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Neoproterozoic—Early Paleozoic evolution of peri-Gondwanan terranes: implications for Laurentia-Gondwana connections

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Abstract Neoproterozoic tectonics is dominated by the amalgamation of the supercontinent Rodinia at ca. 1.0 Ga, its breakup at ca. 0.75 Ga, and the collision between East and West Gondwana between 0.6 and 0.5 Ga. The principal stages in this evolution are recorded by terranes along the northern margin of West Gondwana (Amazonia and West Africa), which continuously faced open oceans during the Neoproterozoic. Two types of these so-called peri-Gondwanan terranes were distributed along this margin in the late Neoproterozoic: (1) Avalonian-type terranes (e.g. West Avalonia, East Avalonia, Carolina, Moravia-Silesia, Oaxaquia, Chortis block that originated from ca. 1.3 to 1.0 Ga juvenile crust within the Panthalassa-type ocean surrounding Rodinia and were accreted to the northern Gondwanan margin by 650 Ma, and (2) Cadomian-type terranes (North Armorica, Saxo-Thuringia, Moldanubia, and fringing terranes South Armorica, Ossa Morena and Tepla-Barrandian) formed along the West African margin by recycling ancient (2–3 Ga) West African crust. Subsequently detached from Gondwana, these terranes are now located within the Appalachian, Caledonide and Variscan orogens of North America and western Europe. Inferred relationships between these peri-Gondwanan terranes and the northern Gondwanan margin can be compared with paleomagnetically constrained movements interpreted for the Amazonian and West African cratons for the interval ca. 800–500 Ma. Since Amazonia is paleomagnetically unconstrained during this interval, in most tectonic syntheses its location is inferred from an interpreted connection with Laurentia. Hence, such an analysis has implications for Laurentia-Gondwana connections and for high latitude versus low latitude models for Laurentia in the interval ca. 615–570 Ma. In the high latitude model, Laurentia-Amazonia would have drifted rapidly south during this interval, and subduction along its leading edge would provide a geodynamic explanation for the voluminous magmatism evident in Neoproterozoic terranes, in a manner analogous to the Mesozoic-Cenozoic westward drift of North America and South America and subduction-related magmatism along the eastern margin of the Pacific ocean. On the other hand, if Laurentia-Amazonia remained at low latitudes during this interval, the most likely explanation for late Neoproterozoic peri-Gondwanan magmatism is the re-establishment of subduction zones following terrane accretion at ca. 650 Ma. Available paleomagnetic data for both West and East Avalonia show systematically lower paleolatitudes than predicted by these analyses, implying that more paleomagnetic data are required to document the movement histories of Laurentia, West Gondwana and the peri-Gondwanan terranes, and test the connections between them.

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Introduction

The Neoproterozoic is a pivotal interval in the Earth's history during which a succession of events, including world-wide orogeny, rapid continental growth, profound changes in ocean geochemistry, and an explosion in biological activity, led to irreversible global change (e.g. Knoll 1992; Hoffman et al. 1998). However, continental reconstructions for the Neoproterozoic are poorly con-

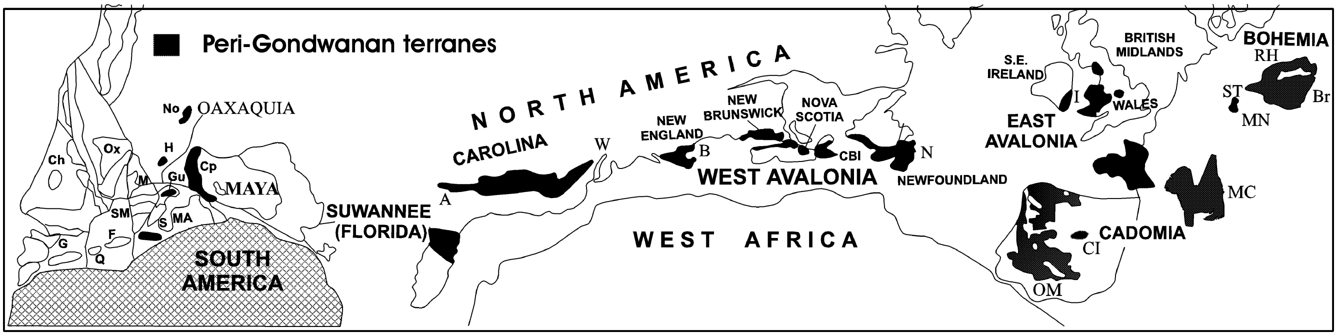


Fig. 1 Early Mesozoic reconstruction of Pangea A, showing the locations of Precambrian peri-Gondwanan terranes (modified from Nance and Murphy 1994; Keppie and Ortega-Gutiérrez 1999; and Weil et al. 2001) and the inferred polarity of Neoproterozoic subduction. Abbreviations: A=Atlanta, B=Boston, Br=Brunia (includes Moravo-Silesia and W. Sudetes), CBI=Cape Breton Island, Ch=Chortis, CI=Central Iberia, Cp=Chiapas, F=Floresta, G=Garzón, Gu=Guajira, H=Huiznopala, I=Ireland, M=Mixtequita, MA=Mérida Andes, MN=Moldanubian, N=Newfoundland, No=Novillo, OM=Ossa-Morena, Ox=Oaxacan Complex, Q=Quetame, RH=Rheno-Hercynian, S=Santander, SM=Santa Marta, ST=Saxo-Thuringian, W=Washington. OAXAQUIA comprises Huiznopala, Mixtequita, Novillo, and Oaxacan Complex

strained. There is broad consensus that Neoproterozoic tectonics was profoundly influenced by the supercontinent Rodinia, which was assembled by collisional events of broadly Grenvillian age (McMenamin and McMenamin 1990; Hoffman 1991) and broke up before 755 Ma (e.g. Wingate and Giddings 2000). However, details of the configuration and breakup history of Rodinia are controversial (e.g., Hoffman 1991; Dalziel 1992, 1997; Powell et al. 1993; Karlstrom et al. 1999; Loewy et al. 2000; Wingate and Giddings 2000; Li and Powell 2001; Pisarevsky et al. 2003).

Most studies of Rodinia have logically focused on the distribution of Grenville-aged orogenic belts responsible for its amalgamation and the evolution of Neoproterozoic passive margin sequences formed as a result of its break up. However, the Neoproterozoic tectonothermal histories of terranes distributed along the northern margin of West Gondwana (part of Amazonia and West Africa), which continuously faced an open ocean as Rodinia assembled and dispersed, provide additional insights into the configuration of Rodinia and the timing of its breakup (e.g. Murphy et al. 2002; Nance et al. 2002; Keppie et al. 2003). Although these so-called "peri-Gondwanan" terranes became detached from West Gondwana in the Paleozoic and now occur as exotic terranes within the Appalachian, Caledonian and Variscan orogens of North America and western Europe (Fig. 1), a wealth of varied geologic data support Neoproterozoic tectonothermal linkages and possible continuity between them. These terranes include those of West Avalonia, Carolina and Florida in North America, Oaxaquia, Yucatan and Chortis in Middle America, and East Avalonia, Cadomia, Iberia and Bohemia in western Europe.

The widely accepted genetic relationship between the peri-Gondwanan terranes and West Gondwana also has implications for Laurentia-Gondwanan connections during the Neoproterozoic. Most reconstructions juxtapose West Gondwana (i.e. Amazonia) and the eastern margin of Laurentia during this time period. If correct, the Neoproterozoic location of Amazonia and West Africa, for which there are no reliable paleomagnetic data, can be inferred from Laurentian paleomagnetic poles (e.g. Hoffman 1991; Dalziel 1992; Dalziel et al. 1994; Weil et al. 1998). However, Forsythe et al. (1993) have shown that the Grenville-age Arequipa-Antofalla terrane of Peru and Chile moved independently in the Early Paleozoic, and Loewy et al. (2000) have shown that this terrane cannot be correlated with either the Grenville Belt of eastern Laurentia or the Grenville-age Sunsas orogen of Bolivia. If so, the Arequipa-Antofalla terrane would represent a microcontinent bordered by oceans. Such an interpretation is consistent with the presence of a Neoproterozoic orogen (the Marañon belt and its continuation into the Tucavaca belt, Ramos and Alemán 2000; V. Ramos, pers. comm., 2001) between the Arequipa massif and the Amazon craton, but would call the Laurentia-Gondwana connection into question.

In this paper we examine the compatibility of the tectonothermal evolution of the northern margin of West Gondwana with the paleomagnetically constrained movements of Laurentia and Gondwana for the interval ca. 800–500 Ma. We acknowledge that the reconstructions we use are not universally agreed upon. Our purpose is broader than the specifics of the reconstructions we — use. We aim to show that paleomagnetically-constrained models of continental reconstructions during this time interval can be tested against the geological record preserved along their continental margins. Our analysis highlights the need for additional paleomagnetic data, particularly in Amazonia, during this crucial time interval. However we point out that the combined paleomagnetic and geologic database, although incomplete, is sufficiently robust to constrain continental reconstructions and to identify key areas that require resolution. For example, we argue that if a tectonothermal linkage existed between the peri-Gondwana terranes and West Gondwana during the late Neoproterozoic, a linkage between Laurentia and Gondwana is unlikely.

Geologic setting

Peri-Gondwanan terranes occur as exotic terranes within the Appalachian, Caledonide, and Variscan orogens (Fig. 1) and are widely interpreted to have evolved along an active continental margin of West Gondwana (Amazonia and West Africa; e.g., O'Brien et al. 1983; Rast and Skehan 1983; Quesada 1990; Nance et al. 1991) in the Neoproterozoic. Paleomagnetic and faunal data for the late Neoproterozoic and earliest Paleozoic place West Avalonia (eastern North America), East Avalonia (southern Britain and the Brabant Massif) and Armorica (NW France) along the northern margin of West Gondwana (Fig. 2A–C) at considerable latitudinal distance from Laurentia (e.g. Cowie 1974; Theokritoff 1979; Johnson and van der Voo 1986; Van der Voo 1988; Strachan and Taylor 1990; McKerrow et al. 1992; Cocks 2000; McNamara et al. 2001; Mac Niocaill et al. 2001).

Over the past decade or so, a wealth of isotopic, geochemical and faunal data indicate that Avalonia and Armorica are but two of a large number of terranes distributed along this margin. In the eastern United States, terranes with a related tectonothermal history include those of the Florida and Carolina (e.g. Heatherington et al. 1996; Hibbard 2000; Hibbard et al. 2002). In central and western Europe, Neoproterozoic-Early Paleozoic basement, collectively referred to as Cadomian, is preserved in several massifs including the Saxo-Thuringian and Tepla-Barrandian zones of the Bohemian Massif (e.g. Linnemann and Romer 2002; Dorr et al. 2002), and the Ossa-Morena and Central Iberian zones of the Iberian Massif (e.g. Quesada 1990; Fernández-Suárez et al. 2000, 2002a, b). Remnants of Cadomian basement also occur within the Alpine chain, the Carpathians and in Turkey (e.g. von Raumer et al. 2002), but their paleogeography relative to other peri-Gondwanan terranes is poorly constrained (e.g. Neubauer 2002) and will not be discussed further here. In Middle America, peri-Gondwanan terranes include Oaxaquia and the Yucatan block of Mexico, and the Chortis block of Honduras and Guatamala (e.g. Keppie and Ramos 1999).

Although there are also some important differences between these terranes, collectively they record a protracted history of subduction beneath the northern margin of West Gondwana. This history began at about 760 Ma, terminated diachronously with the progressive development of a transform system from about 610 to 540 Ma, and was followed by the deposition of a Cambrian platformal sequence containing Gondwanan fauna (e.g. Murphy and Nance 1989; Keppie et al. 1991, 2003; Nance et al. 1991, 2002; Murphy et al. 1999). Neoproterozoic tectonothermal activity is characterized by abundant calc-alkaline volcanic rocks, cogenetic plutons, syn-orogenic sedimentation and deformation associated with the opening and closing of arc-related basins. This record is broadly similar to those of modern Andean or island arc-back arc complexes. However, the precise location of these terranes either along the Gondwanan margin or relative to the orogenic provinces in West African and South America is poorly constrained.

Key to determining the relative paleogeography of these subduction-related complexes is the character of their basement (e.g. Nance and Murphy 1994). However, in keeping with their evolution as part of a peripheral or accretionary orogen, the complexes are characterized by limited uplift and erosion (Murphy and Nance 1991; Windley 1993), so that unequivocal exposures of basement are rare. Only in the Trégor-La Hague terrane of Armorica (Strachan et al. 1996a) is undisputed basement exposed in any of the peri-Gondwanan arc terranes. Fragments of this basement may occur in northwestern Cape Breton Island (Keppie and Dostal 1991) and in the Goochland terrane of eastern Virginia (Hibbard and Samson 1995), but the provenance of these regions is controversial (e.g. Farrar 1984; Barr et al. 1998). The peri-Gondwanan terranes of Middle America expose basement of Grenville (ca. 1 Ga) age (Keppie and Ortega-Gutiérrez 1995, 1999), overlain unconformably by Lower Ordovician rocks containing a Gondwanan fauna (Robison and Pantoja-Alor 1968 revised by Shergold 1975; Boucot et al. 1997). The basement is isotopically distinct from that of the North American Grenville Belt and its Pb isotopic signatures are due to mixing of Archean and juvenile Grenville sources (Ruiz et al. 1999; Cameron et al. 2004).

Despite the lack of exposed basement, clues to its tectonothermal evolution are provided by (1) the Sm-Nd isotopic composition of younger, crustally derived felsic igneous rocks that represent melt fractions extracted from the basement, and (2) U-Pb detrital zircon data that give an indication of adjacent basement sources (e.g. Nance and Murphy 1994). In some situations, U-Pb detrital zircon data could yield ambiguous or misleading results, especially if sediment transport and/or recycling was extensive. Taken together, the data indicate that the peri-Gondwanan terranes fall into two categories: (1) Avalonian-type terranes (e.g. West Avalonia, East Avalonia, Carolina, Moravo-Silesia of Bohemia, Oaxaquia, the Maya terrane, and the Chortis block), that originated from ca. 1.3 to 1.0 Ga juvenile crust within the Panthalassa-type ocean surrounding Rodinia and were accreted to the Amazonian portion of the Gondwanan margin by 650 Ma; and (2) Cadomian-type terranes (North Armorica, Saxo-Thuringia, Moldanubia, and fringing terranes such as South Armorica, Ossa Morena of Iberia and Teplá-Barrandian of Bohemia) formed along the West African margin by recycling ancient (2–3 Ga) West African crust.

The geology of these peri-Gondwanan terranes has been described in several compilations, including D'Lemos et al. (1990), Strachan and Taylor (1990), Nance and Thompson (1996), Eguíluz et al. (2000), Nance et al. (2002), and Keppie et al. (2003). So their geology is only briefly reviewed here.

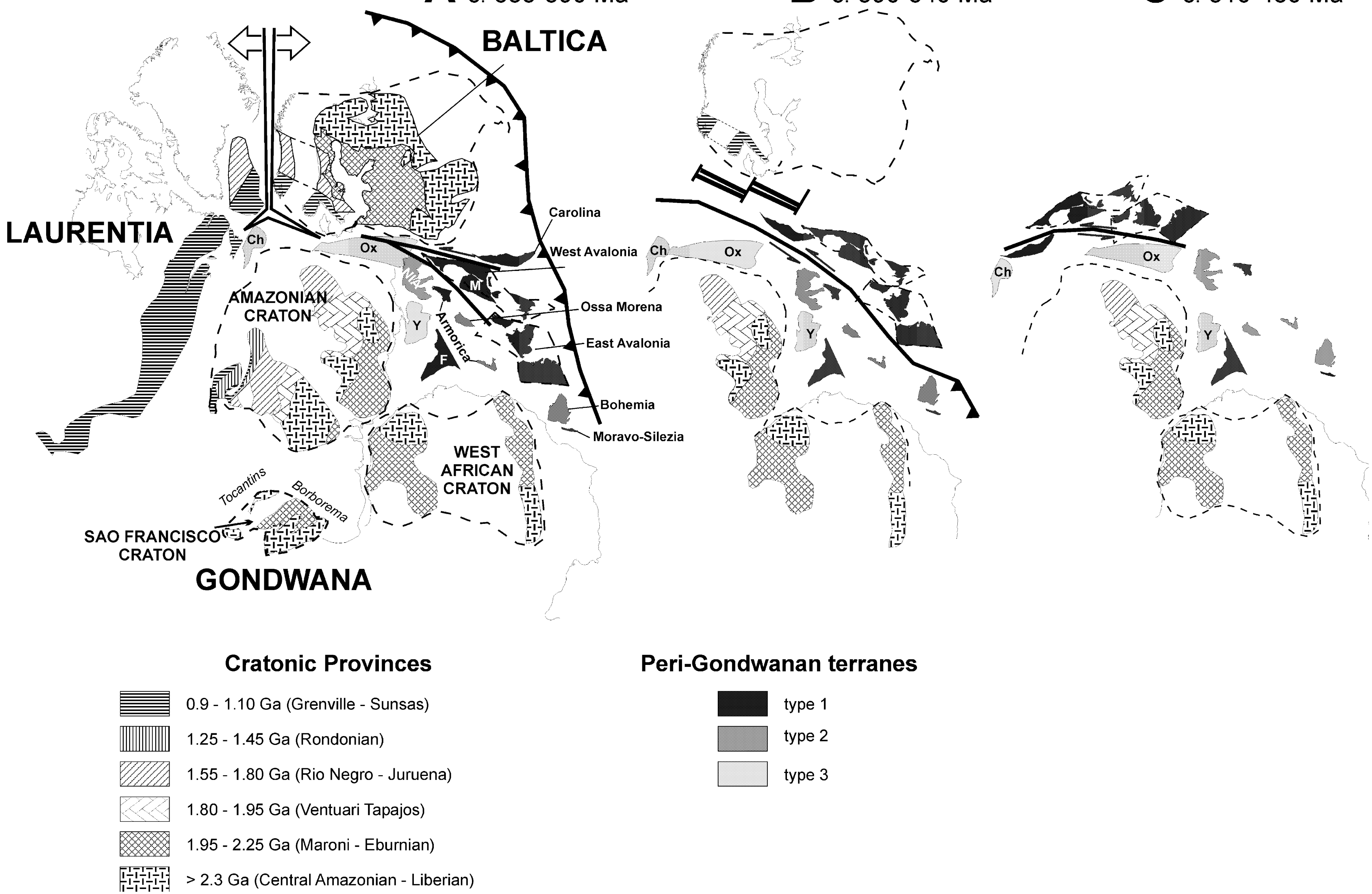


Fig. 2A–C Late Neoproterozoic-Early Paleozoic (635–480 Ma) reconstructions (**A–C**) showing the location of Avalonia and related peri-Gondwanan terranes along the northern margin of Gondwana. (Ch = Chortis Block, Ox = Oaxaquia, Y = Yucatan Block, F = Florida, NIA= Neoproterozoic Iberian Autochthon). Figure modified after Nance and Murphy (1994, 1996), Murphy et al. (1999), Linneman et al. (2000), Nance et al. (2002), and Keppie et al. (2003)

Peri-Gondwanan terranes

Avalonia

Avalonia is subdivided into West Avalonia (in eastern North America) and East Avalonia (in southern Britain and the Brabant Massif). These regions share a diagnostic Cambrian-Ordovician overstep sequence with Acado-Baltic (Avalonian) fauna (Theokritoff 1979; Keppie 1993) and comprised a continuous tectonostratigraphic belt that was sundered by the opening of the North Atlantic (e.g. Keppie et al. 1991).

The main events in the evolution of Avalonia (see Nance et al. 2002) are: (1) the development of juvenile crust at ca. 1.3 to 1.0 Ga, (2) an early arc phase (pre-650 Ma), (3) its accretion to Gondwana at ca. 650 Ma, (4) a main arc phase (640–570 Ma), (5) its transition to a platform (570–540 Ma), (6) the rifting of Avalonia from Gondwana (ca. 540–515 Ma), and (7) its accretion to Laurussia (ca. 440 Ma).

The basement to the main Avalonian arc is nowhere unequivocally exposed. However, constraints on its composition are provided by the Sm-Nd isotopic composition of crustally derived felsic igneous rocks that range in age from 740 to 370 Ma. These igneous rocks have elemental Sm/Nd ratios of ca. 0.19, which is typical of intracrustal melts (Allègre and Ben Othman 1980) and show similar initial ϵ_{Nd} values that range between –2.5 and +5.0 (Thorogood 1990; Barr and Hegner 1992; Whalen et al. 1994; Kerr et al. 1995; Murphy et al. 1996a; Keppie et al. 1997; Murphy et al. 2000; Samson et al. 2000). Extrapolated to the depleted mantle curve, ϵ_{Nd} growth lines consistently yield overlapping model ages (T_{DM}) of 0.8–1.1 Ga in Atlantic Canada and 1.0–1.3 Ga in southern Britain (Thorogood 1990; Murphy et al. 2000).

Although these depleted mantle model ages closely coincide with the timing of Grenville (ca. 1.25–0.95 Ga) orogenesis, which is considered to be responsible for the amalgamation of Rodinia (e.g., Hoffman 1991), igneous rocks in Grenville-aged orogens are characterized by higher model ages, consistent with their derivation from recycled older crust. Avalonian ϵ_{Nd} values, on the other hand, suggest a largely juvenile basement source dominated by c. 1.0 Ga mantle-derived material with only minor elements of older Proterozoic crust.

The interpretation of depleted mantle model ages is controversial (Arndt and Goldstein 1987). For magma produced by recycling of a single crustal source, the model age represents the time at which the crustal basement was itself extracted from the mantle. More commonly, however, magmas contain mixtures of juvenile, mantle-derived material and older crustal components. In these situations, the model age has no geologic significance. Detailed arguments for the interpretation of the Avalonian model ages are presented elsewhere (e.g. Nance and Murphy 1994, 1996; Murphy et al. 2000; Murphy and Nance 2002). That they represent mantle extraction ages, however, is suggested by the similarity in model ages between episodes of Avalonian magmatism ranging from 740 Ma to 370 Ma (Murphy et al. 1996b; Murphy et al. 2000). The generation of such similar model ages in rocks that pre-date the main subduction phase, and their recurrence over such a long time interval, is unlikely to be the outcome of mixing, but instead, indicates the predominant influence of a single basement source.

Hence, the neodymium isotopic data suggest that successive generations of Avalonian felsic magma were produced largely as a result of recycling ca. 1.0–1.3 crust. The depleted mantle model ages are therefore thought to record a genuine tectonothermal event during which the bulk of Avalonian basement was itself extracted from the mantle. Although the formation of Avalonian basement would therefore be broadly coeval with Grenvillian orogenesis, its more primitive isotopic signature suggests that it formed in one or more largely juvenile oceanic island arcs or oceanic plateau (Murphy et al. 2000). These data can be reconciled if the basement developed within the Panthalassa-type ocean that would have surrounded Rodinia following its amalgamation.

Fragmentary evidence for initial subduction in Avalonia dates from at least 730 Ma to 650 Ma and is termed the early arc phase. In Atlantic Canada, examples of this activity include the ca. 734 Ma calc-alkalic Economy River Gneiss in mainland Nova Scotia (Doig et al. 1993), the ca. 681 Ma arc-related Stirling Belt in Cape Breton Island (Bevier et al. 1993), the 680-630 Ma back arc volcanics in Central Cape Breton Island (Keppie and Dostal 1998), and the calc-alkalic ca. 683 Ma Tickle Point Formation and ca. 673 Ma Furby's Cove Intrusive Suite in southern Newfoundland (Swinden and Hunt 1991; O'Brien et al. 1996). The rift ophiolite volcanics of the Burin Group in Newfoundland (Strong et al. 1978) may extend this early Avalonian magmatic activity to ca. 763 Ma (Krogh et al. 1988).

Recent Sm-Nd and U-Pb data from Neoproterozoic metasedimentary sequences in Nova Scotia also support an early phase of Avalonian arc-activity. These sequences are dominated by schists and quartzites and were interpreted as the deposits of an Atlantic-type passive margin that developed along the Amazonian margin of Gondwana prior to the main phase of Avalonian volcanism (e.g. Murphy and Nance 1989). However, recently published geochemical and isotopic data suggest that the schists are derived from a moderately differentiated ocean island arc source composed of juvenile Avalonian basement crust (Murphy 2002), whereas the quartzites were derived from ancient (probably Amazonian) cratonic basement (Keppie et al. 1998). The presence of both juvenile and ancient sources suggests deposition in a rifted arc setting.

In Britain, evidence for early arc-related activity is represented by the ca. 700 Ma calc-alkalic Stanner-Hanter Complex of central Wales (Patchett et al. 1980), and the ca. 677 Ma calc-alkalic Malverns Plutonic Complex of the British Midlands (Tucker and Pharoah 1991). $^{40}Ar/^{39}Ar$ mineral ages of ca. 650 Ma in the Malverns Complex are interpreted to date cooling following upper greenschist to amphibolite facies metamorphism (Strachan et al. 1996b). Early arc activity may also be represented in the undated gneisses of the Rosslare Complex in southeastern Ireland and the Coedana Complex in North Wales (Gibbons and Horák 1996).

A short period of high-grade metamorphism is recorded at ca. 650 Ma in various parts of Avalonia, including coastal Maine (Stewart and Tucker 1998) and the Malvern Plutonic Complex (Strachan et al. 1996b). Amphibolite facies metamorphism of pre-630 Ma age may also be present in central Cape Breton Island (Keppie et al. 1998) and southern Newfoundland (O'Brien et al. 1996), and some form of accretion is implicated by the ophiolitic rocks of the ca. 760 Ma Burin Group (Keppie et al. 1991). This metamorphism is interpreted to reflect the accretion of Avalonia to the Gondwanan continental margin prior to the beginning of the main phase of Avalonian magmatism at ca. 635 Ma, and coincides with a temporary cessation (ca. 650–635 Ma) in subduction-related magmatism. In our reconstructions, therefore, we show the outboard arc terranes of Avalonia colliding with the northern Gondwanan margin at 650 Ma.

The main phase of Avalonian magmatism is recorded in voluminous late Neoproterozoic magmatic arc-related volcanic and cogenetic plutonic rocks with crystallization ages of 635 to 570 Ma (e.g., Nance et al. 1991). Coeval sedimentary successions that are dominated by volcanogenic turbidites are locally associated with these arc-related magmatic rocks, and have been attributed to deposition in a variety of intra-arc, interarc and back arc basins (e.g., Pe-Piper and Murphy 1989; Pe-Piper and Piper 1989; Pauley 1990; Smith and Socci 1990; O'Brien et al. 1996; Murphy et al. 1999). This magmatic activity and the generation of arc-related basins are interpreted to reflect oblique subduction beneath the northern Gondwanan margin.

The timing of the onset of this main phase of activity was broadly synchronous throughout much of Avalonia. However, its cessation was diachronous, terminating at ca. 590 Ma in New England (Kaye and Zartman 1980; Hermes and Zartman 1985, 1992; Thompson et al. 1996; Thompson and Bowring 2000), 600 Ma in southern New Brunswick (Bevier and Barr 1990; Barr et al. 1994; Currie and McNicoll 1999), 605 Ma in mainland Nova Scotia (Doig et al. 1991; Murphy et al. 1997; Keppie et al. 1998), 575 Ma in southern Cape Breton (Barr et al. 1990; Bevier et al. 1993), 585 Ma in Newfoundland (Krogh et al. 1988; O'Brien et al. 1996), and 600 Ma in the British Isles (e.g., Tucker and Pharaoh 1991; Horák 1993; Noble et al. 1993).

Cessation of main-phase subduction was accompanied by a transition to intracontinental extension, marked by the onset of bimodal magmatism. This onset was similarly diachronous, occurring at ca. 595 Ma in New England (Mancusco et al. 1996), at ca. 560 Ma in southern New Brunswick (Bevier and Barr 1990; Barr et al. 1994; Currie and McNicoll 1999), at ca. 605 Ma in mainland Nova Scotia (Murphy et al. 1997), between 575 Ma and 560 Ma in southern Cape Breton Island (Bevier et al. 1993), at ca. 570 Ma in Newfoundland (O'Brien et al. 1996), and in the interval 570–560 Ma in Britain (Tucker and Pharoah 1991). Although the transition was locally accompanied by deformation and metamorphism, no evidence exists for the regional orogenesis, crustal shortening, and crustal thickening and uplift characteristic of continental collision zones. Instead, deformation is usually localized and resulted in the inversion of some of the earlier volcanic arc basin successions.

To account for such a tectonic transition in the apparent absence of a major collisional event, Murphy and Nance (1989) proposed that Avalonian subduction was terminated as a result of transform activity. In their model, the main phase of Avalonian magmatism at ca. 635–570 Ma occurred as the result of oblique subduction, leading to the development of an extensional magmatic arc and a variety of volcanic arc basins. Subsequently, the interaction of a continental margin transform system with the subduction zone resulted in the termination of subduction, the structural inversion of a number of volcanic arc basins, and the formation of new rift and wrench-related basins in the interval ca. 590–540 Ma. Murphy et al. (1999), Keppie et al. (2000, 2003) and Nance et al. (2002) proposed ridge-trench collision as a mechanism for the transition in order to account for the diachronous cessation of arc volcanism and the apparent reversal of kinematics on major basin-bounding faults (e.g. Nance and Murphy 1990).

The distinct Avalonian faunal provinciality suggests that Avalonia separated from Gondwana by the Early Ordovician (Theokritoff 1979; Landing 1996). During the Ordovician, however, faunal and paleomagnetic data indicate increasing separation from Gondwana concurrent with a decrease in the separation between Avalonia and Laurentia (Cowie 1974; Boucot 1975; Pickering et al. 1988; Cocks and Fortey 1990; Trench and Torsvik 1992; Dalziel et al. 1994; Cocks 2000). The Arenig Stiperstone Quartzite in Britain and the correlative Armorican Quartzite of Cadomia and Iberia (e.g., Noblet and Lefort 1990) are thought to reflect the subsidence associated with this separation (Nance et al. 2002). Minor bimodal rift volcanism in Avalonia is predominantly of Cambrian age and may reflect rifting prior to separation (e.g., Murphy et al. 1985; Greenough and Papezik 1986).

Southern Appalachian terranes

Several terranes of peri-Gondwanan affinity occur in the southern Appalachians, including those of Carolina, the Goochland terrane, the Appalachian Piedmont, and the Florida subsurface. Carolina comprises several Neoproterozoic terranes located along the eastern margin of the southern Appalachians. It is juxtaposed against a variety of Piedmont terranes to the west, and surrounds on three sides and is in tectonic contact with the ~1 Ga Goochland terrane, which has been interpreted as either Laurentian basement or an exotic terrane (Hibbard et al. 2002).

The oldest rocks in Carolina are ca. 670 Ma granitoid bodies of the Roanoke Rapids terrane (Hibbard et al. 2002), which are interpreted as evidence of early arc magmatism broadly coeval with that in Avalonia. The basement of Carolina is not exposed. However, initial ϵ_{Nd} values of +0.5 to +5.9 and T_{DM} model ages of 0.7–1.1 Ga from ca. 635–610 Ma volcanic rocks of the Virgilina sequence (Samson et al. 1995; Wortman et al. 2000) suggest that Carolina, like Avalonia, was formed from juvenile peri-Rodinian crust and was located outboard from the northern Gondwanan margin until at least 700 Ma.

Carolina is dominated by a ca. 633–607 Ma juvenile arc assemblage overlain unconformably by a 580–540 Ma mature arc sequence. These are followed by middle Cambrian platformal sedimentary strata containing mixed Tethyan-Avalonian, cool-water trilobites that share faunal affinities with Armorica, Gondwana, and Avalonia (Theokritoff 1979; Samson et al. 1995; Hibbard and Samson 1995; Wortman et al. 2000). However, the presence of 1.1–1.8 Ga detrital zircons in Cambrian quartzites (Samson et al. 1999, 2001) suggest a provenance in Amazonia and/or Baltica.

Possible episodes of arc rifting have been documented at ca. 590–570 Ma and ca. 560–535 Ma (e.g., Dennis and Shervais 1991, 1996; Shervais et al. 1996), separated by an unconformity between the older and younger volcanic successions, which is thought to be coeval with widespread deformation and metamorphism (Dennis and Wright 1997; Barker et al. 1998).

The neighboring Goochland terrane has a ca. 1.0 Ga granulite facies basement that has been interpreted either as part of the Laurentian Grenville Belt (Farrar 1984; Glover 1989) or as an exotic terrane (Rankin 1994) that collided with Carolina at about 590 Ma. Piedmont terrane assemblages are dominated by a Cambro-Ordovician complex of arc, fore-arc and accretionary complexes (Hibbard and Samson 1995) that may be a continuation of the Pampean orogeny of western South America (Keppie and Ramos 1999). The Florida subsurface (Suwannee terrane) contains ca. 550 Ma arc-related volcanic rocks with 1.0–1.6 Ga T_{DM} model ages, and ca. 625 and ca. 550 Ma granitoid rocks with 1.1–1.2 Ga inherited zircons that suggest a crustal basement of Grenville affinity (Heatherington et al. 1996).

Other juvenile terranes

Other remnants of primitive island arcs developed within the peri-Rodinian ocean may be preserved in the ca. 900–700 Ma island arc rocks of the Arabian-Nubian Shield (e.g., Stern 1994; Blasband et al. 2000), and in the ca. 950–900 Ma calc-alkalic granitoid orthogneisses and metarhyolites of the Tocantins province in central Brazil, which yield a similar envelope of e_{Nd} growth lines and almost identical (ca. 0.9–1.2 Ga) depleted mantle model ages to those of Avalonia and Carolina (Pimental and Fuck 1992). On our reconstructions, this juvenile crust, including Avalonia and Carolina, is positioned within the Panthalassa-type peri-Rodinian ocean.

North and South Armorica and correlatives

Armorica, along with Iberia and Bohemia, is traditionally thought to represent one of several places where Neoproterozoic-Early Paleozoic “Cadomian” basement is preserved in western Europe. The Armorican massif is divided into two distinct segments by the E-W North Armorican shear zone, which is thought to be a Cadomian lineament reactivated in the Variscan (e.g. Strachan et al. 1990). To the south, the South Armorican massif (South Armorica) is dominated by Neoproterozoic sedimentary successions that are unconformably overlain by Paleozoic cover. However, these successions do not appear to have been strongly deformed until the Late Paleozoic (Watt and Williams 1979). To the north, the North Armorican massif (North Armorica) records a protracted tectonothermal history. The ca. 2.2–1.8 Ga Icart Gneiss is the only undisputed basement exposed in any of the peri-Gondwanan arc terranes. The age (Piton 1985; Samson and D’Lemos 1998) and isotopic signature (D’Lemos and Brown 1993; Samson and D’Lemos 1998) of this basement resembles that of the 2.1 Ga Eburnian basement of the West African craton (Allègre and Ben Othman 1980). Early arc-related magmatism is recorded by the ca. 746 Ma orthogneiss of the Pentevrian Complex (Egal et al. 1996), and by deformed granodioritic conglomerate cobbles with protolith ages of 670–650 Ma (Guerrot and Peucat 1990). Deformation and metamorphism of the early Cadomian arc occurred in the interval (ca. 650–615 Ma) separating the early and main phases of arc magmatism (Egal et al. 1996; Strachan et al. 1996a).

In the North Armorican massif, voluminous 616–570 Ma arc-related volcanic and cogenetic plutonic rocks accompany coeval sedimentary successions that are dominated by volcanogenic turbidites thought to have been deposited in arc-related basins (e.g., Dennis and Dabard 1988; Chantraine et al. 1994; Egal et al. 1996; Strachan et al. 1996a; Miller et al. 1999). This main phase of arc magmatism was progressively replaced by sinistral strike-slip tectonics in the interval ca. 570–540 Ma (e.g., Strachan et al. 1996a), followed by widespread intracrustal melting, migmatization, bimodal magmatism and post-tectonic granitoid emplacement at ca. 550–540 Ma (e.g., Rabu et al. 1990; Chantraine et al. 1994; Egal et al. 1996).

North Armorican basement isotopic Sm-Nd signatures together with U-Pb detrital zircon data from its late Neoproterozoic (Brioverian) sedimentary succession (Samson et al. 1999; Fernández-Suárez et al. 2002a) suggest a position near the West African craton. Thus, in contrast to Avalonia and Carolina, North Armorica appears to have originated above Paleoproterozoic crust along the continental margin of West Africa, rather than within the peri-Rodinian ocean. These data imply and Avalonia and North Armorica (i.e. the “Avalonian-

Cadomian belt" of Murphy and Nance 1989) did not form a coherent orogenic belt until the collision of Avalonia with northern Gondwana at ca. 650 Ma.

Iberia

Neoproterozoic rocks in the Iberian massif (the Neoproterozoic Iberian Autochthon of Quesada 1990, 1997) occur in the Central Iberian, West Asturia-Leoneses and Cantabrian zones and are dominated by thick, ca. 600–540 Ma pelite-greywacke sequences and interbedded calc-alkaline volcanic rock, overlain by late Vendian-early Cambrian flysch. The Ossa-Morena Zone to the south exposes abundant, ca. 600–575 Ma igneous rocks interpreted as representing a volcanic arc that was polydeformed and metamorphosed in the latest Neoproterozoic to Early Cambrian Cadomian orogeny associated with the development of an Andean-type continental margin at ca. 550–530 Ma. The suture zone between these two zones is defined by the Badajoz-Córdoba shear zone and adjacent accretionary units involving ophiolitic and eclogitic rocks (e.g. Quesada 1990; Quesada and Dallmeyer 1994; Eguiluz et al. 2000; Bandrés et al. 2002).

When the arcuate shape in the Iberian-Armorican arc is removed (Weil et al. 2001), the Neoproterozoic Iberian Allochthon and Ossa-Morena Zone can be correlated with similar units in South Armorica and North Armorica, respectively (e.g. Quesada 1990). Recent detrital zircon data show that the detritus of the Ossa-Morena Zone contains zircon populations typical of the West African Craton (Fernández-Suárez et al. 1998, 2002a, b; Gutiérrez Alonso et al. 2003). The nature of the basement underlying the Neoproterozoic Iberian Allochthon and its affinity is less certain. The presence of ca. 1.0 Ga detrital zircons in the clastic rocks indicate that at least some of the detritus was derived from Amazonia (Fernández-Suárez et al. 2002b; Gutiérrez-Alonso et al. 2003). The presence of shallow marine Tethyan (African) trilobites, the Arenig Armorican Quartzite and late Ordovician glaciomarine diamictites is very similar to time-equivalent successions in the Mauritanide foreland, suggesting a West African connection by the Early Paleozoic (Quesada et al. 1991; Quesada 1997). In addition, redeposited Neoproterozoic bauxitic sediments in the Sierra Albarrama and Sistema Central suggest derivation from West Africa (Quesada 1997). Taken together, these data suggest that the detritus has both Amazonian and West African components and that the 1 Ga detrital zircons could have been transported a considerable distance from the Amazonian/Oaxaquan source. Fernández-Suárez et al. (2002b) and Gutiérrez-Alonso et al. (2003) propose that the NW Iberia (Central Iberia, Westasturian-Leonese and Cantabrian zones) lay off Amazonia/Oaxaquia, but was transferred along the Gondwanan margin and was closer to West Africa in the Early Paleozoic. Alternatively, if the detrital zircons are transported considerable distances, then NW Iberia could have been located off West Africa (Keppie et al. 2003) in the Neoproterozoic.

An important Cambrian rifting event is recorded in the development of a sandstone-limestone platform at ca. 520–510 Ma, and in voluminous bimodal rift magmatism in the Ossa-Morena Zone that ranges from Early Cambrian to Late Ordovician in age (Quesada 1990; Giese and Buehn 1994; Sánchez-García et al. 2003).

By the Early Ordovician time, the existence of a significant tract of new ocean is evidenced by a breakup unconformity (Quesada 1990). Widespread Arenig subsidence, recorded in the broad distribution of the Armorican Quartzite across Cadomia and Iberia (e.g., Noblet and Lefort 1990), suggests that rifting extended into the Early Ordovician,

Bohemia

The Bohemian massif is divided into several zones. A wealth of recent data indicate that the Teplá-Barrandian and Saxothuringian zones have close affinities with Armorica and West Africa, whereas the Moravo-Silesian zone has Avalonian affinities (Zulauf et al. 1999; Finger et al. 2000; Linnemann and Romer 2002). In the Moldanubian zone, the Teplá–Barrandian unit consists of Neoproterozoic arc-related interbedded metasedimentary and metavolcanic rocks that are interpreted to reflect southerly-directed subduction (present co-ordinates) beneath the Gondwanan margin followed by accretion of an island arc with the Gondwanan margin (Zulauf et al. 1999). These sequences are unconformably overlain by unmetamorphosed Cambrian sediments that were deposited in a transtensional regime (Zulauf et al. 1997), and by an Ordovician sequence of sediments and volcanics, which reflect rifting along the Gondwanan margin. U-Pb isotopic data suggesting that the Neoproterozoic sequence is ca. 590–570 Ma in age overlies 2.0 Ga Cadomian (Icartian) basement (Dörr et al. (2002). Correlation of the Teplá–Barrandian unit with North Armorica and the Ossa Morena Zone therefore seems likely.

In the Saxo-Thuringian zone, Neoproterozoic rocks consist of 660–540 Ma arc-related interbedded submarine sedimentary and volcanic rocks and granitoid plutons (Linnemann et al. 2000; Linnemann and Romer 2002). A 2.1–1.7 Ga event has been recorded in U–Pb analyses of zircon from igneous bodies and is interpreted to reflect West African (Eburnian) basement (Linnemann et al. 2000).

Latest Neoproterozoic–earliest Cambrian deformation and basin inversion was followed by 530–500 Ma siliciclastics and carbonates thought to represent deposition along a "San Andreas-style" transform margin (Linnemann and Romer 2002). Sm–Nd isotopic data and stratigraphic criteria (e.g. the Hirnantian records of the Sahara glaciation) support a West African source (Linnemann and Romer 2002).

In the southeastern Bohemian massif (Moravo-Silesian zone), the Brunovistulian unit consists of metasediments thought to have been deposited in a back-arc basin and metamorphosed to amphibolite facies by arc-continent collision and basin inversion at ca. 600 Ma. This sequence is intruded by ca. 590–580 Ma and ca. 550 Ma granitoid rocks (e.g. Finger et al. 2000). According to Finger et al. (2000), the tectonothermal evolution of the Brunovistulian unit strongly resembles Avalonia, an interpretation that is supported by Sm–Nd isotopic data (Hegner and Kröner 2000) and 1 Ga U–Pb detrital zircons and cores of igneous zircons (Friedl et al. 2000), which suggest an Amazonian Neoproterozoic connection. A Cambrian–Ordovician tectonothermal event is thought to reflect crustal thinning and rifting.

Middle American terranes

The presence of Early Paleozoic Gondwanan fauna in several terranes in Middle America indicates that Oaxaquia, (which underlies much of Mexico, Ortega-Gutiérrez et al. 1995), the Maya terrane of the Yucatan Peninsula, and the Chortis Block (Honduras and Guatemala) have peri-Gondwanan affinities (Fig. 2). All of these terranes expose basement of Grenville age (Oaxaquia and Chortis Block) or late Neoproterozoic age (Keppie and Ortega-Gutiérrez 1999). The Grenville-age basement is isotopically transitional between that of the Grenville Belt and the basement massifs of Grenville age in the northern Andes of Columbia (Ruiz et al. 1999), which has been related to mixing of juvenile Grenville and Archean sources (Cameron et al. 2004). The Maya terrane is thought to have been contiguous with the Florida basement until the opening of the Gulf of Mexico in the Mesozoic (e.g. Pindell et al. 1990; Dickinson and Lawton 2001). Following Keppie and Ramos (1999) and Keppie et al. (2003), we position these terranes along the northern margin of Amazonia in accordance with the paleomagnetic data of Ballard et al. (1989).

Of the ~1 Ga basement rocks of Oaxaquia, the Maya terrane, and the Chortis Block, those of Oaxaquia are best known and consist of: (1) a metavolcanic-metasedimentary juvenile arc sequence of uncertain age; (2) a ~1,140 Ma, bimodal, within-plate intrusive suite that was deformed and metamorphosed at ~1,100 Ma; (3) a ~1,012 Ma anorthosite-gabbro unit that was deformed and metamorphosed in the granulite facies at ~980–1,104 Ma; and (4) ~920 Ma post-tectonic calc-alkaline plutonism (Keppie et al. 2001; Ortega-Obregón et al. 2004). This basement complex is unconformably overlain by Lower Ordovician sediments that contain trilobites of Gondwanan affinity (Robison and Pantoja-Alor 1968, taxonomy revised by Shergold 1975) and Silurian rocks containing brachiopods most similar to those in the Mérida Andes of Venezuela (Boucot et al. 1997). These data, together with the distribution of Ordovician facies belts along the margin of Amazonia, suggest that Oaxaquia-Maya-Chortis may have been derived from the gap north of Colombia in the Ordovician facies belts (e.g. Keppie 1977; Cocks and Fortey 1988; Keppie and Ortega-Gutiérrez 1995; Boucot et al. 1997; Keppie et al. 2001). Detrital zircon ages in the Ordovician sedimentary sequences range from 980 to 1,230 Ma, matching the age provinces of the Oaxacan Complex and the ~1 Ga basement massifs in the northern Andes (Gillis et al. 2001).

A variety of data suggest that an ocean lay between Oaxaquia-Maya-Chortis and Laurentia until the Permo-Carboniferous (Keppie and Ramos 1999), implying that Oaxaquia-Maya-Chortis was transferred to Laurentia during the amalgamation of Pangea. The first appearance of fauna with Laurentian affinities in Oaxaquia-Chortis occurs in Mississippian rocks that unconformably overlie those of the Lower Paleozoic (Sour-Tovar et al. 1996; Stewart et al. 1999). The detrital zircon record, which indicates that Oaxaquia was isolated from the southern margin of Laurentia until the Carboniferous (Gillis et al. 2001), is consistent with paleomagnetic data that would locate Oaxaquia between Amazonia and Baltica (Ballard et al. 1989; Keppie and Ortega-Gutiérrez 1999).

The Maya terrane contains ~1.23 Ga orthogneisses that underwent granulite facies metamorphism at 990–975 Ma (Weber and Köhler 1999; Ruiz et al. 1999), a history that suggests a genetic relationship to Oaxaquia (Keppie and Ramos 1999). Zircons from plutonic rocks found in boreholes in the Yucatan Peninsula have yielded late Neoproterozoic ages (Krogh et al. 1993), and Late Silurian ages have been recorded in plutons in the Maya Mountains (Steiner and Walker 1996). The relationship between these units is not exposed. However, restoration of the ~60° anticlockwise rotation that occurred during the Early Mesozoic opening of the Gulf of California (Molina-Garza et al. 1992; Dickinson and Lawton 2001) supports the former continuity of the Maya terrane with northern Oaxaquia.

Although the above data imply a position for Oaxaquia-Chortis and Maya along the periphery of the Amazonian craton throughout the Neoproterozoic, the paucity of Neoproterozoic subduction-related magmatism suggests that these terranes were inboard of the Avalonian-Carolinian arc.

Continental reconstructions

There is considerable disagreement on the location and configuration of the continents during the 800–500 Ma interval. We present the configurations proposed by PLATES as an example of testing paleomagnetically-constrained models of continental reconstructions against the geological record preserved along their continental margins. We think our approach may help distinguish between rival reconstructions.

The above analyses imply that the peri-Gondwanan terranes were linked with West Gondwana during the late Neoproterozoic. This margin of Gondwana was an active margin at the same time that the eastern margin of Laurentia was a developing rift-passive margin (e.g. Cawood et al. 2001). Models for the tectonothermal evolution of these terranes should therefore be testable against the paleomagnetically constrained movements of the Amazonian and West Africa cratons. Our reconstructions begin at 800 Ma, a time when few peri-Gondwanan lithologies existed. However, their Sm-Nd isotopic signatures help constrain the age and nature of the underlying crust from which they were derived and we use these data to help constrain their locations in our reconstructions.

Most reconstructions implicitly assume that Laurentia, Amazonia and West Africa were juxtaposed in the late Neoproterozoic (e.g. Hoffman 1991; Weil et al. 1998; Pisarevsky et al. 2003), and their locations are based on Laurentian poles. The location of peri-Gondwanan terranes, therefore, is also based on Laurentian poles, allowing the tectonothermal evolution of the northern margin of West Gondwana to be compared with paleomagnetically constrained movements of Laurentia and West Gondwana for the interval ca. 800–500 Ma.

However, there is considerable disagreement concerning the paleolatitude of Laurentia during a critical time interval between 625 and 550 Ma. Two reliable paleomagnetic poles from Laurentia exist for this time interval. One is from the 577 Ma Callander Complex (Symons and Chaisson 1991), the other from the Sept Îles intrusion (Tanczyk et al. 1987), dated at 565 Ma (Higgins and van Breeman (1998). Since it is impossible to incorporate both poles into the same tectonic model, two models are presented here. One places Laurentia at a high latitude for this time interval, the other puts it in a low latitude position (Pisarevsky et al. 2000, 2001). The following reconstructions are an initial attempt to evaluate such connections and to identify critical areas of uncertainty that require resolution.

The position of Baltica with respect to Laurentia is also a matter of debate. Most reconstructions suggest the juxtaposition of the Scandinavian margin of Baltica and some part of the Labradorian-Greenland margin of Laurentia (e.g., Winchester 1988; Hoffman 1991; Park 1992; Dalziel 1992; Starmer 1996; Dalziel 1997; Weil et al. 1998; Grelling and Smith 2000; Pisarevsky et al. 2003). Recently the "Baltica upside-down" model was proposed (Torsvik et al. 1996; Hartz and Torsvik 2002) which juxtaposes the eastern (Uralian) margin of Baltica to the East Greenland. This reconstruction is based on paleomagnetic data from the Komagnes dyke in the southern part of the Varanger peninsula, two dykes in the Sredny peninsula (see references in Torsvik et al. 1996), and the subset of Laurentian palaeomagnetic poles corresponded to the high-latitude model of Laurentia (see above). The 580 Ma assigned age for these Baltican dykes was based on the old K-Ar determinations and varied from 360 to 580 Ma. However, recently Guise and Roberts (2002) reported the high-quality 378 ± 2 Ma ^{40}Ar-^{39}Ar plateau age for the Komagnes dyke, probably ruling out a possibility for the mentioned poles to be Vendian or Cambrian. Popov et al. (2002) published the 555 Ma high-quality pole from the Winter Coast sediments. This result is apparently the best for the latest Neoproterozoic to Early Cambrian Baltica (and the only one with the proven primary magnetization), and it does not support the "upside down" model. Popov et al. (2002) correctly pointed out a similarity of the Komagnes/Sredny poles to the Jurassic part of the European Apparent Polar Wander Path, suggesting a Jurassic remagnetisation for these dykes. The "upside down" model also contradicts the geological data – the correlation of the Precambrian crustal blocks and orogens in Laurentia and Baltica (e.g., Winchester 1988; Hoffman 1989; Gorbatschev and Bogdanova 1993; Park et al. 1994; Karlstrom et al. 1999), the absence of any traces of the Grenvillian orogeny in the eastern margin of Baltica, the provenance studies (Willner et al. 2003) and others. Probably the strongest argument against the "upside down" model is the tectonic regime in the eastern Baltica in Neoproterozoic. There is a broad agreement, that huge (up to 15 km) Uralian Riphean successions represent a long-lived passive margin (at least in the late Riphean) with change to the active margin conditions after Early Vendian (ca. 620 Ma) (e.g., Nikishin et al. 1996; Willner et al. 2001, 2003; Maslov and Isherskaya 2002; Puchkov 2003 and references therein). The "upside down" model predicts a completely different history – intracontinental basin until ca. 550 Ma, then – progressive rifting and passive margin until at least 500 Ma. In particular, this suggests a thick Cambrian passive margin succession, however, Cambrian deposits are virtually absent in the Urals (Maslov et al. 1997 and references therein).

For the abovementioned reasons we prefer the traditional fit constrained by the early Neoproterozoic palaeomagnetic data (Weil et al. 1998; Pisarevsky et al. 2003) with Baltica juxtaposed to the south-eastern Greenland – Labrador with the Rockall plateau and probably Scottish blocks in between. This reconstruction is also similar to those of Winchester (1988), Park (1992), Starmer (1996), Grelling and Smith (2000) and others. Following the recommendation of Winchester (1988), we included palinspastic reconstructions of northwestern Scandinavia and eastern Greenland that removes several hundreds of kilometers of Caledonian shortening in both cases. Similar margin restorations were done by Winchester (1988), Soper et al. (1992), Park et al. (1994), Fairchild and Hambrey (1995), Higgins et al. (2001) and others. Such palinspastic restorations are necessary to avoid strong overlapping of the continental blocks during the spherical rotations. The approximate position of the pre-Caledonian continental boundaries were calculated in accordance with the studies of Andreasson (1994) for Scandinavia, and of Higgins and Leslie (2000) for East Greenland.

750–615 Ma:

Between 750 and 610 Ma, there is no variation in the two models, so they are described together. Sm-Nd isotopic data suggest that Avalonia and Carolina originated as juvenile crust in the peri-Rodinian ocean (Fig. 3, after Pisarevsky et al. 2003), presumably by a combination of ocean ridge processes, ensimatic subduction, oceanic plateau generation and plume activity (Murphy et al., in

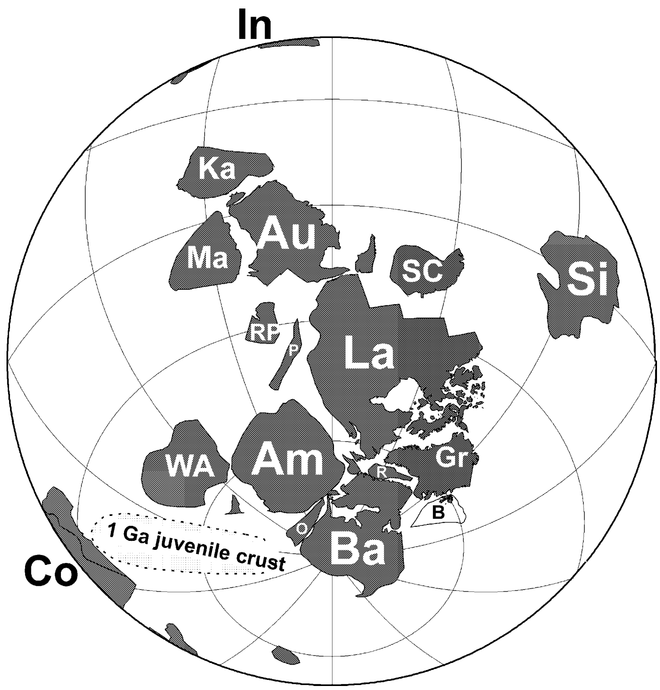


Fig. 3 Rodinia at 990 Ma (modified after Pisarevsky et al. 2003; Pisarevsky and Natapov 2003). Am – Amazonia; B – Barentsia; Ba – Baltica; Ch – Chortis; Gr – Greenland; La – Laurentia; O – Oaxaquia; P – Pampean terrane; R – Rockall; RP – Río de La Plata; WA – West Africa; In – India; Ka – Kalahari; Si – Siberia

press). At 750 Ma, these terranes are positioned well outboard of the Gondwanan margin (Fig. 4A). However, Neoproterozoic metasedimentary rocks in Avalonia, deposited along the Amazonian margin of Rodinia prior to the main ca. 650–550 Ma phase of Avalonian subduction, have geochemical and isotopic signatures that reflect deposition in a western Pacific-like setting (Keppie and Dostal 1998; Murphy 2002), although the presence of detrital zircons of Amazonian/Oaxaquan provenance suggests an ocean of limited width across which cratonic detritus was transported. These data, together with ca. 680 and 650 Ma high grade metamorphism in Avalonia which is interpreted to reflect collision with the Amazonian margin, suggest convergence between the Avalonia and the northern Gondwanan margin between 750 and 650 Ma (Fig. 4B). This convergence is accommodated in large part by subduction of the oceanic lithosphere outboard of the Gondwanan margin, and is held to be responsible for the early arc stage of the peri-Gondwanan terranes. Given that there is little evidence of coeval arc-related activity along the cratonic Gondwanan margin, closure of this intervening tract of oceanic lithosphere requires either (a) a subduction zone angled away from the Gondwanan

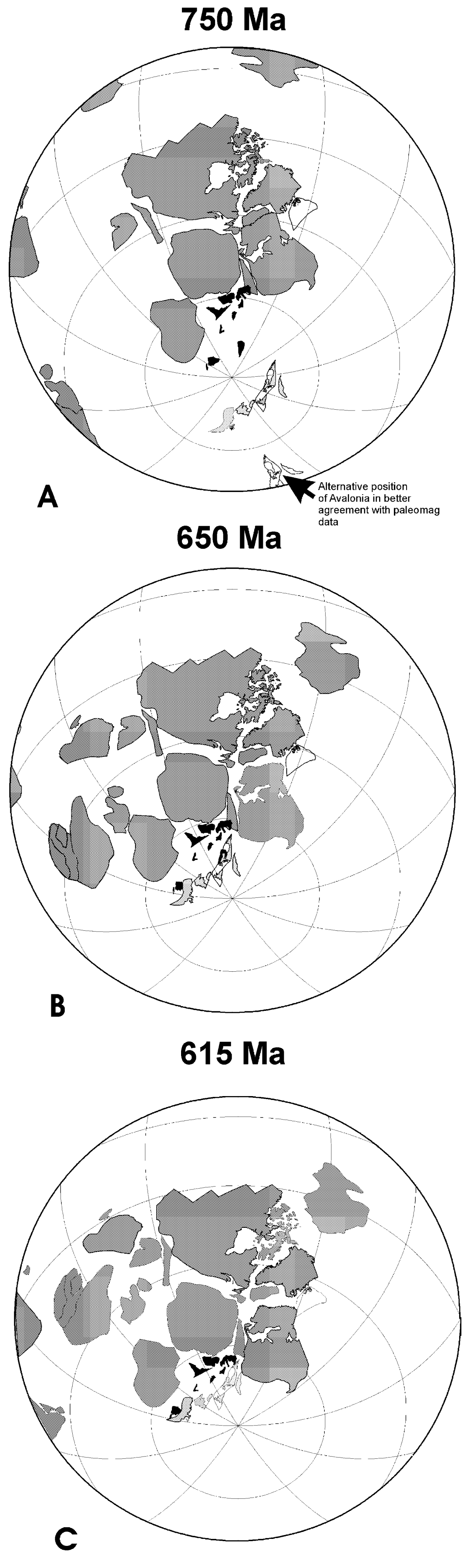


Fig. 4A–C A–C 750–615 Ma reconstructions of Laurentia-Gondwana-Baltica, emphasizing the history of the peri-Gondwanan terranes (modified from Murphy et al. 2001). This reconstruction assigns the minimum movement to the continents required to satisfy the paleomagnetic data. Euler rotation parameters are given in Table 1 margin, or (b) the development of a Western Pacific-type margin in which Gondwana is separated from the early Avalonian arc by a back arc basin. In contrast, isotopic data indicate that northern Armorica, the Ossa Morena Zone of Iberia and most of Bohemia have ancient West African basement. These terranes are consequently positioned adjacent to the West Africa craton.

The collision of Avalonia-Carolina with the Gondwanan margin by ca. 650 Ma brings the so-called "Avalonian-Cadomian belt" into alignment for the first time and broadly coincides with a brief hiatus in arc magmatism. The formation of the Avalonian-Cadomian belt is analogous to the Mesozoic-Cenozoic evolution of western North America in that proximal and exotic terranes were incorporated into a single belt that shared a similar subsequent history.

By ca. 635 Ma, the occurrence of abundant ensialic arc-related magmatism in all peri-Gondwanan terranes, together with the presence of Gondwanan detrital zircons, indicates that a subduction zone had been established outboard of the peri-Gondwanan terranes and was angled beneath these accreted terranes and the cratonic margin of Gondwana (Fig. 4C).

615–550 Ma

The critical time interval between 615 Ma and 550 Ma presents the greatest uncertainty in the reconstructions because of the paucity and controversial nature of the paleomagnetic database. As a result, there is considerable uncertainty about the paleolatitude of Laurentia. Since many Neoproterozoic continental reconstructions juxtapose eastern Laurentia and West Gondwana, resolution of this issue has fundamental implications for the interpretation of the geodynamic significance of peri-Gondwanan tectonothermal events.

In a high latitude configuration, Laurentia, and by implication, Amazonia, drifts rapidly southward, between 615 to 570 Ma (Fig. 5A–C), implying oblique sinistral convergence across the active northern Gondwanan margin. This is consistent with field data in Avalonia (Nance and Murphy 1990, Murphy et al. 2000; Nance et al. 2002) where the opening of intra-arc basins has been attributed to sinistrally oblique subduction. Such convergence would also provide a geodynamic explanation for the onset of the main phase of arc-related magmatism characteristic of the terranes along the northern Gondwanan margin. This scenario would be analogous to the modern relationship between the westward drift of North America and South America and the style of tectonic activity along the eastern margin of the Pacific Ocean.

If on the other hand, Laurentia remained at low latitudes during this time interval (Fig. 6), the main phase of

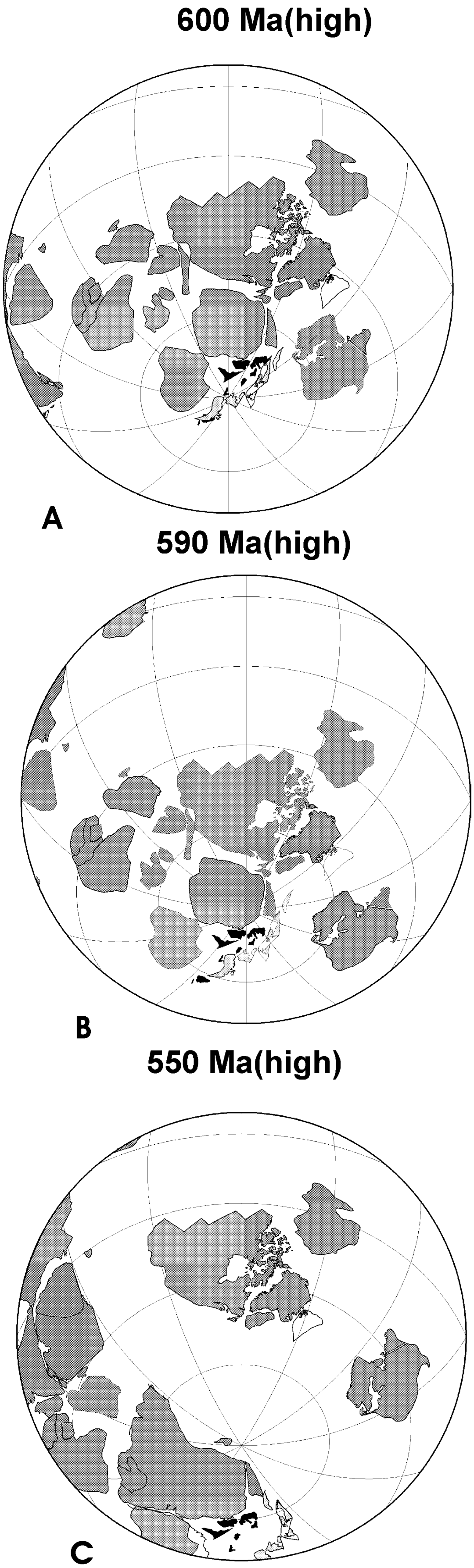


Fig. 5A–C A–C This reconstruction incorporates the high latitude option for Laurentia between 600 and 550 Ma (modified from Murphy et al. 2001). Euler rotation parameters are given in Table 1

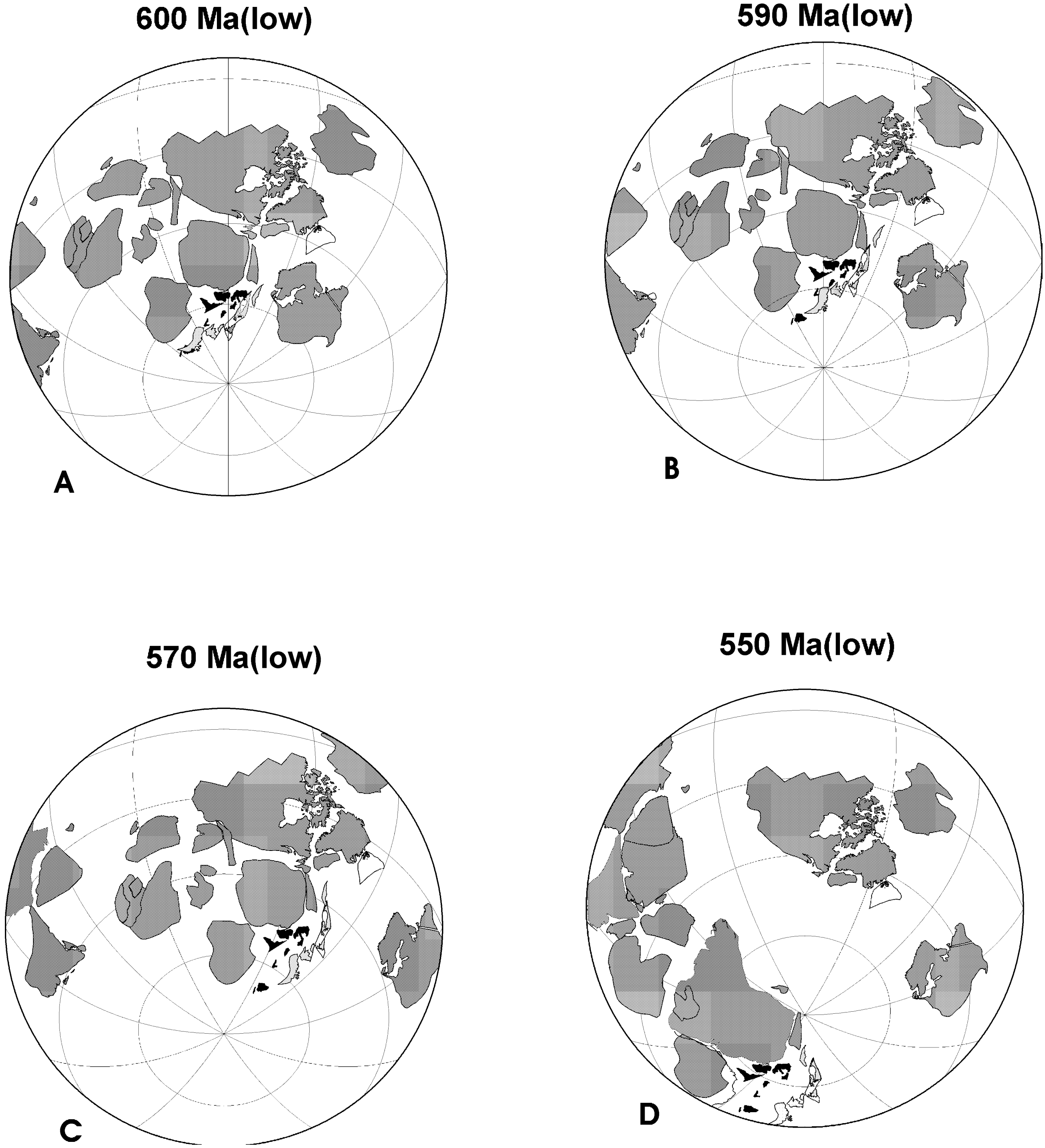
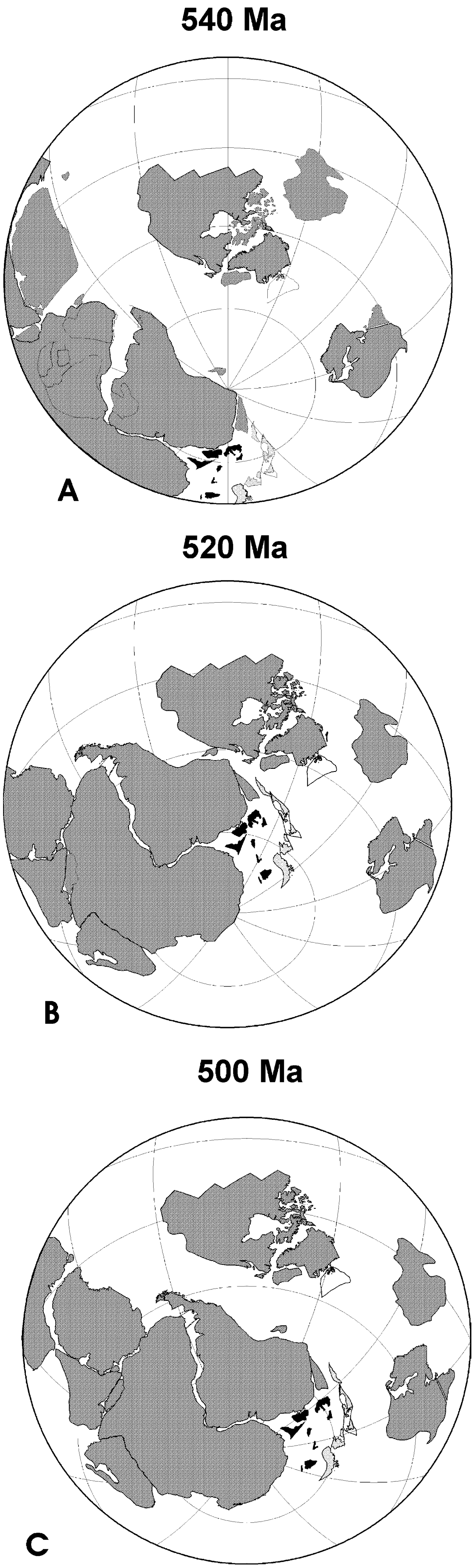


Fig. 6A–D A–D This reconstruction incorporates the low latitude option for Laurentia between 600 and 550 Ma (modified from Murphy et al. 2001). Euler rotation parameters are given in Table 1

tectonothermal activity along the northern Gondwanan margin would require a different explanation. In this scenario, the most likely explanation would be the re-establishment of subduction along the margin following the accretion of outboard terranes such as Avalonia and Carolina. However, the geodynamic relationship between this event and global-scale plate motions is unclear.

The potentially profound influence of the separation of Baltica from Laurentia at ca. 600 Ma (Meert et al. 1996; Cawood et al. 2001) is apparent in both the high-latitude and low-latitude models. This separation would imply the existence of a spreading ridge between these two continents. According to Murphy et al. (1999), Nance et al. (2002), and Keppie et al. (2003) it is likely to have been the collision of a spreading ridge with the northern



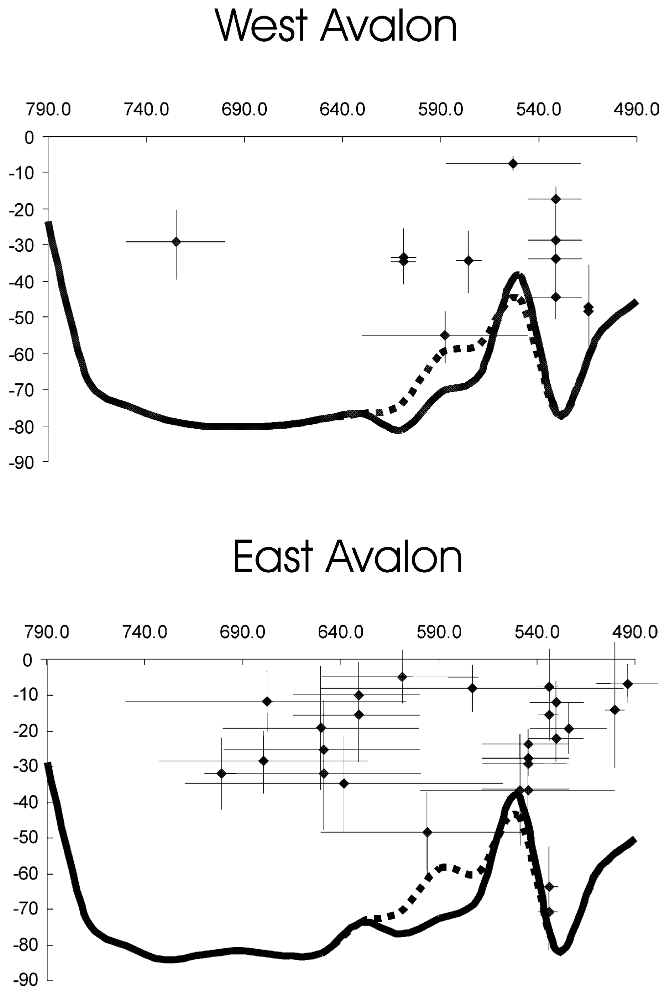


Fig. 8 Paleolatitudes of West Avalonia (representative point 46 N, 60 W) and East Avalonia (representative point 52 N, 0 E) predicted by the reconstructions shown in Figs. 2, 3, 4 and 5. *Solid lines* = high-latitude Laurentia model, *dashed lines* = low-latitude Laurentia model. Magnetic paleolatitude (Q>2) result numbers from Global Paleomagnetic Database Ver. 4.4 (December, 2002) (Pisarevsky and McElhinny 2003) are: 121, 122, 409, 410, 411, 798, 799, 801, 868, 1000, 1001, 1130, 1242, 1339, 1340, 1341, 1342, 1345, 1347, 1649, 1747, 1748, 1753, 2157, 2158, 2390, 2943, 3528, 3737, 3738, 3802, 6035, 6036, 6037, 6038, 6039, 6040, 6041, 8683

Gondwanan margin that was responsible for the diachronous cessation of arc-related magmatism and the onset of strike-slip tectonics. Such a collision would additionally explain the change from sinistral to dextral motion along basin-bounding faults within Avalonia that occurs at about this time (e.g. Nance and Murphy 1990). However, both reconstructions suggest that the colliding ridge could equally have been the spreading ridge between Baltica and Laurentia. The orientation of the

Fig. 7A–C A–C 540–500 Ma reconstructions of Laurentia-Gondwana-Baltica, emphasizing the history of the peri-Gondwanan terranes (modified from Murphy et al. 2001). This reconstruction assigns the minimum movement to the continents required to satisfy the paleomagnetic data. Euler rotation parameters are given in Table 1

Table 1 Euler rotation parameters

Craton/block/terrane	Age	Pole		Angle
	(Ma)	(°N)	(°E)	(°)
Laurentia to absolute framework	990	13.9	-144.1	-134.7
	750	19.6	-138.0	-95.4
	650	18.0	-130.4	-104.3
	615	15.4	-127.4	-106.8
	(High-latitude model)			
	600	5.6	-133.1	-103.0
	590	0.4	44.2	124.1
	570	0.6	-136.2	-123.9
	550	15.3	-130.5	-109.7
	(Low-latitude model)			
	600	16.3	-124.6	-96.1
	590	16.9	-122.4	-89.0
	570	7.4	-126.3	-73.6
	550	14.6	-121.1	-105.6
	(Single model again)			
	540	14.3	-127.7	-117.5
	520	15.1	-127.0	-96.7
	500	20.1	-127.8	-92.0
Baltica to Laurentia	990–750	75.8	-95.8	-59.2
	650	74.4	-65.8	-65.7
	615	73.3	-58.6	-68.1
	600	64.4	-71.8	-47.8
	590	52.7	-79.4	-35.7
	570	3.0	87.7	23.8
	550	39.5	88.5	31.0
	540	27.8	108.5	26.1
	520	6.1	-37.3	-29.1
	500	24.6	-18.3	-44.4
Greenland to Laurentia	990–500	67.5	-118.5	-13.8
Amazonia to Laurentia	990–570	12.0	-47.0	-110.7
	550	17.8	135.9	123.0
	540	11.8	141.3	121.7
West Africa to Amazonia	990–540	53.0	-35.0	-51.0
Rio de La Plata to Laurentia	990–750	9.9	-47.4	-93.7
	650	11.4	-44.7	-95.9
	615	10.0	-48.9	-103.0
	600	9.3	-50.9	-106.7
	590	9.6	-50.5	-107.1
	570	10.1	-49.7	-107.9
	550	17.8	135.9	123.0
	540	11.8	141.3	121.7
Pampean to Rio de La Plata	990–750	70.9	-10.8	-3.8
	650	70.9	-10.1	-1.5
	615	70.6	-9.6	-1.0
	600	72.0	-10.2	-0.8
	590	70.4	-10.6	-0.6
	570	71.8	-7.5	-0.3
	550	90.0	0.0	0.0
Rockall to Laurentia	990–500	75.3	159.6	-23.5
Oaxaquia to Amazonia	990–550	12.1	81.7	53.4
	615	11.0	78.0	54.5
	600	9.9	74.5	55.9
	590	10.4	73.5	55.5
	570	11.6	71.5	54.9
	550	12.7	69.3	54.3
	540	13.3	68.3	54.1
	520	16.2	42.9	49.9
	500	0.9	87.4	42.9
Chortis to Amazonia	990–570	5.7	-78.5	139.8
	550–540	0.8	-79.0	147.0
	520	-6.7	-89.0	162.9
	500	8.4	-81.7	149.4

Table 1 (continued)

Craton/block/terrane	Age	Pole		Angle
	(Ma)	(°N)	(°E)	(°)
Siberia to Laurentia	990	65.0	159.3	-69.6
	750	65.0	144.0	141.8
	650	36.1	5.0	20.2
	615–540	2.2	174.4	-22.1
	520	26.8	70.9	34.2
	500	27.7	88.8	44.8
South China to absolute framework	990	66.4	-107.9	127.9
	750	46.3	165.3	-178.6
Australia to absolute framework	990	42.6	-5.2	115.8
	750	49.1	74.1	70.6
	650	38.2	82.0	66.6
	615	37.2	96.8	61.5
	(High-latitude model)			
	600	52.9	90.6	61.4
	590	54.5	57.4	75.5
	570	53.9	60.6	85.3
	550	57.8	91.0	78.4
	(Low-latitude model)			
	600	37.8	106.7	69.5
	590	37.0	112.1	75.3
	570	44.5	123.7	78.4
	550	56.4	100.3	91.9
	(Single model again)			
	540	50.3	94.5	80.9
Mawson to Australia	990–540	1.3	37.7	30.3
Kalahari to Australia	990–750	79.8	97.1	73.4
Kalahari to absolute framework	650	34.7	115.7	152.6
	615	36.1	119.0	164.8
	(High-latitude model)			
	600	36.9	126.7	151.3
	590	48.0	125.6	145.7
	570	45.6	123.3	144.0
	550	53.8	113.9	126.7
	(Low-latitude model)			
	600	29.8	122.4	166.4
	590	25.5	124.6	167.4
	570	19.9	133.2	155.3
	550	52.2	117.7	141.1
	(Single model again)			
	540	50.7	117.8	130.6
Dronning Maud Land to Kalahari	990–540	9.7	148.7	-56.3
India to absolute framework	990	58.6	-3.9	86.3
	750	72.5	26.8	46.9
India to Australia	650	13.9	-175.9	55.5
	615–540	14.0	-168.3	65.8
Sri Lanka to India	990–540	9.8	82.9	-24.3
Rayner to India	990–540	4.9	-163.4	-93.2
Congo to absolute framework	990	45.6	83.8	68.3
	750	10.5	82.0	140.1
	650	16.1	109.3	140.1
	615	27.4	118.4	160.1
	(High-latitude model)			
	600	30.0	124.6	146.0
	590	42.2	122.6	141.4
	570	41.6	121.5	141.3
	550	51.7	112.4	125.8
	(Low-latitude model)			
	600	22.7	122.1	161.9
	590	19.5	124.5	163.2
	570	16.0	132.6	151.5
	550	50.2	116.6	140.0
	(Single model again)			
	540	49.7	117.2	130.0

Table 1 (continued)

Craton/block/terrane	Age (Ma)	Pole (°N)	(°E)	Angle (°)
São Francisco to Congo	990–540	53.0	-35.0	51.0
Paraná to São Francisco	990	15.4	-40.4	-31
	750–500	90.0	0.0	0.0
Gondwanaland to Laurentia	520	14.9	115.2	128.6
Easternmost Greenland to Greenland	990–500	15.1	-59.2	-3.9
Barentsia to easternmost Greenland	990–500	83.6	-30.0	-58.9
Westernmost Scandinavia to Baltica	990–500	33.6	-21.0	6.1
Yukatan to W. Africa	990–500	33.3	113.8	77.8
Florida to W. Africa	990–500	66.7	-12.0	77.6
W. Avalonia to W. Africa	750	60.5	-44.0	64.7
	650	48.0	-16.7	75.5
	615	46.0	-12.1	73.6
	600	45.0	-10.2	72.9
	590	38.4	-13.2	78.3
	570	34.1	-18.2	83.9
	550–500	37.3	-23.9	83.1
E. Avalonia to W. Avalonia	750–500	76.1	-60.6	-58.8
Carolina to W. Avalonia	750–650	53.4	-126.5	31.2
	615	51.4	-132.1	24.3
	600	26.2	-171.3	8.4
	590	29.2	-41.3	-7.7
	570	0.7	135.0	6.0
	550	36.7	130.2	6.5
	540	53.3	149.0	5.7
	520	60.0	-125.8	6.7
	500	44.3	-98.0	10.2
CIZ to W. Africa	750–500	10.8	-0.5	87.3
Bohemia to W. Africa	750–600	22.9	-134.7	-30.6
	590	24.4	-135.4	-31.6
	570	27.1	-136.5	-33.6
	550	29.5	-137.7	-35.7
	540	30.6	-138.2	-36.8
Bohemia to Gondwanaland*	520–500	31.6	-138.7	-37.9
Ossa Morena to W. Africa	750–500	15.2	-2.0	80.4
Moravia-Silezia to W.Africa	750–600	21.3	-137.2	-28.7
	590	23.1	-137.4	-29.7
	570	26.4	-137.6	-31.8
	550	29.3	-137.8	-34.0
	540	30.6	-137.9	-35.2
Moravia-Silezia to Gondwanaland	520–500	31.9	-138.0	-36.3
S. Armorica to W. Africa	750–600	14.8	4.1	85.7
	590	14.3	4.1	85.1
	570	13.2	4.0	83.9
	550	12.1	4.0	82.7
	540	11.6	4.0	82.2
S. Armorica to Gondwanaland	520–500	11.0	4.0	81.6
N. Armorica to W. Africa	750–600	21.3	10.2	72.3
	590	20.9	9.8	72.3
	570	20.4	9.1	71.5
	550	19.7	8.3	70.7
	540	19.4	8.0	70.3
N. Armorica to Gondwanaland	520–500	19.1	7.6	69.9

* Gondwanaland – in West African coordinates, according to McElhinny et al.(2003)

spreading ridge between Laurentia and Amazonia would have been highly oblique to the peri-Gondwanan subduction zone, resulting in the eastward drift of Gondwana-peri-Gondwana relative to Laurentia, and permitting the continuation of subduction in localized areas such as Anglesey (Gibbons and Horak 1996).

On the other hand, arc magmatism would be expected to continue along the leading edge of Baltica (NE Norway and NW Russia), which is consistent with recent geochronological data from drill-holes beneath the Pechora Basin (Roberts and Siedlecka 1999; Roberts 2003).

550–500 Ma

In this time interval, there are fundamental differences in implication between the high-latitude and low-latitude models for Laurentia. A high-latitude position for Laurentia at 570 Ma implies its northward drift relative to Amazonia between 570 and 550 Ma associated with the opening of this portion of the Iapetus Ocean (Fig. 5C, D). With Laurentia in a low latitude position (Fig. 6), on the other hand, the opening of Iapetus between these blocks would require the rapid southward drift of Amazonia and, by implication, the attached peri-Gondwanan terranes. This setting would be analogous to the modern relationship between the westward drift of South America as a result of spreading in the South Atlantic, and the style of magmatism along the Andean margin. However, the peri-Gondwanan terranes are dominated by wrench-related tectonics during this interval. The relationship between this style of tectonics and the rapid movement of Laurentia is not immediately obvious, unless the vector of plate motion was at a low angle to the peri-Gondwanan portion of the continental margin. Such a direction would have been at a high angle to East Gondwana, consistent with near-orthogonal collision that resulted in the formation of Gondwanaland at ca. 530 Ma (e.g. Hoffman et al. 1998).

By 540 Ma (Fig. 7), both models for Laurentia show the essentially the same configuration, with Laurentia at low latitudes. However, they also suggest that spreading between Laurentia and Baltica after 600 Ma was coincident with subduction beneath the leading edge of Baltica. The growing evidence for subduction-related tectonothermal activity between 600 and 550 Ma along the present northern margin of Baltica (e.g. Roberts 2003) suggests it was this margin that was at the leading edge. This observation may shed light on controversies concerning the orientation of Baltica relative to Laurentia in the late Neoproterozoic and Early Paleozoic (e.g. Torsvik et al. 1996; Dalziel 1997).

At 535 Ma, Baltica had reached its maximum latitudinal separation from northern Gondwana. Although subsequent convergence may be reflected in the Pampean orogeny of South America, the peri-Gondwanan terranes are dominated by stable platformal assemblages and localized rift-related magmatism at this time.

Paleomagnetic constraints from Avalonia

In Fig. 8, we use our models to construct the paleolatitudinal positions for West and East Avalonia (representative points are 46°N, 60°W and 52°N, 0°E, respectively). Unfortunately there are no high-quality paleomagnetic data for Avalonia with well-constrained ages older than 600 Ma. Instead, we show all available magnetic paleolatitudes for results with reliability criteria of Q>2 (Van der Voo 1990). These paleolatitudes are systematically lower than those predicted by our models. This discrepancy could be reduced slightly if the Amazonia-Laurentia fit of Dalziel (1997) is used. However, this fit contradicts the abundant Neoproterozoic paleomagnetic data from Laurentia and Baltica (e.g., Pisarevsky and Bylund 1998; Weil et al. 1998). Combining the available paleomagnetic data for Laurentia, Baltica and Avalonia for both the high latitude and low latitude models reveals critical uncertainties in the paleomagnetic database, and/or assumed Laurentia-West Gondwana-Avalonia connections. Our analysis implies that either Laurentia had a more complicated movement history between 720 and 615 Ma than is currently constrained by the available data, or the configuration of Laurentia-West Gondwana-Avalonia on many reconstructions requires re-evaluation. Recent geologic data, such as the apparent lack of correlation between the Dalradian of Scotland and the Arequipa massif of Peru, together with the possible existence of the Neoproterozoic Marañón-Tucavaca belt east of the northern Andes, supports the contention that this configuration requires substantial re-evaluation. Paleomagnetic data for Amazonia, currently unavailable, would go a long way to testing these configurations.

Conclusions

Although there is general consensus that the amalgamation and dispersal of the supercontinent Rodinia profoundly influenced the evolution of Earth systems in the Neoproterozoic, the configuration of this supercontinent is controversial.

The reconstructions presented for the crucial time interval between 750 and 500 Ma permit an examination of the potential geodynamic linkages between the tectonothermal evolution of peri-Gondwanan terranes and Laurentia-Amazonia-Baltica continental configurations. Each reconstruction has several simplifying assumptions and some critical uncertainties. However, using the Mesozoic-Cenozoic breakup of Pangea as a modern analogue, they serve to focus attention on potential geodynamic linkages between regional tectonothermal events. The most critical uncertainty is the paleolatitude of Laurentia and, by implication, Amazonia, at ca. 570 Ma. The high latitude and low latitude options for Laurentia at this time allow for very different geodynamic interpretations of the evolution of peri-Gondwanan terranes and the opening of the Iapetus Ocean.

However, such reconstructions focus attention on uncertainties in the database. For example, paleomagnetic data for the peri-Gondwanan terranes prior to 600 Ma, which meets the reliability criteria of Van der Voo (1988), yield lower paleolatitudes than those predicted by our models. This suggests that the Laurentia-Amazonia had more complicated plate motions between 720 and 615 Ma than is suggested by the available database and/or that Laurentia-West Gondwana-Avalonia configurations shown on many reconstructions require a re-evaluation.

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References

Allègre CJ, Ben Othman D (1980) Nd-Sr isotopic relationship in granitoid rocks and continental crust development: a chemical approach to orogenesis. Nature 286:335–342

Andreasson PG (1994) The Baltoscandian margin in Neoproterozoic – early Palaeozoic times. Some constraints on terrane derivation and accretion in the Arctic Scandinavian Caledonides. Tectonophys 231:1–32

Arndt NT, Goldstein SL (1987) Use and abuse of crust-formation ages. Geology 15:893–895

Ballard MM, van der Voo R, Urrutia-Fucugauchi J (1989) Paleomagnetic results from Grenvillian-aged rocks from Oaxaca, Mexico: evidence for a displaced terrane. Precamb Res 42:343–352

Bandrés A, Eguíluz L, Gil Ibarguchi JI, Palacios T (2002) Geodynamic evolution of a Cadomian arc region: the northern Ossa-Morena zone, Iberian massif. Tectonophys 352:105–120

Barker C, Secor DT Jr, Pray J, Wright J (1998) Age and deformation of the Longtown meta-granite, South Carolina Piedmont: A possible constraint on the origin of the Carolina terrane. J Geol 106:713–725

Barr SM, Hegner E (1992) Nd isotopic composition of felsic igneous rocks in Cape Breton Island, Nova Scotia. Can J Earth Sci 29:650–657

Barr SM, Dunning GR, Raeside RP, Jamieson RA (1990) Contrasting U-Pb ages from plutons in the Bras d'Or and Mira terranes of Cape Breton Island, Nova Scotia. Can J Earth Sci 27:1200–1208

Barr SM, Bevier ML, White CE, Doig R (1994) Magmatic history of the Avalon terrane in southern New Brunswick, Canada, based on U-Pb (zircon) geochronology. J Geol 102:399–409

Barr SM, Raeside RP, White CE (1998) Geological correlations between Cape Breton Island and Newfoundland, northern Appalachian Orogen. Can J Earth Sci 35:1252–1270

Bevier ML, Barr SM (1990) U-Pb age constraints on the stratigraphy and tectonic history of the Avalon terrane, New Brunswick, Canada. J Geol 98:53–63

Bevier ML, Barr SM, White CE, Macdonald AS (1993) U-Pb geochronologic constraints on the volcanic evolution of the Mira (Avalon) terrane, southeastern Cape Breton Island, Nova Scotia. Can J Earth Sci 30:1–10

Blasband B, White S, Brooijmans P, De Boorder H, Visser W (2000) Late Proterozoic extensional collapse in the Arabian-Nubian Shield. J Geol Soc Lond 157:615–628

Boucot AJ (1975) Evolution and Extinction Rate Controls. Developments in Palaeontology and Stratigraphy I. Elsevier, New York, 427 pp

Boucot AJ, Blodgett RB, Stewart JH (1997) European Province Late Silurian brachiopods from the Ciudad Victoria area, Tamaulipas, northeastern Mexico. In: Klapper G, Murphy MA, Talent JA (eds) Paleozoic sequence stratigraphy, biostratigraphy, and biogeography: Studies in Honor of J. Grenville ("Jess") Johnson. Geol Soc Am Spec Pap 321:273–293

Cameron KL, López R, Solari L, Ortega-Gutiérrez F, Keppie JD (2004) U-Pb Geochronology and Pb Isotope Compositions of Leached Feldspars: Constrains on the Origin and Evolution of Grenvillian Rocks from Eastern and Southern Mexico. In: Tollo RP, Corriveau L, McLelland J, Bartholomew MJ (eds) Proterozoic Tectonic Evolution of the Grenville Orogen in North America: Geol Soc Am Mem 197 (in press)

Cawood PA, McCausland PJA, Dunning GR (2001) Opening Iapetus: constraints from the Laurential margin of Newfoundland. Geol Soc Am Bull 113:443–453

Chantraine J, Auvray B, Brun JP, Chauvel JJ, Rabu D (1994) The Cadomian Orogeny in the Armorican Massif. In: Keppie JD (ed) Pre-Mesozoic Geology in France and Related Areas. Springer, Berlin Heidelberg New York, pp 75–128

Cocks LRM (2000) The Early Paleozoic geography of Europe. J Geol Soc Lond 157:1–10

Cocks LRM, Fortey RA (1988) Lower Paleozoic facies and faunas around Gondwana. In: Audley-Charles MG, Hallam A (eds) Gondwana and Tethys. Geol Soc Spec Pub 37, pp 183–200

Cocks LRM, Fortey RA (1990) Biogeography of Ordovician and Silurian faunas. In: McKerrow WS, Scotese CR (eds) Paleozoic Paleogeography and Biogeography. Geol Soc Mem 12:97–104

Cowie JR (1974) The Cambrian of Spitzbergen and Scotland. In: Holland CH (ed) Cambrian of the British Isles, Norden and Spitzbergen: Lower Paleozoic Rocks of the World 2. Wiley, New York, pp 123–156

Currie KL, McNicoll VJ (1999) New data on the age and geographic distribution of Neoproterozoic plutons near Saint John, New Brunswick. Atl Geol 35:157–166

Dalziel IWD (1992) On the organization of American plates in the Neoproterozoic and the breakout of Laurentia. GSA Today 2(11):238–241

Dalziel IWD (1997) Overview: Neoproterozoic-Paleozoic geography and tectonics: review, hypotheses and environmental speculations. Geol Soc Am Bull 109:16–42

Dalziel IWD, Dalla Salda LH, Gahagan LM (1994) Paleozoic Laurentia-Gondwana interaction and the origin of the Appalachian-Andean mountain system. Geol Soc Am Bull 106:243–252

Dennis E, Dabard MP (1988) Sandstone petrography and geochemistry of late Proterozoic sediments of the Armorican Massif (France) - a key to basin development during the Cadomian Orogeny. Precambr Res 42:189–206

Dennis A, Shervais J (1991) Arc rifting of the Carolina terrane in northwestern South Carolina. Geology 19:226–229

Dennis A, Shervais J (1996) The Carolina terrane in northwestern South Carolina: Insights into the development of an evolving island arc. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:237–256

Dennis A, Wright JE (1997) The Carolina terrane in northwestern South Carolina: age of deformation and metamorphism in an exotic arc. Tectonics 16:460–473

Dickinson WR, Lawton TF (2001) Carboniferous to Cretaceous assembly and fragmentation of Mexico. Geol Soc Am Bull 113:1142–1160

D'Lemos RS, Brown M (1993) Sm-Nd isotope characteristics of late Cadomian granite magmatism in northern France and the Channel Islands. Geol Mag 130:797–804

D'Lemos RS, Strachan RA, Topley CG (eds) (1990) The Cadomian Orogeny. Geol Soc Lond Spec Publ 51, 423 pp

Doig R, Murphy JB, Nance RD (1991) U-Pb geochronology of Late Proterozoic rocks of the eastern Cobequid Highlands, Avalon Composite Terrane, Nova Scotia. Can J Earth Sci 28:504–511

Doig R, Murphy JB, Nance RD (1993) Tectonic significance of the Late Proterozoic Economy River Gneiss, Cobequid Highlands, Avalon composite terrane, Nova Scotia. Can J Earth Sci 30:474–479

Dörr W, Zulauf G, Fiala J, Franke W, Vejnar Z (2002) Neoproterozoic to Early Cambrian history of an active plate margin in the Teplá-Barrandian unit-a correlation of U-Pb isotopic-dilution-TIMS ages (Bohemia, Czech Republic). Tectonophys 352:65–85

Dostal J, Keppie JD, Cousens BL, Murphy JB (1996) 550–580 Ma magmatism in Cape Breton Island (Nova Scotia, Canada): the product of NW-dipping subduction during the final stage of assembly of Gondwana. Precamb Res 76:96–113
Egal E, Guerrot C, Le Goff D, Thiéblemont D, Chantraine J (1996) The Cadomian orogeny revisited in northern France. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:281–318
Eguíluz L, Gil Ibarguchi JI, Ábalos B, Apraiz A (2000) Superposed Hercynian and Cadomian orogenic cycles in the Ossa-Morena zone and related areas of the Iberian Massif. Geol Soc Am Bull 112:1398–1413
Fairchild IJ, Hambrey MJ (1995) Vendian basin evolution in East Greenland and NE Svalbard. Precamb Res 73:217–233
Farrar SS (1984) The Goochland granulite terrane; remobilized Grenville basement in the eastern Virginia Piedmont. In: Bartholomew MJ (ed) Grenville Event in the Appalachians and Related Topics. Geol Soc Am Spec Pap 194:215–227
Fernández-Suárez J, Gutiérrez-Alonso G, Jenner GA, Jackson S (1998) Geochronology and geochemistry of the Pola de Allande granitoids (northern Spain). The bearing on the Cadomian/Avalonian evolution of NW Iberia. Can J Earth Sci 35:1–15
Fernández-Suárez J, Gutiérrez-Alonso G, Jenner GA, Tubrett MN (2000) New ideas on the Proterozoic-early Palaeozoic evolution of NW Iberia; insights from U-Pb detrital zircon ages. Precamb Res 102:185–206
Fernández-Suárez J, Gutiérrez Alonso G, Jeffries TE (2002a) The importance of along-margin terrane transport in northern Gondwana: insights from detrital zircon parentage in Neoproterozoic rocks from Iberia and Brittany. Earth Plan Sci Lett 204:75–88
Fernández-Suárez J, Gutiérrez-Alonso G, Cox R, Jenner GA (2002b) Assembly of the Armorica Microplate: A Strike-Slip Terrane Delivery? Evidence from U-Pb Ages of Detrital Zircons. J Geol 110:619–626
Finger F, Hanzl P, Pin C, von Quadt A, Steyrer HP (2000) The Brunovistulian: Avalonian Precambrian sequence at the eastern end of the Central European Variscides? In: Franke W, Haak V, Oncken O, Tanner B (eds) Orogenic Processes: Quantification and Modeling in the Variscan Belt. Geol Soc Lond Spec Publ 179: 103–112
Forsythe RD, Davidson J, Mpodozis C, Jesinkey C (1993) Lower Paleozoic relative motion of the Arequipa block and Gondwana; paleomagnetic evidence from Sierra de Almeida of Northern Chile. Tectonics 12:219–236
Friedl G, Finger F, McNaughton NJ, Fletcher IR (2000) Deducing the ancestry of terranes: SHRIMP evidence for South America-derived Gondwana fragments in central Europe. Geology 28:1035–1038
Gibbons W, Horák, JM (1996) The evolution of the Neoproterozoic Avalonian subduction system: Evidence from the British Isles. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:269–280
Giese U, Buehn B (1994) Early Paleozoic rifting and bimodal volcanism in the Ossa-Morena Zone of south-west Spain. Geol Rund 83:143–160
Gillis RJ, Gehrels GE, Flores de Dios A, Ruiz J (2001) Paleogeographic implications of detrital zircon ages from the Oaxaca terrane of southern Mexico. Geol Soc Am Abstr Prog 33(6):A-428
Glover LG III (1989) Tectonics of the Virginia Blue Ridge and Piedmont. Am Geophys Union, Field Trip Guidebook T363, 59 pp
Gorbatschev R, Bogdanova S (1993) Frontiers in the Baltic Shield. Precambr Res 64:3–21
Greenough JG, Papezik VS (1986) Acado-Baltic volcanism in eastern North America and western Europe: Implications for Cambrian tectonism. Mar Sed Atl Geol 22:240–251
Grelling RO, Smith AG (2000) The Dalradian of Scotland: missing link between the Vendian of northern and southern Scandinavia? Phys Chem Earth (A) 25:495–498
Guerrot C, Peucat JJ (1990) U-Pb geochronology of the Upper Proterozoic Cadomian orogeny in the northern Armorican Massif, France. In: D'Lemos RS, Strachan RA, Topley CG (eds) The Cadomian Orogeny. Geol Soc Lond Spec Publ 51:13–26
Guise PG, Roberts D (2002) Devonian ages from 40Ar-39Ar dating of plagioclase in dolerite dykes, eastern Varanger Peninsula, North Norway. NGU Bull 440:27–36
Gutiérrez-Alonso G, Fernández-Suárez J, Jeffries TE, Jenner GA, Tubrett MN, Cox R, Jackson SE (2003) Terrane accretion and dispersal in the northern Gondwana margin. An Early Paleozoic analogue of a long-lived active margin. Tectonophys 365:221–232
Hartz EH, Torsvik TH (2002) Baltica upside down: a new plate tectonic model for Rodinia and the Iapetus Ocean. Geology 30:255–258
Heatherington AL, Mueller PA, Nutman AP (1996) Neoproterozoic magmatism in the Suwannee terrane: Implications for terrane correlation. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:257–268
Hegner E, Kröner A (2000) Review of Nd isotopic data and xenocrystic and detrital zircon ages from the pre-Variscan basement in the eastern Bohemian Massif: speculations on palinspastic reconstructions. In: Franke W, Haak V, Oncken O, Tanner D (eds) Orogenic Processes: Quantification and Modelling in the Variscan Belt. Geol Soc Lond Spec Publ 179:113–129
Hermes OD, Zartman RE (1985) Late Proterozoic and Devonian plutonic terrane within the Avalon zone of Rhode Island. Geol Soc Am Bull 96:272–282
Hermes OD, Zartman RE (1992) Late Proterozoic and Silurian alkaline plutons within the southeastern New England Avalon zone. J Geol 100:477–486
Hibbard JP (2000) Docking Carolina: Mid-Paleozoic accretion in the southern Appalachians. Geology 28:127–130
Hibbard JP, Samson S (1995) Orogenesis exotic to the Iapetan cycle in the southern Appalachians. In: Hibbard J, van Staal C, Cawood P (eds) Current Perspectives in the Appalachian-Caledonian Orogen. Geol Assoc Can Spec Pap 41:191–205
Hibbard JP, Stoddard EF, Secor DT, Dennis AJ (2002) The Carolina Zone: overview of Neoproterozoic to Early Paleozoic peri-Gondwanan terranes along the eastern flank of the southern Appalachians. Earth Sci Rev 57:299–339
Higgins AK, Leslie AG (2000) Restoring thrusting in the East Greenland Caledonides. Geology 28:1019–1022
Higgins AK, Smith MP, Soper NJ, Leslie AG, Rasmussen JA, Sønderholm M (2001) The Neoproterozoic Hekla Sund Basin, eastern North Greenland: a pre-Iapetan extensional sequence thrust across its rift shoulders during the Caledonian orogeny. J Geol Soc Lond 158:487–499
Higgins MD, van Breemen O (1998) The age of the Sept Iles layered mafic intrusion, Canada: Implications for the Late Neoproterozoic /Cambrian history of southern Canada. J Geol 106:421–431
Hoffman PF (1989) Precambrian geology and tectonic history of North America. In: Bally AW, Palmer AR (eds) The Geology of North America – an overview. Boulder, Colorado. Geol Soc Am, pp 447–512
Hoffman PF (1991) Did the breakout of Laurentia turn Gondwanaland inside out? Science 252:1409–1412
Hoffman PF, Kaufman AJ, Halverson GP, Schrag DP (1998) A Neoproterozoic snowball Earth. Science 281:1342–1346
Horák JM (1993) The late Precambrian Coedana and Sarn Complexes, northwest Wales—A geochemical and petrologic study. PhD Thesis, Univ Wales, Cardiff, 415 pp
Johnson RJE, Van der Voo R (1986) Paleomagnetism of the Late Precambrian Fourchu Group, Cape Breton Island, Nova Scotia. Can J Earth Sci 23:1673–1685

Karlstrom KE, Williams ML, McLelland J, Geissman JW, Ahäll K-I (1999) Refining Rodinia: geologic evidence for the Australia-western U.S. connection in the Proterozoic. GSA Today 9:1–7

Kaye CA, Zartman RE (1980) A late Proterozoic Z to Cambrian age for the stratified rocks of the Boston Basin, Massachusetts, U.S.A. In: Wones DR (ed) The Caledonides of the U.S.A. IGCP Project 27, Caledonide Orogen, 1979 Meeting Proceedings, Blacksburg, Virginia. Dept Geol Sci, Virginia Polytechnical Institute and State University, Mem 2, pp 257–261

Keppie JD (1977) Plate tectonic interpretation of Paleozoic world maps (with emphasis on circum-Atlantic orogens and southern Nova Scotia). NS Dept Mines Pap 77–3, 45 pp

Keppie JD (1993) Synthesis of Paleozoic deformational events and terrane accretion in the Canadian Appalachians. Geol Rund 82:381–431

Keppie JD, Dostal J (1991) Late Proterozoic tectonic model for the Avalon terrane in Maritime Canada. Tectonics 10:842–850

Keppie JD, Dostal J (1998) Birth of the Avalonian arc in Nova Scotia, Canada: geochemical evidence for ~700–630 Ma back-arc rift volcanism off Gondwana. Geol Mag 135:171–181

Keppie JD, Ortega-Gutiérrez F (1995) Provenance of Mexican Terranes: Isotopic constraints. Int Geology Review 37:813–824

Keppie JD, Ortega-Gutiérrez F (1999) Middle American Precambrian basement: A missing piece of the reconstructed 1-Ga orogen. In: Ramos VA, Keppie JD (eds) Laurentia-Gondwana Connections Before Pangea. Geol Soc Am Spec Pap 336:199–210

Keppie JD, Ramos VA (1999) Odyssey of terranes in the Iapetus and Rheic oceans during the Paleozoic. In: Ramos VA, Keppie JD (eds) Laurentia-Gondwana Connections Before Pangea. Geol Soc Am Spec Pap 336:267–276

Keppie JD, Nance RD, Murphy JB, Dostal J (1991) Northern Appalachians: Avalon and Meguma Terranes. In: Dallmeyer RD, Lécorché JP (eds) The West African Orogens and Circum-Atlantic Correlatives. Springer, Berlin Heidelberg New York, pp 315–334

Keppie JD, Cousens BL, Dostal J, Murphy JB (1997) Palaeozoic within-plate volcanic rocks in Nova Scotia (Canada) reinterpreted; isotopic constraints on magmatic source and palaeocontinental reconstructions. Geol Mag 134:425–447

Keppie JD, Davis DW, Krogh TE (1998) U-Pb geochronological constraints on Precambrian stratified units in the Avalon composite terrane of Nova Scotia, Canada: Tectonic implications. Can J Earth Sci 35:222–236

Keppie JD, Dostal J, Dallmeyer RD, Doig R (2000) Superposed Neoproterozoic and Silurian magmatic arcs in central Cape Breton Island, Canada: geochemical and geochronological constraints. Geol Mag 137:137–153

Keppie JD, Dostal J, Ortega-Gutiérrez F, López R (2001) A Grenvillian arc on the margin of Amazonia: evidence from the southern Oaxacan Complex, southern Mexico. Precambr Res 112(3–4):165–181

Keppie JD, Nance RD, Murphy JB, Dostal J (2003) Tethyan, Mediterranean, and Pacific analogues for the Neoproterozoic-Paleozoic birth and development of peri-Gondwanan terranes and their transfer to Laurentia and Laurussia. Tectonophys 365:195–219

Kerr A, Jenner GA, Fryer BJ (1995) Sm-Nd isotopic geochemistry of Precambrian to Paleozoic granitoid suites and the deep-crustal structure of the southeast margin of the Newfoundland Appalachians. Can J Earth Sci 32:224–245

Knoll AH (1992) The early evolution of eukaryotes, a geological perspective. Science 256:622–637

Krogh TE, Strong DF, O'Brien SJ, Papezik VS (1988) Precise U-Pb zircon dates from the Avalon Terrane in Newfoundland. Can J Earth Sci 25:442–453

Krogh TE, Kamo SL, Sharpton B, Marin L, Hildebrand AR (1993) U–Pb ages of single shocked zircons linking distal K/T ejecta to the Chicxulub crater. Nature 366:731–734

Landing E (1996) Avalon: Insular continent by the latest Precambrian. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:29–63

Li ZX, Powell CMcA (2001) An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic. Earth Sci Rev 53:237–277

Linnemann U, Romer RL (2002) The Cadomian Orogeny in Saxo-Thuringia, Germany: geochemical and Nd-Sr-Pb isotopic characterization of marginal basins with constraints to geotectonic setting and provenance. Tectonophys 352:33–64

Linnemann U, Gehmlich M, Tichomirowa M, Buschmann B, Nasdala L, Jonas P, Lützner H, Bombach K (2000) From Cadomian Subduction to Early Palaeozoic Rifting: The Evolution of Saxo-Thuringia at the margin of Gondwana in the Light of Single Zircon Geochronology and Basin Development (Central European Variscides, Germany). In: Franke W, Altherr R, Haak V, Oncken O,Tanner D (eds) Orogenic Processes—Quantification and Modelling in the Variscan Belt of Central Europe. Spec Publ Geol Soc Lond 179, pp 131–153

Loewy S, Connelly JN, Dalziel IWD, Gower CF, Cawood PA (2000) Testing a proposed Rodinia reconstruction using Pb isotopes and U-Pb geochronology. Geol Soc Am Absts Progs 32(7):A455

Mac Niocaill C, van der Pluijm BA, Van der Voo R, McNamara AK (2001) Discussion and Reply: West African proximity of Avalon in the latest Precambrian. Geol Soc Am Bull 114:1049–1052

Mancusco CI, Gates AE, Puffer JH (1996) Geochemical and petrologic evidence of Avalonian arc to rift transition from granitoids in southeastern Rhode Island. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:29–63

Maslov AV, Isherskaya MV (2002) Riphean sedimentary sequences of the eastern and northeastern margins of the Eastern European craton. Russ J Earth Sci 4:271–276

Maslov AV, Erdtmann B-D, Ivanov KS, Ivanov SN, Krupenin MT (1997) The main tectonic events, depositional history, and the palaeogeography of the southern Urals during the Riphean – early Palaeozoic. Tectonophys 276:313–335

McElhinny MW, Powell CMcA, Pisarevsky SA (2003) Paleozoic terranes of Eastern Australia and the drift history of Gondwana. Tectonophys 362:41–65

McKerrow WS, Scotese CR, Brasier MD (1992) Early Cambrian continental reconstructions. J Geol Soc London 149:599–606

McMenamin MAS, McMenamin DL (1990) The Emergence of Animals; The Cambrian Breakthrough. Columbia Univ Press, New York, 217 pp

McNamara AK, Mac Niocaill C, van der Pluijm BA, Van der Voo R (2001) West African proximity of Avalon in the latest Precambrian. Geol Soc Am Bull 113:1161–1170

Meert JG, Eide EE, Torsvik TH (1996) Paleomagnetic investigation of the Neoproterozoic Fen carbonatite complex, S. Norway; constraints on Neoproterozoic rifting between Laurentia and Baltica. Geol Soc Am Abstr Progs 28(7):494

Miller BV, Samson SD, D'Lemos RS (1999) Time span of plutonism, fabric development, and cooling in a Neoproterozoic magmatic arc segment: U-Pb age constraints from syntectonic plutons, Sark, Channel Islands, UK. Tectonophys 312:79–95

Molina-Garza RS, Van der Voo R, Urrutia-Fucugauchi J (1992) Paleomagnetism of the Chiapas massif, southern México: evidence for rotation of the Maya block and implications for the opening of the Gulf of México. Geol Soc Am Bulletin 104:1156–1168

Murphy JB (2002) Geochemistry of the Neoproterozoic metasedimentary Gamble Brook Formation, Avalon terrane, Nova Scotia: evidence for a rifted arc environment along the west Gondwanan margin of Rodinia. J Geol 110:407–420

Murphy JB, Nance RD (1989) Model for the evolution of the Avalonian-Cadomian belt. Geology 17:735–738

Murphy JB, Nance RD (1991) Supercontinent model for the contrasting character of Late Proterozoic orogenic belts. Geology 19:469–472

Murphy JB, Nance RD (2002) Nd-Sm isotopic systematics as tectonic tracers: an example from West Avalonia, Canadian Appalachians. Earth Sci Rev 59:77–100

Murphy JB, Cameron K, Dostal J, Keppie JD, Hynes AJ (1985) Cambrian volcanism in Nova Scotia. Can J Earth Sci 22:599–606

Murphy JB, Keppie JD, Dostal J, Cousins BL (1996a) Repeated late Neoproterozoic-Silurian lower crustal melting beneath the Antigonish Highlands, Nova Scotia: Nd isotopic evidence and tectonic interpretations. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:109–120

Murphy JB, Keppie JD, Dostal J, Waldron JWF, Cude MP (1996b) Geochemical and isotopic characteristics of Early Silurian clastic sequences in Antigonish Highlands, Nova Scotia, Canada: constraints on the accretion of Avalonia in the Appalachian- Caledonide Orogen. Can J Earth Sci 33:379–388

Murphy JB, Keppie JD, Davis D, Krogh TE (1997) Regional significance of new U-Pb age data for Neoproterozoic igneous units in Avalonian rocks of northern mainland Nova Scotia, Canada. Geol Mag 134:113–120

Murphy JB, Keppie JD, Dostal J, Nance RD (1999) Neoproterozoic-early Paleozoic evolution of Avalonia. In: Ramos VA, Keppie JD (eds) Laurentia-Gondwana Connections Before Pangea. Geol Soc Am Spec Pap 336:253–266

Murphy JB, Strachan RA, Nance RD, Parker KD, Fowler MB (2000) Proto-Avalonia: a 1.2–1.0 Ga tectonothermal event and constraints for the evolution of Rodinia. Geology 28:1071–1074

Murphy JB, Pisarevsky SA, Nance RD, Keppie JD (2001) Animated History of Avalonia in Neoproterozoic-Early Palaeozoic. In: Jessell MJ (ed) General Contributions: 2001. J Virtual Explorer 3:45–58

Murphy JB, Eguiluz L, Zulauf G (2002) Cadomian orogens, peri-Gondwanan correlatives and Laurentia-Baltica connections. Tectonophys 352:1–9

Murphy JB, Dostal J, Nance RD, Keppie JD (2004) Grenville-aged juvenile crust development in the peri-Rodinian ocean. Submitted to Grenville Volume. Geol Soc Am Spec Publ 197 (in press)

Nance RD, Murphy JB (1990) Kinematic history of the Bass River Complex, Nova Scotia: Cadomian tectonostratigraphic relations in the Avalon terrane of the Canadian Appalachians. In: D'Lemos RS, Strachan RA, Topley CG (eds) The Cadomian orogeny. Geol Soc Lond Spec Publ 51:395–406

Nance RD, Murphy JB (1994) Contrasting basement isotopic signatures and the palinspastic restoration of peripheral orogens: Example from the Neoproterozoic Avalonian-Cadomian belt. Geology 22:617–620

Nance RD, Murphy JB (1996) Basement isotopic signatures and Neoproterozoic paleogeography of Avalonian-Cadomian and related terranes in the circum-North Atlantic. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:333–346

Nance RD, Thompson MD (eds) (1996) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:390

Nance RD, Murphy JB, Strachan RA, D'Lemos RS, Taylor GK (1991) Late Proterozoic tectonostratigraphic evolution of the Avalonian and Cadomian terranes. Precambr Res 53:41–78

Nance RD, Murphy JB, Keppie JD (2002) Cordilleran model for the evolution of Avalonia. Tectonophys 352:11–32

Neubauer F (2002) Evolution of late Neoproterozoic to early Paleozoic tectonic elements in Central and Southeast European Alpine mountain belts: review and synthesis. Tectonophys 352:87–103

Nikishin AM, Ziegler PA, Stephenson RA, Cloetingh SAPL, Furne AV, Fokin PA, Ershov AV, Bolotov SN, Korotaev MV, Alekseev AS, Gorbachev VI, Shipilov EV, Lankreijer A, Bembinova EYu, Shalimov IV (1996) Late Precambrian to Triassic history of the East European Craton: dynamics of sedimentary basin evolution. Tectonophysics 268:23–63

Noble SR, Tucker RD, Pharaoh TC (1993) Lower Paleozoic and Precambrian igneous rocks from eastern England, and their bearing on Late Ordovician closure of the Tornquist Sea: constraints from U-Pb and Nd isotopes. Geol Mag 130:835–846

Noblet Ch, Lefort JP (1990) Sedimentological evidence for a limited separation between Armorica and Gondwana during the Early Ordovician. Geology 18:303–306

O'Brien SJ, Wardle RJ, King AF (1983) The Avalon zone: a Pan-African terrane in the Appalachian orogen of Canada. Geol J 18:195–222

O'Brien SJ, O'Brien BH, Dunning GR, Tucker RD (1996) Late Neoproterozoic Avalonian and related peri-Gondwanan rocks of the Newfoundland Appalachians. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:9–28

Ortega-Gutiérrez F, Ruiz J, Centeno-García E (1995) Oaxaquia, a Proterozoic microcontinent accreted to North America during the late Paleozoic. Geology 23:1127–1130

Ortega-Obregón C, Keppie JD, Solari LA, Ortega-Gutiérrez F, Dostal J, López R, Ortega-Rivera A, Lee JWK (2004) Geochronology and geochemistry of the ~917 Ma, calc-alkaline Etla granitoid pluton (Oaxaca, southern Mexico): evidence of post-Grenvillian subduction along the northern margin of Amazonia. International Geology Review (in press)

Park RG (1992) Plate kinematic history of Baltica during the Middle to Late Proterozoic: a model. Geology 20:725–728

Park RG, Cliff RA, Fettes DJ, Stewart AD (1994) Precambrian rocks in northwest Scotland west of the Moine Thrust: the Lewisian Complex and the Torridonian. In: Gibbons W, Harris AL (eds) A revised correlation of Precambrian rocks in the British Isles. Geol Soc Lond Spec Rept 22:6–20

Patchett PJ, Gale NH, Goodwin R, Humm MJ (1980) Rb-Sr whole-rock isochron ages of late Precambrian to Cambrian igneous rocks from southern Britain. J Geol Soc Lond 137:649–656

Pauley JC (1990) The Longmyndian Supergroup and related Precambrian sediments of England and Wales. In: Strachan RA, Taylor GK (eds) Avalonian and Cadomian Geology of the North Atlantic. Blackie, London, pp 5–27

Pe-Piper G, Murphy JB (1989) Geochemistry and tectonic setting of the late Precambrian Folly River Formation, Cobequid Highlands, Avalon Terrane, Nova Scotia: a continental rift within a volcanic-arc environment. Atl Geol 25:143–151

Pe-Piper G, Piper DJW (1989) The Hadrynian Jeffers Group, Cobequid Highlands, Avalon Zone of Nova Scotia: a back-arc volcanic complex. Geol Soc Am Bull 101:364–376

Pickering K, Basset MG, Siveter DJ (1988) Late Ordovician-Early Silurian destruction of the Iapetus Ocean: Newfoundland, British Isles and Scandinavia—A discussion. Trans Roy Soc Edin 79:361–382

Pimentel MM, Fuck RA (1992) Neoproterozoic crustal accretion in central Brazil. Geology 20:375–379

Pindell JL, Barrett SF, Case JE (1990). Geologic evolution of the Caribbean region; a plate tectonic perspective In: Dengo G, Case JE (eds) Caribbean Region. Decade of North American Geology, vol. H. Boulder, CO. Geol Soc Am, pp 405–432

Pisarevsky SA, Bylund G (1998) Palaeomagnetism of a key section of the Protogine Zone, southern Sweden. Geophys J Int 133:185–200

Pisarevsky SA, McElhinny MW (2003) Global Paleomagnetic Data Base developed into its visual form. EOS transactions 84:192

Pisarevsky SA, Natapov LM (2003) Siberia and Rodinia. Tectonophysics 375:221-245

Pisarevsky SA, Komissarova RA, Khramov AN (2000) New palaeomagnetic results from Vendian red sediments in Cisbaikalia and the problem of the relationship of Siberia and Laurentia in the Vendian. Geophys J Int 40:598–610

Pisarevsky SA, Komissarova, RA, Khramov AN (2001) Reply to comment by J. Meert and R. Van der Voo on 'New palaeomagnetic result from Vendian red sediments in Cisbaikalia and the problem of the relationship of Siberia and Laurentia in the Vendian'. Geophys J Int 146:871–873

Pisarevsky SA, Wingate MTD, Powell CMcA, Johnson S, Evans DAD (2003) Models of Rodinia assembly and fragmentation. In: Yoshida M, Windley B, Dasgupta S (eds) Proterozoic East Gondwana: supercontinent assembly and breakup. Geol Soc Lond Spec Publ 206:35–55

Piton P (1985) Etude géochimique et géochronologique de la croûte continentale protérozoïque (1.8–2.2) au Nord du Massif Armoricain. Raport de Diplôme d'Etudes Approfondies. Univ Rennes, Rennes, France

Popov V, Iosifidi A, Khramov A, Tait J, Bachtadse V (2002) Paleomagnetism of Upper Vendian sediments from the Winter Coast, White Sea region, Russia: implications for the paleogeography of Baltica during Neoproterozoic times. J Geophys Res 107(B11):2315

Powell CMcA, Li ZX, McElhinney MW, Meert JG, Park JK (1993) Paleomagnetic constraints on the timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana. Geology 21:889–892

Puchkov VN (ed) (2003) Magmatism on passive margins of the Rodinia. Materials of the international conference. Ufa, Geological Institute of the USC RAS, 40 pp

Quesada C (1990) Precambrian terranes in the Iberian Variscan foldbelt. In: Strachan RA, Taylor GK (eds) Avalonian and Cadomian Geology of the North Atlantic. Blackie, London, pp 109–133

Quesada C (1997) Evolución geodinámica de la zona Ossa-Morena durante el ciclo Cadomiense. In: Livro de Homenagem ao Prof. Francisco Goncalves: Estudio sobre a Geologia de zona de Ossa-Morena (Macico Ibérico). Univ Évora, Portugal, pp 205–230

Quesada C, Dallmeyer RD (1994) Tectonothermal evolution of the Badajoz–Córdoba shear zone (SW Iberia): characteristics and $^{40}Ar/^{39}Ar$ mineral age constraints. Tectonophys 231:195–213

Quesada C, Bellido F, Dallmeyer RD, Gil Ibarguchi JI, Oliveira JT, Pérez Estaún A, Ribeiro A, Robardet M, Silva JB (1991) Terranes within the Iberian Massif: correlations with West African sequences. In: Dallmeyer RD, Lecorché JP (eds) The West African Orogens and Circum–Atlantic Correlations. Springer, Berlin Heidelberg New York, pp 267–294

Rabu D, Chantraine J, Chauvel JJ, Denis E, Balé P, Bardy Ph (1990) The Brioverian (Upper Proterozoic) and the Cadomian orogeny in the Armorican Massif. In: D'Lemos RS, Strachan RA, Topley CG (eds) The Cadomian Orogeny. Geol Soc Lond Spec Publ 51:81–94

Rainbird RH, Hamilton MA, Young GM (2001) Detrital zircon geochronology and provenance of the Torridonian, NW Scotland. J Geol Soc Lond 158:15–27

Ramos VA, Alemán A (2000) Tectonic Evolution of the Andes. In: Cordani UG, Milani EJ, Thomaz Filo A, Campos DA (eds) Tectonic Evolution of South America, 31st Int Geol Congress, Rio de Janeiro, Brazil, pp 635–685

Rankin D (1994) Continental margin of the eastern United States: past and present. In: Speed R (ed) Phanerozoic Evolution of North American Continent–Ocean Transitions. Geol Soc Am, Decade of North American Geology Continent–Ocean Transect Volume, pp 129–218

Rast N, Skehan JW (1983) The evolution of the Avalonian Plate. Tectonophys 100:257–286

Roberts D (2003) The Scandinavian Caledonides: event chronology, palaeogeographic settings and likely modern analogues. Tectonophys 365:283–299

Roberts D, Siedlecka A (1999) Baikalian/Cadomian deformation and metamorphism along the northern margin of Baltica, NW Russia and NE Norway. J Conf Abstr 4(3):1019

Robison R, Pantoja-Alor J (1968) Tremadocian trilobites from Nochixtlan region, Oaxaca, Mexico. J Paleo 42:767–800

Ruiz J, Tosdal RM, Restrepo PA, Murillo-Muñetón, G (1999) Pb isotope evidence for Columbia-southern Mexico connections in the Proterozoic. In: Ramos VA, Keppie JD (eds) Laurentia-Gondwana Connections Before Pangea. Geol Soc Am Spec Pap 336:183–197

Samson SD, D'Lemos RS (1998) U-Pb geochemistry and Sm-Nd isotopic composition of Proterozoic gneisses, Channel Islands, U.K. J Geol Soc Lond 155:609–618

Samson SD, Hibbard JP, Wortman GL (1995) Nd isotopic evidence for juvenile crust in the Carolina terrane, southern Appalachians. Contrib Mineral Petrol 121:171–184

Samson SD, Secor DT, Stern R (1999) Provenance and paleogeography of Neoproterozoic circum-Atlantic arc-terranes: constraints from U-Pb ages of detrital zircons. Geol Soc Am Abstr Progs 31(7):A-429

Samson SD, Barr SM, White CE (2000) Nd isotopic characteristics of terranes within the Avalon Zone, southern New Brunswick. Can J Earth Sci 37:1039–1052

Samson SD, Secor DT, Hamilton MA (2001) Wandering Carolina: tracking exotic terranes with detrital zircons. Geol Soc Am Abstr Progr 33(6):A-263

Sánchez-García T, Bellido F, Quesada C (2003) Geodynamic setting and geochemical signatures of Cambrian–Ordovician rift-related igneous rocks (Ossa-Morena Zone, SW Iberia). Tectonophys 365:233–255

Shergold JH (1975) Late Cambrian and Early Ordovician trilobites from the Burke River Structural Belt, Western Queensland, Australia. Comm Australia Bur Min Res Geol Geoph Bull 153, 251 pp

Shervais JW, Shelley SA, Secor DT Jr (1996) Geochemistry of volcanic rocks of the Carolina and Augusta terranes in central South Carolina: An exotic rifted arc? In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:219–236

Smith GW, Socci AD (1990) Late Precambrian sedimentary geology of the Boston Basin. In: Socci AD, Skehan JW, Smith GW (eds) Geology of the Composite Avalon Terrane of Southern New England. Geol Soc Am Spec Pap 245:75–84

Sour-Tovar F, Quiroz-Barroso SA, Navarro-Santillán D (1996) Carboniferous invertebrates from Oaxaca, southern Mexico: mid-continent paleogeographic extension. Geol Soc Am Abstr Progr 28(7):A365

Soper NJ, Strachan RA, Holdsworth, RE, Gayer RA, Greiling RO (1992) Sinistral transpression and the Silurian closure of Iapetus. J Geol Soc Lond 149:871–880

Starmer IC (1996) Accretion, rifting and collision in the North Atlantic supercontinent, 1700 – 950 Ma. In: Brewer TS (ed) Precambrian Crustal Evolution in the North Atlantic region. Geol Soc Lond Spec Publ 112:219–248

Steiner MB, Walker JD (1996) Late Silurian plutons in Yucatan. J Geophys Res 101:17727–17735

Stern RJ (1994) Arc assembly and continental collision in the Neoproterozoic East African Orogen: Implications for the consolidation of Gondwanaland. Ann Rev Earth Plan Sci 22:319–351

Stewart DB, Tucker RD (1998) Geology of the northern Penobscot Bay, Maine. US Geol Surv, Miscell Invest Ser Map I-2551, scale 1:62,500

Stewart JH, Blodgett RB, Boucot AJ, Carter JL, López R (1999) Exotic Paleozoic strata of Gondwanan provenance near Ciudad Victoria, Tamaulipas, México. In: Ramos VA, Keppie JD (eds) Laurentia-Gondwana connections before Pangea: Boulder, Colorado, Geol Soc Am Spec Pap 336:227–252

Strachan RA, Taylor GK (eds) (1990) Avalonian and Cadomian Geology of the North Atlantic. Blackie, London, 252 pp

Strachan RA, Nance RD, Dallmeyer RD, D'Lemos RS, Murphy JB, Watts, GR (1996a) Late Precambrian tectonothermal evolution of the Malverns Complex. J Geol Soc Lond 153:589–600

Strachan RA, D'Lemos RS, Dallmeyer RD (1996b) Late Precambrian evolution of an active plate margin: North Armorican Massif, France. In: Nance Rd, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:319–332.

Strong DF, O'Brien SJ, Taylor SW, Strong PG, Wilton DH (1978) Aborted Proterozoic rifting in eastern Newfoundland. Can J Earth Sci 15:117–131
Swinden HS, Hunt PA (1991) A U-Pb zircon age from the Connaigre Bay Group, southwestern Avalon Zone, Newfoundland: Implications for regional correlations and metallogenesis. In: Radiometric Age and Isotopic Studies, Rept 4. Geol Surv Can Pap 90–2:3–10
Symons DTA, Chaisson AD (1991) Paleomagnetism of the Callander Complex and the Cambrian apparent polar wander path for North America. Can J Earth Sci 28:355–363
Tanczyk EI, Lapointe P, Morris WA, Schmidt PW (1987) A paleomagnetic study of the layered mafic intrusion at Sept-Iles, Quebec. Can J Earth Sci 24:1431–1438
Theokritoff G (1979) Early Cambrian provincialism and biogeographic boundaries in the North Atlantic region. Lethaia 12:281–295
Thompson MD, Bowring SA (2000) Age of the Squantum "Tillite", Boston Basin, Massachusetts: U-Pb zircon constraints on terminal Neoproterozoic glaciation. Am J Sci 300:630–655
Thompson MD, Hermes OD, Bowring SA, Isachsen CE, Besancon JR, Kelly KL (1996) Tectonostratigraphic implications of Late Proterozoic U-Pb zircon ages in the Avalon Zone of southeastern New England. In: Nance RD, Thompson MD (eds) Avalonian and Related Peri-Gondwanan Terranes of the Circum-North Atlantic. Geol Soc Am Spec Pap 304:179–191
Thorogood EJ (1990) Provenance of the pre-Devonian sediments of England and Wales: Sm-Nd isotopic evidence. J Geol Soc Lond 147:591–594
Torsvik TH, Smethurst MA, Meert JG, Van der Voo R, McKerrow WS, Brasier MD, Sturt BA, Walderhaug HJ (1996) Continental break-up and collision in the Neoproterozoic and Palaeozoic-a tale of Baltica and Laurentia. Earth Sci Rev 40:229–258
Trench A, Torsvik TH (1992) The closure of the Iapetus Ocean and Tornquist Sea: New paleomagnetic constraints. J Geol Soc Lond 149:867–870
Tucker RD, Pharoah TC (1991) U-Pb zircon ages of late Precambrian rocks in southern Britain. J Geol Soc Lond 148:435–443
Van der Voo R (1988) Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: comparisons of paleomagnetism with paleoclimatology and biogeographical patterns. Geol Soc Am Bull 100:311–324
Van der Voo R (1990) The reliability of paleomagnetic data. Tectonophys 184:1–9
von Raumer JF, Stampfl GM, Bore G, Bussy F (2002) Organization of pre-Variscan basement areas at the north-Gondwanan margin. Int J Earth Sci 91:35–52
Watt MJ, Williams GD (1979) Fault rocks as indicators of progressive shear deformation in the Guingamp region, Brittany. J Struct Geol 1:323–332
Weber B, Köhler H (1999) Sm/Nd, Rb/Sr, and U-Pb geochronology of a Grenville terrane in southern Mexico: origin and geologic history of the Guichicovi complex. Precambr Res 96:245–262
Weil AB, Van der Voo R, Mac Niocaill C, Meert JG (1998) The Proterozoic supercontinent Rodinia: paleomagnetically derived reconstruction for 1100 to 800 Ma. Earth Planet Sci Lett 154:13–24
Weil AB, Van der Voo R, van der Pluijm B (2001) Oroclinal bending and evidence against the Pangea megashear: the Cantabrian–Asturias arc (northern Spain). Geology 29:901–904
Whalen JB, Jenne GA, Currie KL, Barr SM, Longstaffe FJ, Hegner E (1994) Geochemical and isotopic characteristics of granitoids of the Avalon Zone, southern New Brunswick: possible evidence of repeated delamination events. J Geol 102:269–282
Willner AP, Ermolaeva T, Stroink L, Glasmacher UA, Giese U, Puchkov VN, Kozlov VI, Walter R (2001) Contrasting provenance signals in Riphean and Vendian sandstones in the SW Urals (Russia): constraints for a change from passive to active continental margin conditions in the Neoproterozoic. Precambr Res 110:215–239
Willner AP, Sindern S, Metzger R, Ermolaeva T, Kramm U, Puchkov V, Kronz A (2003) Typology and single grain U/Pb ages of detrital zircons from Proterozoic sandstones in the SW Urals (Russia): early time marks at the eastern margin of Baltica. Precambr Res 124:1–20
Windley BF (1993) Uniformitarianism today: plate tectonics is the key to the past. J Geol Soc Lond 150:7–19
Winchester JA (1988) Later Proterozoic environments and tectonic evolution in the northern Atlantic lands. In: Winchester JA (ed) Later Proterozoic stratigraphy of the Northern Atlantic regions. Blackie, Glasgow, pp 253–270
Wingate MTD, Giddings JW (2000) Age and paleomagnetism of the Mundine Well dyke system, Western Australia: implications for Australia-Laurentia connection at 755 Ma. Precambr Res 100:335–357
Wortman GL, Samson SD, Hibbard JP (2000) Precise U-Pb zircon constraints on the earliest magmatic history of the Carolina terrane. J Geol 108:321–338
Zulauf G, Dörr W, Fiala J, Vejnar Z (1997) Late Cadomian crustal tilting and Cambrian transtension in the Teplá-Barrandian unit (Bohemian Massif, Central European Variscides). Geol Rundsch 86:571–584
Zulauf G, Schitter F, Riegler G, Finger F, Fiala J, Vejnar Z (1999) Age constraints on the Cadomian evolution of the Teplá-Barrandian unit (Bohemian Massif) through electron microprobe dating of metamorphic monazite. Z Dtsch Geol Ges 150(4): 627–639