enigmatic and controversial. Early tectonic models for the southwestern United States and the midcontinent were rooted in explaining the origin and emplacement of widespread ferroan (or "A-type") granitoids (Figs. 1 and 2A). The geochemical and isotopic characteristics of these granitoids and the lack of obvious deformation led to the proposal of an "anorogenic" setting associated with mantle upwelling and continental extension in the midcontinent and southwest United States (Anderson, 1983; Thomas et al., 1984; Anderson and Bender, 1989; Hoffman, 1989; Anderson and Morrison, 1992; Bickford and Anderson, 1993; Frost and Frost, 1997). However, since the mid-1990s, numerous studies have documented deformation and the syntectonic emplacement of granitoids in the southwestern United States (Aleinikoff et al., 1993; Nyman et al., 1994; Kirby et al., 1995; Duebendorfer and Christensen, 1995; Gonzales et al., 1996; Nyman and Karlstrom, 1997; Jessup et al., 2006; Jones et al., 2010; Amato et al., 2011). Nyman et al. (1994) proposed that the emplacement of the granitoids was synorogenic and associated with a transpressive convergent margin along the southern edge of Laurentia at ca. 1450 Ma. Alternatively, Goodge and Vervoort (2006) suggested that the ferroan granites in southern Laurentia formed by radioactive heating and subsequent melting of continental crust tectonically thickened during the ca. 1650 Ma Mazatzal orogeny.

Although the "anorogenic" model remained ingrained in the literature (Anderson and Morrison, 2005; Frost and Frost, 2013), alternative hypotheses favoring an active-margin setting have gained increasing acceptance. These attribute the generation of many of the granitoids to partial melting of lower continental crust in a continental arc and back-arc setting and document geochemical or isotopic evidence that is permissive of, or consistent with, Mesoproterozoic subduction (Patchett and Ruiz, 1989; Karlstrom et al., 2001; Menuge et al., 2002; Walker et al., 2002; Slagstad et al., 2009; Bickford et al., 2015; Marshall et al., 2017). Furthermore, in eastern Canada, a subduction

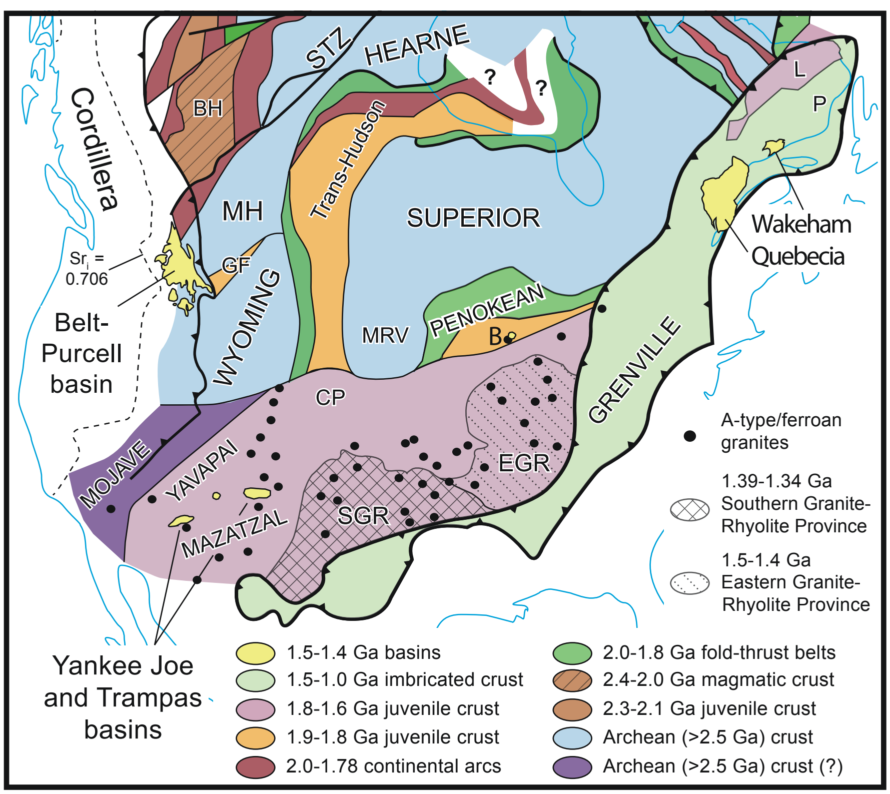


Figure 1. Simplified geologic map of crustal provinces, ca. 1500–1400 Ma basins, and ca. 1500–1340 Ma plutons within North America. Abbreviations: B—Baldwin metaconglomerate; BH—Buffalo Head terrane; CP—Central Plains Province; EGR—Eastern Granite-Rhyolite Province; GF—Great Falls tectonic zone; L—Labradorian Province; MH—Medicine Hat block; MRV—Minnesota River valley subprovince; P—Pinware terrane; SGR—Southern Granite-Rhyolite Province; STZ—Snowbird tectonic zone. Figure is modified from Jones et al. (2015).

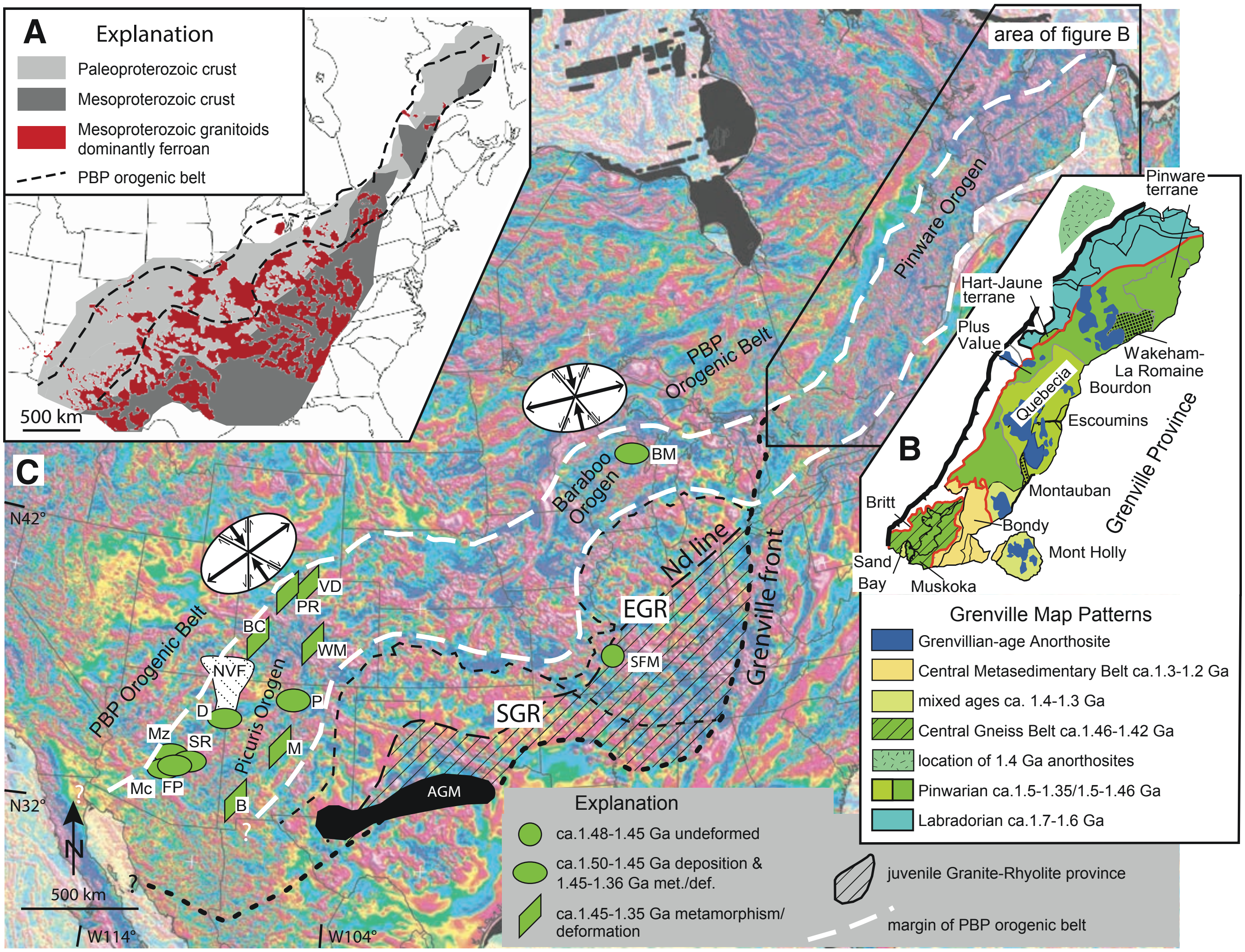


Figure 2. (A) Inset shows simplified geologic map of Paleoproterozoic and Mesoproterozoic crustal provinces across the central United States and eastern Canada, exposed and inferred Mesoproterozoic (ca. 1500–1350 Ma), dominantly ferroan granitoids (modified from Whitmeyer and Karlstrom, 2007), and the approximate outline of the Pinware-Baraboo-Picuris (PBP) orogen. (B) Simplified geologic map of eastern Canada that highlights the extent of ca. 1500–1435 Ma crust and the juvenile Quebecia terrane (modified from Groulier et al., 2020). (C) Aeromagnetic anomaly map of North America (Bankey et al., 2002) with locations of ca. 1500–1450 Ma deposition, and ca. 1450–1350 Ma regional metamorphism and deformation that define the approximate extent of the Pinware-Baraboo-Picuris orogeny. Abbreviations: D—Defiance uplift (Doe et al., 2013); FP—Four Peaks (Mako et al., 2015); Mc—MacDowell Mountains (Skotnicki and Gruber, 2019); P—Picuris Mountains (Daniel et al., 2013b; Aronoff et al., 2016); and SR—Salt River Canyon (Doe et al., 2013). Additional control points are based on ca. 1450–1350 Ma regional deformation and metamorphism (met./def.) of Paleoproterozoic rocks and deformation associated with ca. 1500–1350 Ma plutons. Abbreviations: BC—Black Canyon (Jessup et al., 2006); B—Burro Mountains (Amato et al., 2011); M—Manzano Mountains (Holland et al., 2020); PR—Park Range and VD—Virginia Dell (Shaw et al., 2005); WM—Wet Mountains (Jones et al., 2010; Hernández-Montenegro et al., 2019). Control points in the midcontinent include the undeformed Mesoproterozoic St. Francis Mountains (SFM; du Bray et al., 2018, 2021) and the deformed and contact metamorphosed ca. 1490–1470 Ma Baldwin metaconglomerate (BM; Medaris et al., 2021). Strain ellipsoids for the southwest United States and the northern midcontinent are modified from Jones et al. (2010) and Craddock and McKiernan (2007), respectively. The Southern and Eastern Granite-Rhyolite terranes (SGR and EGR) are outlined with the thin, black dashed line. Other abbreviations include AGM—Abilene gravity minimum and NVF—Navajo volcanic field. Pinware-Baraboo-Picuris (PBP) orogenic belt is outlined by white dashed lines that denote the approximate area of ca. 1450–1350 Ma regional metamorphism, deformation, and magmatism. Heavy black dashed line represents the approximate location of the Grenville deformation front. Mz—northern Mazatzal mountains (Doe and Daniel, 2019).

model was adopted in the late 1990s, and an Andean analog was invoked, which is supported by remnant Mesoproterozoic arc-type lithologic associations in the Grenville Province (Fig. 1; e.g., Rivers, 1997; Gower and Krogh, 2002; Slagstad et al., 2009; Groulier et al., 2020).

A critical turning point in our understanding of the Proterozoic tectonic evolution of the Laurentian margin in the southwestern United States and the midcontinent took place with the recognition of Mesoproterozoic (ca. 1500–1450 Ma) depositional ages of supracrustal rocks previously thought to be Paleoproterozoic (Figs. 1 and 3; Jones et al., 2011; Doe et al., 2012; Daniel et al., 2013a, 2013b; Doe et al., 2013; Mako et al., 2015; Medaris et al., 2021). Numerous studies have documented the ca. 1470–1350 Ma timing of regional metamorphism and deformation in Mesoproterozoic and underlying Paleoproterozoic supracrustal rocks (Williams et al., 1999; Daniel and Pyle, 2006; Jones et al., 2010, 2011; Doe et al., 2012, 2013; Daniel et al., 2013a, 2013b; Mako et al., 2015; Aronoff et al., 2016; Doe and Daniel, 2019; Medaris et al., 2021). The goal of this chapter is to summarize the evidence for Mesoproterozoic ca. 1520–1340 Ma deposition, plutonism, metamorphism, and deformation in the Pinware orogen of eastern Canada, the Baraboo orogen of the midcontinent, and the Picuris orogen in the southwestern United States and to define a previously unrecognized Mesoproterozoic, ca. 1520–1340 Ma trans-Laurentian orogenic belt.

## GEOLOGIC ELEMENTS OF THE PINWARE-BARABOO-PICURIS OROGENIC BELT

### Description of Orogenic Provinces

#### *1500–1350 Ma Grenville Province and the Pinwarian Orogen*

The Grenville Province (Figs. 2B and 3) preserves a record of widespread crustal addition and reworking from ca. 1520 to 1340 Ma, despite substantial overprinting by the late Mesoproterozoic, ca. 1090–980 Grenvillian orogeny. As originally defined, the Pinwarian orogeny spanned ca. 1500–1470 Ma, based upon sporadic, but locally well-preserved, evidence for deformation and metamorphism in the eastern Grenville Province (Tucker and Gower, 1994). Subsequent work expanded the timing of the orogeny from ca. 1520 to 1460 Ma (Gower and Krogh, 2002). In the same broad region, widespread felsic plutonism occurred at 1510–1460 Ma, represented dominantly by K-rich granites and subordinate anorthosite-mangerite-charnockite-granite (AMCG)–type lithologies (Figs. 2B and 3). In addition, north of the Grenville front, there is a broad N-S–trending belt of AMCG suites that range in age from 1478 to 1420 Ma (Fig. 2B; Michikamau, Harp Lake, Mistasin) to ca. 1300 Ma (see Gower and Krogh, 2002).

Pinware-age plutons intruding Paleoproterozoic (Labradorian-age) rocks represent most of the exposed crust in the Pinware terrane in the eastern Grenville Province (Fig. 2B; Tucker and Gower, 1994), and they are interpreted as having formed in a continental arc system associated with subduction under Laurentia (Fig. 3; Gower and Krogh, 2002). To the south, the Pinware terrane transitions into a ca. 1520–1490 Ma volcano-sedimentary succession of continental to shallow-marine siliciclastic sedimentary rocks overlain by dominantly felsic volcanic rocks in the eastern Wakeham–La Romaine supracrustal belts (Figs. 2B and 3; Corriveau and Bonnet, 2005). These belts and their plutonic substratum of granodiorite to granite are interpreted to be remnants of a continental back-arc system (see also Groulier et al., 2020). Pinwarian crust in the eastern Grenville Province has ca. 1750–1650 Ma Nd model ages (Labradoria of Dickin et al., 2010).

In contrast, the Mesoproterozoic part of the central Grenville Province is dominated by a largely juvenile terrane (Quebecia; Figs. 2B and 3) with 1500 Ma Nd model ages (Dickin et al., 2010), interpreted as a composite arc belt (Vautour and Dickin, 2019; Groulier et al., 2020), which consists of (1) ca. 1500 Ma metasedimentary sequences (Plus Value and Bourdon complexes) attributed to earlier rifting of the Laurentian margin (Figs. 2B and 3); (2) remnants of 1500–1450 Ma peri-Laurentian oceanic arcs to the south built on rifted crustal slivers (Escoumins supracrustal belt and Montauban Group); (3) 1430–1370 Ma variably gneissic granite to tonalite plutonic belts, with a subset at ca. 1400–1390 Ma marking the time of accretion of Quebecia to Laurentia; and (4) 1380–1350 Ma AMCG complexes attributed to slab breakoff following arc accretion (Groulier et al., 2020). In the central Grenville Province (Figs. 2B and 3), evidence of Pinwarian-age metamorphism (granulite facies) and deformation is only present north of Quebecia (Hart Jaune terrane; see Gower and Krogh, 2002).

In the southwestern Grenville Province, there is a transition from older, 1480–1450 Ma plutonism and local metamorphism to younger, 1390–1300 Ma magmatism and deposition (Fig. 3). In southwestern Quebec, a 1468 Ma granite and charnockite igneous suite intrudes Labradorian-age rocks, and a ca. 1380–1365 Ma association of granitic to tonalitic orthogneisses constitutes the tectonic basement of the Central Metasedimentary belt to the south (Indares et al., this volume). In the Central Gneiss belt in Ontario, 1480–1450 Ma magnesian granitoid plutonism, which is prominent in the Muskoka domain (Fig. 3), is linked in time and space with ferroan granites (Slagstad et al., 2009). In addition, Paleoproterozoic rocks (correlative with the Penokean and Yavapai/Mazatzal crustal provinces) of the structurally lowest Britt domain (north of Muskoka) are intruded by ca. 1450 Ma ferroan granitic plutons, anorthosite, and gabbro (Figs. 2B and 3). Overall, the ferroan-type magmatism is subordinate and inferred to represent a rapid transition from an arc to a back-arc setting. In the Muskoka domain, Nd model ages of 1740–1660 Ma in the north and 1620–1500 Ma in the south prompted correlation with the Nd line of Van Schmus et al. (2007) in the Granite-Rhyolite Province (Slagstad et al., 2009). In addition, the Britt domain (Fig. 2B) records evidence for ca. 1450 Ma granulite-facies metamorphism (with pressure and temperature estimates of 7.2–8.4 kbar and 625–700 °C, respectively) and contractional deformation (Ketchum et al., 1994).

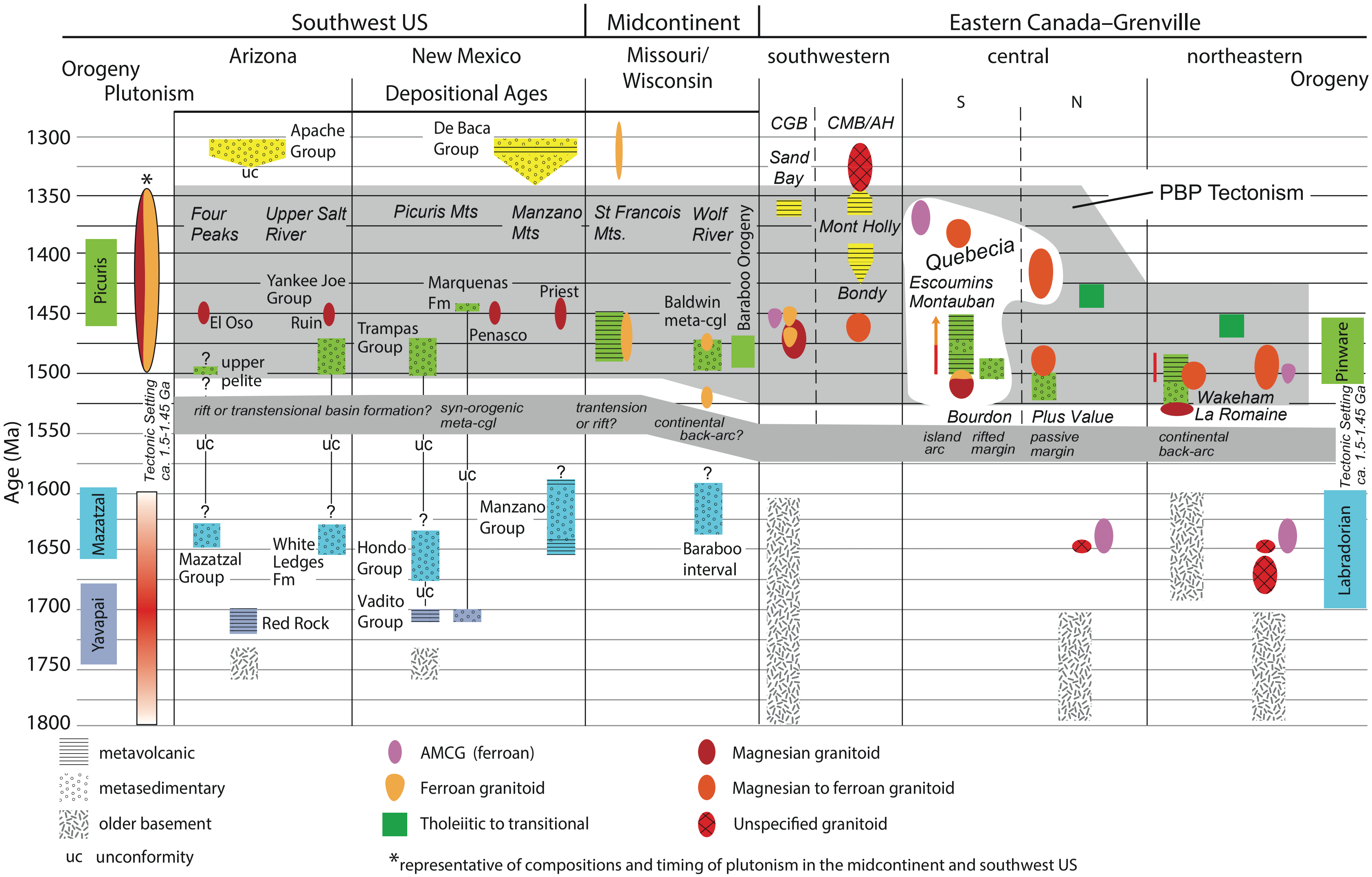


Figure 3. Simplified composite correlation diagram showing the depositional ages of key Mesoproterozoic sections from the southwest United States, midcontinent, and eastern Canada, the timing of local and regional magmatism, and regional orogenesis. Magmatism in the midcontinent was dominantly ferroan. Magmatism in the southwest United States ranged from ferroan to magnesian. Plutons shown in the diagram for the southwest United States are used to illustrate timing constraints on deposition and/or deformation; they are not representative of the compositional variation of plutons across the region (for more information, see du Bray et al., 2018). Abbreviations: AH—Adirondack highlands; AMCG—anorthosite-mangerite-charnockite-granite; CGB—Central Gneiss belt; CMB—Central Metamorphic belt; meta-cgl—metaconglomerate; PBP—Pinware-Baraboo-Picuris orogeny; uc—unconformity.

Supracrustal successions include the Bondy gneissic complex (Figs. 2B and 3), interpreted as derived from a bimodal volcanic suite and ca. 1390 Ma tonalitic plutons in a mature island arc undergoing rifting (Wodicka et al., 2004; Blein et al., 2003), and the bimodal 1360 Ma Sand Bay gneiss association, attributed to a back-arc setting (Figs. 2B and 3; Culshaw and Dostal, 1997). Farther south, in the Green Mountains, Vermont, ca. 1360 Ma metavolcanic rocks of dacitic and basaltic composition in the Mont Holly complex were intruded by felsic orthogneisses at 1340–1300 Ma (Figs. 2B and 3; see also Rivers and Corrigan, 2000; Aleinikoff et al., 2011). These younger successions are attributed to outboard stepping of subduction (see Carr et al., 2000; Slagstad et al., 2009).

In summary, Mesoproterozoic crust in the Grenville Province is inferred to consist of two continental arc segments separated by a composite arc belt (Quebecia) with remnants of pericratonic island arcs (Groulier et al., 2020; Indares et al., this volume). The onset of tectonic activity in the northeastern segment and in Quebecia is characterized by ca. 1520 Ma magmatism and deposition, whereas magmatism in the southwestern segment began at ca. 1485 Ma (Fig. 3). Regional metamorphism, deformation, and crustal thickening associated with the Pinwarian orogeny was under way by ca. 1510 Ma and ended ca. 1460 Ma.

### *Midcontinent Baraboo Orogeny*

Supermature siliciclastic sedimentary rocks of the Paleoproterozoic Baraboo interval provide key evidence for ca. 1490 Ma deformation in the midcontinent (Figs. 2C and 3). These distinctive sedimentary rocks were deposited on Algoman, Penokean, and Yavapai basement (Fig. 1) over an ~300,000 km$^2$ area in the southern Lake Superior region, reaching a thickness of ~1.5 km in the Baraboo Range in south-central Wisconsin. Detrital zircons from the lower part of the Waterloo Quartzite, located ~60 km east of the Baraboo Range, define a maximum depositional age of 1643 ± 11 Ma ($n$ = 42, mean square of weighted deviates [MSWD] = 1.05; Medaris et al., 2021). In the western and northern areas of the southern Lake Superior region, Baraboo interval strata are flat-lying, whereas to the east and south, the strata within the Baraboo orogen are folded and contain greenschist-facies mineral assemblages. Metasomatic muscovite from Baraboo interval strata yields $^{40}Ar/^{39}Ar$ cooling ages between 1478 ± 12 and 1467 ± 11 Ma. The Seely Slate, which overlies the Baraboo Quartzite, contains muscovite aligned parallel to axial plane cleavage and yields whole-rock $^{40}Ar/^{39}Ar$ cooling ages between 1493 ± 3 and 1473 ± 3 Ma (Medaris et al., 2021). Similarly, muscovite that decorates a crenulation cleavage in Waterloo metapelite yields an age of 1465 ± 5 Ma (Medaris et al., 2021). These results record the hydrothermal introduction of potassium and crystallization of muscovite along permeable channels in the shallow crust during geon 14 regional deformation and metamorphism. In addition, U-Th–total Pb dating of neoblastic overgrowths on detrital monazite gives an age of 1488 ± 20 Ma, and recrystallized hematite in folded metapelite gives a mean U/Th–He age of 1411 ± 39 Ma, both from the Baraboo Range (Medaris et al., 2021).

The Baldwin Conglomerate, which is located at the northern edge of the Wolf River batholith (Figs. 1, 2C, and 3), is the only early Mesoproterozoic (Calymmian) sedimentary rock recognized so far in the southern Lake Superior region (Medaris et al., 2021). It lies unconformably on Penokean granitic gneiss and basaltic metavolcanic rocks and is intruded and metamorphosed by the Hager granite and feldspar porphyry, which are subvolcanic plutons in the Wolf River batholith. The conglomerate is polymictic and chemically immature, containing clasts of the underlying Penokean lithologies and quartzite set in a medium-grained feldspathic matrix. Detrital zircon from the conglomerate yields a U-Pb relative age probability plot with a youngest age peak at 1493 Ma (Medaris et al., 2021). The conglomerate was intruded at a relatively shallow crustal level by the Hager granite porphyry, which has a concordant, multigrain thermal ionization mass spectrometry (TIMS) zircon crystallization age of 1471 ± 2 Ma (DeWayne and Van Schmus, 2007).

The magmatic component of the Baraboo orogeny resides in the geon 14 Wolf River granitic batholith, which underlies an area of ~9200 km$^2$ in east-central Wisconsin, where it intrudes the geon 18 Penokean Province, the geon 17 Yavapai Province, Baraboo interval quartzites, and the Baldwin conglomerate (Van Schmus et al., 1975; Anderson and Cullers, 1978; Anderson, 1980; DeWayne and Van Schmus, 2007; Medaris et al., 2021). The batholith is the only geon 14 igneous unit exposed in the southern Lake Superior region, although granites of this age occur widely in the subsurface to the south in the Granite-Rhyolite Province (Bickford et al., 2015; du Bray et al., 2018; Freiburg et al., 2020). The batholith, which consists mainly of 1476–1470 Ma granite and quartz monzonite and includes minor occurrences of older monzonite and anorthosite, was derived by partial melting of tonalitic to granodioritic crust at depths of 25–36 km and emplaced at depths of 3.8 km or less (Anderson and Cullers, 1978; Anderson, 1980; Goodge and Vervoort, 2006). The granite and quartz monzonite plutons are ferroan in composition (0.81 < Fe# < 0.95), have an alkali-lime index of 51 (on the boundary between the alkaline and alkali-calcic fields), and range from metaluminous to peraluminous (0.92 < aluminum saturation index < 1.12).

Deformed Baraboo interval strata extend ~300 km across strike from the Flambeau syncline in the north to the Baraboo syncline in the south and are interpreted as the remnants of a south-vergent fold-and-thrust belt (Craddock and McKiernan, 2007). Quartzite in the Baraboo syncline is interpreted to have recrystallized at a depth of ~10 km and at temperatures near 350 °C (Craddock and McKiernan, 2007; Czeck and Ormand, 2007). Fold axes are oriented ENE-WSW, for which finite strain analyses have documented NW-SE tectonic shortening (Craddock and McKiernan, 2007). Finite strain magnitudes increase from the undeformed Sioux and Barron quartzites in the northwest to the folded Baraboo and Waterloo quartzites in the southeast, with the axial ratios of strain ellipsoids for quartz increasing from 1.08:1:0.92 in the northwest to 1.24:1:0.79 in the southeast. Although the Wolf River batholith is largely undeformed on a macroscopic scale, the orientations of healed microcracks and planes of fluid inclusions in quartz record a NW-SE maximum horizontal stress for the region at ca. 1470 Ma (Jang et al., 1989; Jang and Wang, 1991), which is consistent with the strain regime for the folded quartzites. The timing of the Baraboo orogen, characterized by folding and greenschist-facies metamorphism of the Baraboo interval rocks and deformation of the Baldwin metaconglomerate and Wolf River batholith, is estimated at ca. 1490–1470 Ma. Prior to the discovery of the Mesoproterozoic protolith and metamorphic ages for these rocks, they were interpreted to have experienced metamorphism and deformation associated with the ca. 1650 Ma Mazatzal orogeny (Craddock and McKiernan, 2007; Czeck and Ormand, 2007; Holm et al., 2007, 2020).

### *Southwestern U.S. Picuris Orogeny*

The Picuris orogeny was defined in northern New Mexico based upon the occurrence of deformed, amphibolite-facies metasedimentary rocks with Mesoproterozoic ca. 1500–1450 Ma depositional ages, including the Trampas Group and the Marqueñas metaconglomerate (Figs. 2C and 3; Daniel et al., 2013a, 2013b; Bristol et al., 2014; Aronoff et al., 2016). Mesoproterozoic and Paleoproterozoic supracrustal rocks in northern New Mexico commonly yield metamorphic mineral growth ages and cooling ages between ca. 1435 and 1350 Ma (Karlstrom et al., 1997; Lanzirotti and Hanson, 1997; Williams et al., 1999; Shaw et al., 2005; Daniel and Pyle, 2006; Daniel et al., 2013b; Aronoff et al., 2016). A few isolated areas in central and northern New Mexico, including the central Manzano and Manzanita Mountains (Holland et al., 2020) and the Cimarron River tectonic unit of Grambling and Dallmeyer (1993), preserve Paleoproterozoic cooling ages and escaped the Picuris amphibolite-facies overprint. Regional metamorphic rocks in northern New Mexico and southern Colorado yield clockwise pressure-temperature (*P-T*) loops where $P_{max}$ commonly precedes $T_{max}$ (Fig. 4; Pedrick et al., 1998; Daniel and Pyle, 2006; Barnhart et al., 2012; Hernández-Montenegro et al., 2019). Maximum pressures vary between ~0.3 and 0.8 GPa, peak temperatures range from 550 °C to 700 °C, and *P-T* paths record ~0.1–0.4 GPa of decompression (Pedrick et al., 1998; Daniel and Pyle, 2006; Barnhart et al., 2012; Aronoff et al., 2016).

The Picuris orogen extends to central Arizona and includes clastic metasedimentary rocks with Mesoproterozoic ca. 1570–1450 Ma depositional ages from the Defiance area, the upper Salt River Canyon, Four Peaks, and northern Mazatzal Mountains of Arizona (Figs. 2C and 3; Doe et al., 2012, 2013; Bristol et al., 2014; Mako et al., 2015; Doe and Daniel, 2019). Within the McDowell Mountains, mixed volcanic and clastic rocks yield depositional ages of ca. 1546 Ma and older (Skotnicki and Gruber, 2019; Skotnicki and van Soest, 2019). All areas exhibit greenschist-facies metamorphism with superimposed contact metamorphic aureoles associated with the emplacement of ca. 1450–1425 Ma granitic plutons (Doe et al., 2012, 2013; Mako et al., 2015; Doe and Daniel, 2019). In summary, deformation and metamorphism attributed to the Picuris orogeny are estimated to have occurred from ca. 1460 to 1390 Ma. Prior to the discovery of the ca. 1540–1450 Ma protolith ages for these rocks, they were interpreted to have been deposited in the Paleoproterozoic Era, and to have experienced metamorphism and deformation associated with the ca. 1650 Ma Mazatzal orogeny.

### Mesoproterozoic Circa 1525–1350 Ma Trans-Laurentian Magmatic Belt

The igneous component of the Pinware-Baraboo-Picuris orogen is represented by ferroan to magnesian granitoids and subordinate volcanic rocks that were emplaced in a wide swath across North America between ca. 1520 and 1350 Ma (Figs. 1 and 2A; Bickford et al., 2015; du Bray et al., 2018; Indares et al., this volume). Ferroan granitoid magmatism was originally described as "A-type" by Anderson (1983). Anderson and Morrison (2005) distinguished three groups of granite: (1) an ilmenite series (ferroan) in Wyoming, Wisconsin, and Labrador (Canada), which is associated with anorthosite and monzonite; (2) a magnetite series (ferroan) in the central to southwestern United States; and (3) a two-mica series (magnesian) in Colorado to central Arizona. All three groups are rich in alkali feldspar and range in mineralogical composition from quartz monzonite to granite,

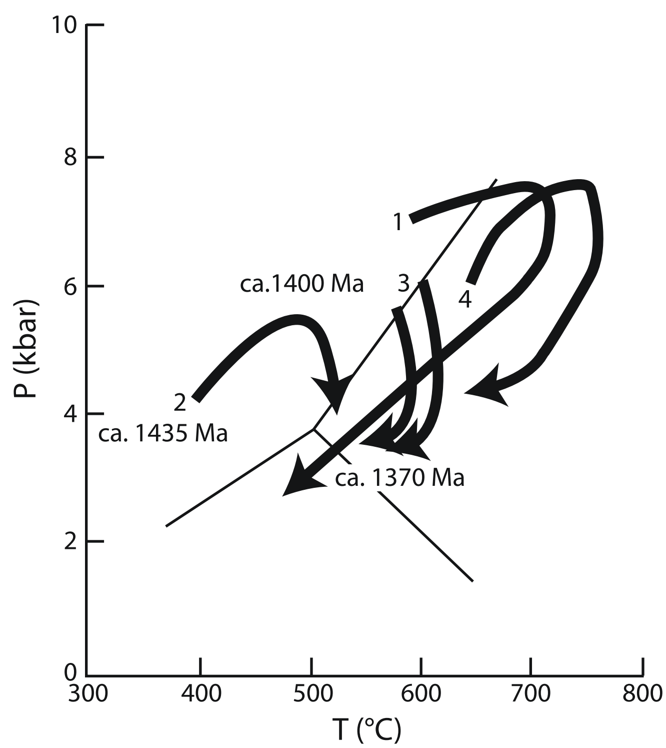


Figure 4. Summary of Mesoproterozoic metamorphic pressure-temperature (*P-T*) paths from northern New Mexico, including (1) northern Taos mountains (Pedrick et al., 1998); (2) northern Picuris Mountains (Daniel and Pyle, 2006); (3) Cerro Colorado (Barnhart et al., 2012); and (4) the southern Wet Mountains, southern Colorado (Hernández-Montenegro et al., 2019).

being markedly distinct from the plagioclase-rich compositions of I-type granites characteristic of convergent margin settings. Whole-rock major-element, trace-element, and oxygen isotopic compositions (Anderson, 1983; Anderson and Thomas, 1985; Anderson and Bender, 1989; Anderson and Morrison, 2005) and zircon Lu-Hf isotopic data (Goodge and Vervoort, 2006; Bickford et al., 2015) are consistent with derivation of the 1485–1350 Ma granite suites by partial melting of lower continental crust in different Paleoproterozoic geologic provinces.

The Granite-Rhyolite Province of the southern midcontinent preserves a 1550 Ma "Nd line" between Mesoproterozoic granites derived from older (depleted mantle model age [$T_{DM}$] > 1550 Ma) reworked Paleoproterozoic crust to the northwest and dominantly juvenile granites ($T_{DM}$ < 1550 Ma) to the southeast (Van Schmus et al., 1996; Rohs and Van Schmus, 2007; Bickford et al., 2015). The origin of the juvenile rocks exposed in the St. Francois Mountains of southeast Missouri is controversial. Numerous studies have proposed an extensional tectonic setting while others have proposed a subduction zone setting (see Walker et al., 2002; Menuge et al., 2002; Anderson and Morrison, 2005; Slagstad et al., 2009; Bickford et al., 2015; du Bray et al., 2018, 2021, for further references and discussions). Bickford et al. (2015) speculated that rocks such as the ca. 1462 ± 1 Ma Hawn Park gneiss in the St. Francois Mountains and the ca. 1390 Ma Blue River gneiss, Arbuckle Mountains, Oklahoma, may represent parts of a Mesoproterozoic arc. Although direct evidence of a magmatic arc is scarce in the midcontinent, the Abilene gravity minimum (Fig. 2C) is inferred to be a buried magmatic arc of possible Mesoproterozoic age (Adams and Keller, 1996).

The extension of the ferroan (A-type) magmatic belt into eastern Canada was proposed by Anderson (1983) based on the 1400 Ma AMCG suites in Labrador. Since then, widespread 1500–1350 Ma granitoid magmatism has been identified in the Grenville Province, but it is seldom associated with AMCG magmatism (Figs. 2B and 3; see review in Indares et al., this volume). A large part of this magmatism is represented by plutons and felsic orthogneisses spatially associated with arc-related supracrustal belts to the south (e.g., Wakeham–La Romaine groups, Escoumins supracrustal belt, Bondy gneiss complex; Fig. 2B). In these settings, tonalitic to granodioritic, magnesian, and mostly calc-alkalic plutonism transitions to dominantly ferroan, calc-alkalic to alkali-calcic granitic lithologies. In contrast, farther inboard, felsic magmatism is dominantly granitic ferroan and alkali-calcic (to locally alkalic) and is associated in some instances with AMCG magmatism (e.g., in the Pinware terrane, Muskoka). Specific suites are peraluminous and marginal or metaluminous, and most of them, in any setting, have trace-element signatures that range from volcanic-arc to within-plate settings. The geochemical patterns shown in Indares et al. (this volume) are consistent with a subduction environment with episodes of back-arc extension, as commonly advocated for the 1500–1350 Ma crustal domains in the Grenville Province (e.g., Corriveau and Bonnet, 2005; Slagstad et al., 2009; Groulier et al., 2020). The AMCG suites north of the Grenville Province in Labrador are distinct, as they follow N-S–trending Paleoproterozoic crustal boundaries and are part of an intermittent 1540–1300 Ma AMCG magmatic event (Fig. 2B). Proposed interpretations include a back-arc setting (Rivers, 1997) or flat funneled subduction (Gower and Krogh, 2002), but their origin and relation to the 1500–1350 Ma magmatic events in the eastern Canada remain poorly understood.

## Summary of Geochronology from the Pinware-Baraboo-Picuris Orogen

Selected dates from multiple isotopic systems and minerals were compiled across all three orogenic provinces to compare the timing of magmatism, detrital zircon age populations, and metamorphic mineral growth and cooling ages (Supplemental Table S1[1]). The data are summarized in Figure 5 as normalized age distribution plots. Figure 5 was constructed by plotting the compiled dates for each area, method, and mineral, and then cropping the plot to show only the age distribution curves between 1800 and 1300 Ma. The data set consists of previously published dates, except for 12 Sm-Nd garnet dates and four monazite dates from the Picuris Mountains provided by Bollen (2021, personal commun.). Detrital zircon dates are generally restricted to rock units deposited between ca. 1530 and 1440 Ma. Mesoproterozoic metamorphic dates from the midcontinent and eastern Canada are especially limited due to the relatively small, exposed area of the Baraboo orogen and overprinting Grenville-age metamorphism, respectively.

The lowermost zircon age distribution (Fig. 5A) is from plutonic and supracrustal rocks in eastern Canada (*n* = 119), and it shows igneous crystallization ages with a multimodal peak age distribution. Three relatively prominent age peaks appear in the Mesoproterozoic at ca. 1500, 1460, and 1375 Ma, along with a Paleoproterozoic peak age of ca. 1650 Ma. Zircon crystallization ages (*n* = 203) for plutonic and supracrustal rocks from the midcontinent are characterized by a bimodal Mesoproterozoic age distribution with distinct peaks at ca. 1465 Ma and 1370 Ma (Fig. 5B). The Mesoproterozoic age peaks correlate with the Mesoproterozoic trans-Laurentian magmatic event, and the bimodal distribution has been noted in previous studies (Goodge and Vervoort, 2006; Bickford et al., 2015; du Bray et al., 2018). The southwestern United States (Fig. 5C) yields a bimodal age distribution for igneous zircon ages (*n* = 376) with a broad Paleoproterozoic peak between ca. 1800 and 1650 Ma and a dominant peak at ca. 1435 Ma. A minor peak occurs near 1370 Ma. Both metamorphic and igneous zircon dates from crustal xenoliths from the Navajo volcanic field (*n* = 99) are represented in Figure 5D and yield a well-defined peak at ca. 1405 Ma. These zircon dates indicate significant

[1]Supplemental Material. Table S1: Compilation of selected geochronological data and PDF listing references used to construct Figure 5. Please visit https://doi.org/10.1130/MWR.S.21035323 to access the supplemental material, and contact editing@geosociety.org with any questions.

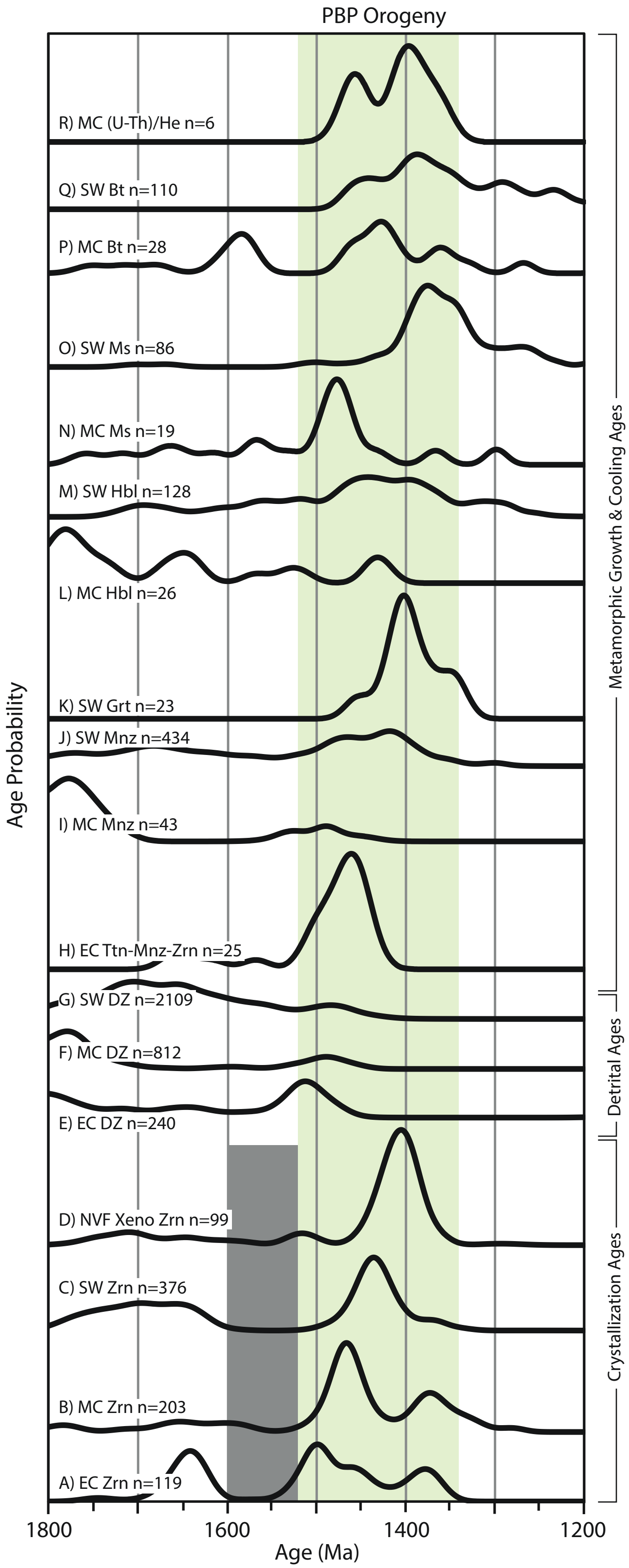


Figure 5. Summary plot of normalized age density distributions for geochronology data across the Pinware-Baraboo-Picuris (PBP) orogenic belt: EC—eastern Canada; MC—midcontinent; SW—southwestern United States; NVF—Navajo volcanic field. From the bottom up, (A) U-Pb igneous zircon crystallization ages, eastern Canada; (B) U-Pb igneous zircon crystallization, midcontinent; (C) U-Pb zircon crystallization ages, southwestern United States. (D) Zircon ages from crustal xenoliths in the Navajo volcanic field. (E–G) U-Pb detrital zircon (DZ) age distributions from eastern Canada, the midcontinent, and the southwestern United States, respectfully. (H) U-Pb zircon, monazite, and titanite metamorphic ages, eastern Canada. (I–J) U-Pb and U-Th–total Pb monazite ages from the southwestern United States and midcontinent. (K) Lu-Hf and Sm-Nd garnet ages from northern New Mexico and crustal xenoliths in the Navajo volcanic field. (L–M) $^{40}Ar/^{39}Ar$ hornblende crystallization and cooling ages from the midcontinent and southwestern United States. (N–O) $^{40}Ar/^{39}Ar$ muscovite cooling ages from the midcontinent and southwestern United States. (P–Q) $^{40}Ar/^{39}Ar$ biotite cooling ages from the midcontinent and southwestern United States. (R) (U-Th)/He hematite recrystallization ages from the midcontinent. Green shaded area corresponds to the approximate time span of the Pinware-Baraboo-Picuris (PBP) orogeny, 1500–1340 Ma. Gray shaded area corresponds to the approximate time span of the North American magmatic gap, 1600–1500 Ma. Mineral abbreviations are after Whitney and Evans (2010). See Supplemental Table 1 for references (see text footnote 1).

metamorphism and/or metasomatism in the lower crust that we attribute to the Picuris orogeny.

Detrital zircon age populations for eastern Canada (*n* = 240), the midcontinent (*n* = 812), and the southwestern United States (*n* = 2109) are shown in the next three age distributions, respectively (Figs. 5E–5G). Detrital zircons in eastern Canada yield a broad Paleoproterozoic peak at ca. 1800 Ma and a unimodal Mesoproterozoic peak at 1515 Ma (Fig. 5E), separated by a "magmatic gap" between ca. 1600 Ma and 1520 Ma (gray field in Fig. 5). Detrital zircon age distributions in the midcontinent and the southwest United States (Figs. 5F and 5G) are dominated by Paleoproterozoic zircon with peaks at ca. 1780 and 1710–1660 Ma, along with smaller Mesoproterozoic peaks at ca. 1490 and 1480 Ma, respectively.

Metamorphic mineral growth ages include a combination of zircon, monazite, and titanite from eastern Canada, monazite from the midcontinent, and garnet and monazite from the southwestern United States (Figs. 5H–5K). The metamorphic mineral age distribution from eastern Canada includes zircon, monazite, and titanite U-Pb ages (Fig. 5H; *n* = 25) that show a dominant peak at ca. 1460 Ma with a shoulder at ca. 1500 Ma. Relatively few Pinwarian metamorphic ages are reported due to a pervasive Grenvillian overprint. Monazite age distributions from the midcontinent and the southwestern United States (Figs. 5I–5J) reflect growth in contact metamorphic and regional metamorphic settings (Kopera, 2003; Daniel and Pyle, 2006; Holm et al., 2007; Amato et al., 2011; Mako et al., 2015; Medaris et al., 2021). The age populations include electron microprobe dates (U-Th–total Pb) and U-Pb isotopic dates from laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) analyses. In the midcontinent, monazite yields a dominant peak in the Paleoproterozoic, ca. 1775 Ma, and a smaller bimodal Mesoproterozoic age distribution with peaks at ca. 1530 and 1490 Ma (Fig. 5I; $n = 43$). Some of the older dates are interpreted to reflect detrital monazite cores, whereas the younger rims are interpreted to reflect contact metamorphic effects of the Wolf River batholith (Medaris et al., 2021). In the southwest United States (Fig. 5J; $n = 434$), monazite ages show a low, broad peak at ca. 1680 Ma representing Paleoproterozoic detrital grains (Kopera, 2003). Overlapping peaks at ca. 1470 and 1420 Ma correspond to metamorphic overgrowths on older detrital cores or to new monazite growth during the Picuris orogeny (Kopera, 2003; Daniel and Pyle, 2006). The garnet age distribution contains both Lu-Hf and Sm-Nd ages from regional metamorphic rocks of northern New Mexico and crustal xenoliths from the Navajo volcanic field. The garnet age distribution ($n = 23$) shows a relatively small peak at ca. 1455 Ma, a dominant peak at ca. 1405 Ma, and a younger shoulder at ca. 1350 Ma. Garnet growth is associated with middle- to upper-amphibolite-facies metamorphism in the Picuris mountains and lower-crustal, granulite-facies metamorphism beneath the Navajo volcanic field (Fig. 5K).

Figures 5L–5Q show $^{40}Ar/^{39}Ar$ crystallization and cooling age distributions from hornblende, muscovite, and biotite for the midcontinent and southwestern United States. Hornblende in the midcontinent shows multiple discrete Paleoproterozoic age peaks at ca. 1780 and 1650 Ma, with minor Mesoproterozoic age peaks at ca. 1570 and 1525 Ma and a third isolated peak at ca. 1430 Ma (Fig. 5L; $n = 26$). Hornblende from the southwest United States shows a broad age distribution between ca. 1500 and 1340 Ma (Fig. 5M; $n = 128$) with maxima at ca. 1445 and 1395 Ma. These age distributions reflect both primary crystallization ages and cooling ages associated with contact and regional metamorphism during the Paleoproterozoic and Mesoproterozoic Eras. Muscovite and biotite show broader peaks with dominantly Mesoproterozoic ages (Figs. 5N–5Q). The number of Paleoproterozoic muscovite and biotite ages is relatively low and indicates the pervasive nature of contact metamorphism and the regional metamorphic overprinting during the Baraboo and Picuris orogenies. The topmost curve shows (U-Th)/He ages from recrystallized hematite in Baraboo interval quartzites (Fig. 5R; $n = 6$). The bimodal peak ages near 1480 Ma and 1395 Ma are consistent with cooling following the Baraboo orogeny. The diachronous timing of Mesoproterozoic igneous crystallization ages, Mesoproterozoic detrital zircon peak ages, and metamorphic mineral growth and cooling ages across the Pinware, Baraboo, and Picuris orogens supports the hypothesis of an evolving, tectonically active south Laurentian plate margin between ca. 1520 and 1340 Ma.

### Aeromagnetic Interpretation Linking the Pinware, Baraboo, and Picuris Orogenic Provinces

Figure 2C shows key control points in the southwestern United States where the timing of Mesoproterozoic deposition and/or regional metamorphism and deformation is relatively well documented (Karlstrom et al., 1997; Shaw et al., 2005; Daniel and Pyle, 2006; Jones et al., 2010, 2011; Amato et al., 2011; Doe et al., 2012, 2013; Daniel et al., 2013b; Mako et al., 2015; Aronoff et al., 2016; Doe and Daniel, 2019; Holland et al., 2020; Medaris et al., 2021). In northern Colorado, Mesoproterozoic ca. 1450–1400 Ma deformation is more partitioned and associated with the reactivation of Paleoproterozoic shear zones (Shaw et al., 2001; McCoy et al., 2005; Duebendorfer et al., 2015). The Mesoproterozoic Baldwin conglomerate and deformed Baraboo interval quartzites provide key control points for the orogenic belt in the midcontinent, which then continues into eastern Canada. We used aeromagnetic anomalies (Fig. 2C) to guide the spatial correlation of the Pinware, Baraboo, and Picuris orogenies. These anomalies were in part used to define the Central Plains orogen of Sims and Peterman (1986). Alternatively, these features may represent a composite of both Paleoproterozoic and Mesoproterozoic deformation. We reinterpreted these arcuate trends in aeromagnetic highs along the northern margin of the Southern Granite-Rhyolite Province (Fig. 2C) to be a continuation of the ca. 1450–1350 Ma Picuris orogenic belt into the midcontinent region and continuing into eastern Canada.

## DISCUSSION

### Tectonic Setting of the Pinware-Baraboo-Picuris Orogen

The tectonic interpretations discussed below build upon data and discussions from previous studies that attempt to accommodate evidence for both contractional deformation in the crust and the need for lithospheric extension and thinning to accommodate widespread ferroan magmatism (Nyman et al., 1994; Karlstrom et al., 2001; Menuge et al., 2002; Walker et al., 2002; Shaw et al., 2005; Slagstad et al., 2009; Jones et al., 2010; Amato et al., 2011; Condie, 2013; Bickford et al., 2015; Holland et al., 2020). Phanerozoic examples of extensional accretionary orogens and tectonic switching have been discussed by Collins (2002a, 2020b) and Kemp et al. (2009).

We propose that the Pinware-Baraboo-Picuris orogen formed along an evolving, diachronous convergent margin, where the initiation of Mesoproterozoic magmatism, sedimentation, metamorphism, and deformation became younger from northeast to southwest (Fig. 5), due to southwestward migration of a subduction zone. Figure 6 displays a speculative accretionary orogenic model at ca. 1400 Ma where the margin is divided into three different segments based upon differences in the geochemistry and timing of magmatism, and the nature and timing of metamorphism and deformation within each orogenic province. The segmentation of the convergent margin by oceanic fracture zones allows for variations in subduction angle, arc development, and differences in the timing of tectonic switching between intra-arc and back-arc extension and compression as discussed below.

The Pinwarian segment preserves the earliest evidence of magmatism, deposition, metamorphism, and deformation (Figs. 5A, 5E, and 5H) and is shown as a subduction zone that approximates an inferred, pre-Grenville margin. This margin was strongly reworked by the Grenville orogeny, and a more detailed model of the Mesoproterozoic tectonic evolution of this segment was given by Groulier et al. (2020). Geochemical signatures of plutonism (granodiorite to granite) associated with the volcano-sedimentary belts to the south (based on data from the eastern Wakeham–La Romaine, and Escoumins areas) range from calcic to calc-alkalic magnesian to alkali-calcic ferroan, consistent with a transition from arc to rift-arc/back-arc settings (Groulier et al., 2020; Indares et al., this volume). Similar geochemical signatures are also reported from orthogneisses of uncertain broader settings in Quebecia and in the western continental arc segment. In contrast, inboard plutons (monzonite to granite) are ferroan and alkali-calcic to alkalic in the continental arc portions and locally associated with AMCG plutons, suggestive of an extensional environment such as a back-arc.

The tectonic evolution of the Baraboo segment is more speculative. If a continental arc formed within the midcontinent, it was likely within the juvenile ($T_{DM}$ < 1550 Ma) part of the Eastern Granite-Rhyolite Province and is buried in the subsurface, underneath the St. Francois Mountain igneous complex, or more south-to-southeast (outboard) of the St. Francois Mountains (Fig. 6). Within this segment, the inboard Wolf River batholith and the marginal St. Francois Mountains reflect continental back-arc– and arc-related settings, respectively. The Baraboo interval fold-and-thrust belt records greenschist-facies metamorphism and deformation near 1470 Ma (Fig. 6) and possibly reflects rapid tectonic switching from an extensional to a more compressional back-arc setting (Collins, 2002b). We propose that deformation and greenschist-facies metamorphism of Baraboo interval strata reflect closure of a transtensional or back-arc basin that represents the northern limit of crustal deformation (Fig. 6).

The westernmost tectonic segment is represented by the Picuris orogen, where the onset of magmatism, deposition, metamorphism, and deformation are generally younger than in the Baraboo and Pinware orogens (Fig. 5). Syntectonic pluton emplacement occurred generally between ca. 1465 and 1410 Ma, and the plutons record NW-SE compression and NE-SW extension (Nyman et al., 1994; Kirby et al., 1995; Amato et al., 2011). This region also experienced significant contractional deformation, crustal thickening, and regional metamorphism between ca. 1450 and 1390 Ma, followed by tectonic and/or erosional unroofing. The transition from crustal thickening to unroofing (Fig. 4) at around 1390 Ma also coincides with a local minimum in the age distribution of Mesoproterozoic plutons in the southwest (Fig. 5C). We interpret ca. 1390 Ma to be a time of tectonic switching from a compressional to an extensional subduction margin, thus changing the continental deformational regime from a compressive continental arc and back-arc setting to a more extensional one. Back-arc and intra-arc extension led to a second peak in

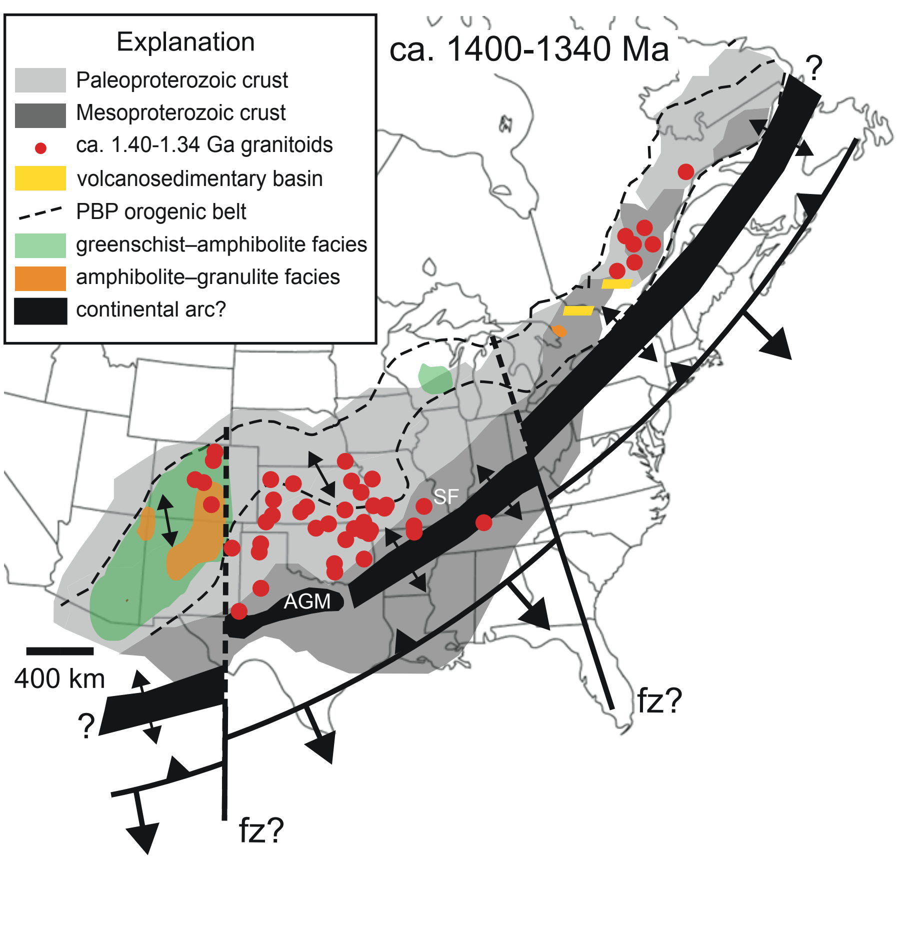


Figure 6. Speculative tectonic setting of the south Laurentian margin, ca. 1400–1340 Ma, with a simplified representation of ferroan granites that crystallized between ca. 1400 and 1340 Ma (granite locations simplified from du Bray et al., 2018; tectonic model from Daniel et al., this volume). See text for discussion. Abbreviations: AGM—Abilene gravity minimum; fz—oceanic fracture zone; PBP—Pinware-Baraboo-Picuris; SF—St. Francois Mountains.

magmatism near 1375 Ma in the southwest United States (Fig. 5) and midcontinent regions. In general, ca. 1450–1390 Ma was a time of an advancing subduction margin, consistent with proposed ca. 1400 subduction in the southwest United States based upon Re-Os and Sm-Nd isotopic data from clinopyroxene in Proterozoic peridotite xenoliths from the Navajo volcanic field (Marshall et al., 2017). The time interval from ca. 1390 to at least 1340 Ma is interpreted to be associated with a retreating subduction zone.

The region of greenschist- to granulite-facies metamorphism (Fig. 6) could be interpreted as an orogenic plateau developing behind a continental arc following the model of Shaw et al. (2005). Alternatively, crustal thickening in this zone could reflect a zone of collision between the Southern Granite-Rhyolite Province and the margin of Laurentia, an idea proposed by Bickford et al. (2015). In such a setting, we envision a new arc that developed along a rifted fragment of the Granite-Rhyolite terrane and subsequently collided between ca. 1450 and 1400 Ma, analogous to the Quebecia terrane.

In summary, orogenesis or crustal thickening across the Pinware-Baraboo-Picuris orogen as evidenced by regional deformation and metamorphism occurred from ca. 1510 to 1460 Ma in the Pinware orogen (Fig. 5H) and yielded maximum metamorphic pressures of ~7–8 kbar (Ketchum et al., 1994). In the Picuris orogen, crustal thickening occurred from ca. 1460 to 1390 Ma (Figs. 5J, 5K, and 5M) and yielded metamorphic pressures up to ~8 kbar (Pedrick et al., 1998; Hernández-Montenegro et al., 2019). However, the Baraboo orogeny occurred over a shorter time span of ca. 1490–1470 Ma (Figs. 5I and 5N), and crustal thickening was significantly less, with estimated metamorphic pressures of 2.5–3 kbar. The Baraboo orogen is interpreted to have been part of the foreland of the Pinware-Baraboo-Picuris orogen.

The onset of the Grenville collisional orogeny (Ottawan and Rigolet phases; Rivers, 2008) marked the end of south Laurentian accretionary tectonic processes and reworked nearly the entire Pinware orogenic province. This resulted in the preservation of different structural levels of the Pinware orogen within the Grenville Province, but it also largely overprinted the metamorphic signature of the Pinware orogeny. The Grenville orogeny also overprinted portions of the Granite-Rhyolite Province of the southwestern United States, which remains buried beneath the subsurface. However, the Baraboo segment, which lies outside the Grenville orogen, shows no evidence of ca. 1000 Ma crustal shortening; in contrast, the Baraboo terrane is transected by the ca. 1100 Ma Keweenawan Rift. The Picuris segment of the orogen shows little evidence of a Grenvillian overprint, and in Arizona, it is unconformably overlain by relatively flat-lying sediments of the post–1320 Ma Apache Group (Doe, 2014; Doe and Daniel, 2019).

## Pinware-Baraboo-Picuris Orogen in a Global Context

The Pinware-Baraboo-Picuris orogenic belt extends for ~5000 km along the southern Laurentian margin with an estimated present-day width that varies from ~200 to 800 km (Fig. 3C). These dimensions are comparable to the modern-day South American Cordilleran margin. Following previous correlations of crustal belts across Laurentia, Baltica, and Amazonia (Johansson, 2009; Condie, 2013), we propose that the newly defined Pinware-Baraboo-Picuris orogen may be correlative with the ca. 1520–1480 Telemarkian and ca. 1465–1385 Hallandian orogens of Baltica (Ulmius et al., 2015; Bingen et al., 2021) and the ca. 1480–1420 Ma Santa Helena and 1440–1380 Ma Rio Alegre orogens in the Rondonian–San Ignacio Province of Amazonia (Fig. 7; Tassinari and Macambira, 1999; Bettencourt et al., 2010). When combined, these orogens define an ~15,000-km-long accretionary margin at ca. 1400 Ma (Fig. 7) and are a significant component of the proposed ca. 2.0–1.0 Ga Great Proterozoic accretionary orogen (Condie, 2013).

Recognition of the proposed ca. 1520–1340 Ma trans-Laurentian Pinware-Baraboo-Picuris orogen may represent a turning point in our understanding of the tectonic evolution of Laurentia. The potential connections with Baltica and Amazonia would form a dominantly accretionary orogenic margin analogous in scale to the modern-day Cordilleran margin of North and South America, or Asia and Oceania of the Pacific Rim.

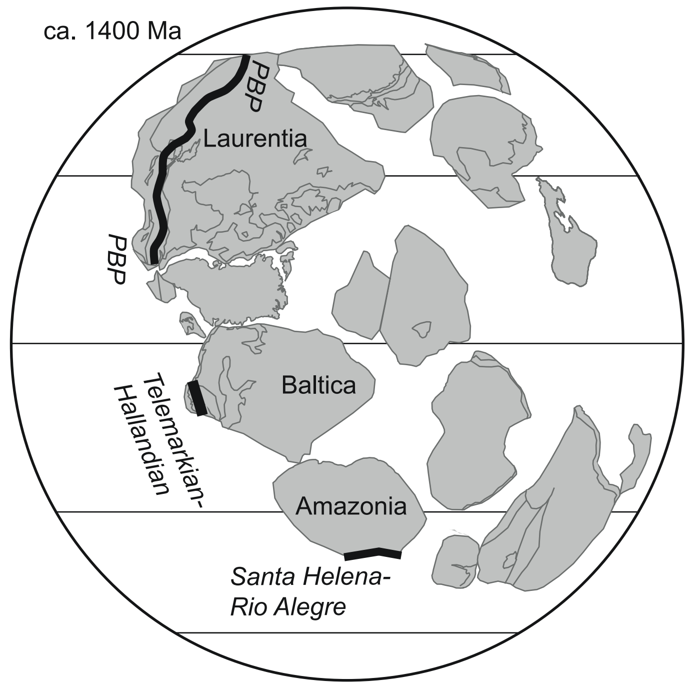


Figure 7. Global paleogeographic reconstruction ca. 1400 Ma (simplified from Gong et al., 2021). Heavy black line corresponds to the approximate location of the ca. 1500–1350 Ma Pinware-Baraboo-Picuris (PBP) orogenic belt in Laurentia (this work), the ca. 1520–1480 Ma Telemarkian and ca. 1470–1380 Ma Hallandian orogens in Baltica (Ulmius et al., 2015; Bingen et al., 2021), and the ca. 1480–1420 Ma Santa Helena and 1440–1380 Ma Rio Alegre orogens in the Rondonian–San Ignacio Province of Amazonia (Tassinari and Macambira, 1999; Bettencourt et al., 2010).

Extension of this orogenic belt into Australia and/or Antarctica seems likely, but exploration of these possible correlations is beyond the scope of this work (Karlstrom et al., 2001; Doe et al., 2012; Goodge et al., 2017).

## CONCLUSION

The recognition of ca. 1520–1450 Ma sedimentation, ca. 1520–1340 Ma magmatism, and ca. 1510–1340 Ma regional metamorphism and deformation along the length of the Laurentian margin provides a new perspective to better understand the tectonic evolution of Laurentia. When combined with the geochemical and isotopic studies of the associated magmatic rocks, an evolving accretionary margin characterized by an advancing and retreating subduction margin is envisioned to have accommodated the depositional, deformational, metamorphic, and magmatic evolution of the continental margin. The Pinware-Baraboo-Picuris orogen is characterized by significant crustal thickening, deformation, and regional metamorphism in parts of the Pinware and Picuris segments, with significantly less crustal thickening and less intense deformation and metamorphism in the presently exposed Baraboo segment.

We correlate the Pinware-Baraboo-Picuris orogen with the ca. 1520–1480 Ma Telemarkian and ca. 1465–1385 Ma Hallandian orogens of Baltica (Ulmius et al., 2015; Bingen et al., 2021) and the ca. 1480–1420 Ma Santa Helena and 1440–1380 Ma Rio Alegre orogenies in the Rondonian–San Ignacio Province of Amazonia (Tassinari and Macambira, 1999; Bettencourt et al., 2010). We have attempted to interpret the Mesoproterozoic southern margin of Laurentia in the context of modern plate-tectonic processes and propose that the Pinware-Baraboo-Picuris orogen formed inboard of a subduction margin analogous to the modern-day Cordilleran margin of North and South America.


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