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Some key issues in reconstructions of Proterozoic supercontinents

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Abstract

Supercontinents containing most of the earth's continental crust are considered to have existed at least twice in Proterozoic time. The younger one, Rodinia, formed at ~1.0 Ga by accretion and collision of fragments produced by breakup of the older supercontinent, Columbia, which was assembled by global-scale 2.0–1.8 Ga collisional events. Little consensus has been reached regarding configurations of these supercontinents because of some unresolved issues concerning continental fits. One of these issues concerns how Siberia was related to Laurentia. Previous reconstructions that consider the Aldan Shield of Siberia as a continuation of the Wyoming Province of Laurentia have been largely abandoned in favor of models connecting Siberia to northern Laurentia, but it remains controversial which part of Siberia is contiguous with northern Laurentia. Also at issue is the western Laurentia–Australia–East Antarctica connection. Most Rodinia reconstructions place Australia, together with East Antarctica, adjacent to either western Canada (the SWEAT hypothesis) or the western United States (the AUSWUS hypothesis). However, recent studies combining paleomagnetic and isotopic age data have called into question the validity of SWEAT, AUSWUS and other variants. Another issue is the position of North China in Rodinia/Columbia. Limited paleomagnetic data seem to be consistent with the Paleo-Mesoproterozoic North China–Siberia/Baltica connection, whereas geological data support the recently proposed Archean to Mesoproterozoic North China–India connection. Controversial issues have also been raised about the timing and history of the amalgamation and fragmentation of South America and West Africa. Both geological and paleomagnetic data suggest that South America (São Francisco and Amazonia Cratons) and West Africa (Congo and West African Cratons) coalesced into a single landmass along the 2.1–2.0 Ga Transamazonian/Eburnean orogens. However, whether they were divorced and then re-married to form part of Gondwana, or remained largely coherent from their amalgamation at 2.1–2.0 Ga until their incorporation into Gondwana is unclear. Also little known is the position of Amazonia–West Africa in the proposed supercontinents, with some workers believing that they existed as a separate landmass, whereas others place Amazonia–West Africa adjacent to Baltica. In summary, although geological and paleomagnetic data are supportive of the existence of Proterozoic supercontinents Rodinia and Columbia, they are insufficient to determine their exact geometries.

Keywords: Supercontinent; Paleo-Mesoproterozoic; Geological correlations; Paleomagnetism; Reconstruction

1. Introduction

The Earth's surface consists of a number of rigid plates that either drift apart to create new oceanic crust, or collide to generate mountain belts. A supercontinent forms when most of the earth's continental blocks collide with each other and coalesce into a single landmass. In Earth's history, the youngest supercontinent is Pangea which formed by assembly of all continents about 300–250 Ma ago (Lottes and Rowley, 1990; Rogers, 1993, 1996), and which itself consisted of Gondwana (Australia, India, East Antarctica, South America and Africa) as its southern half, and Laurasia (North America, Greenland and Eurasia) as its northern half (Fig. 1a). Since the 1980s, the notion of Proterozoic supercontinents has attracted much attention. Piper (1982, 1987) produced paleomagnetic evidence for the existence of a long-lived Proterozoic supercontinent. Hoffman (1989) and Gower et al. (1990) provided geological evidence for a supercontinent (named Nena) that was assembled in the period 2.0–1.8 Ga. McMenamin and MacMenamin (1990) outlined growing evidence for a Meso-Neoproterozoic supercontinent, named Rodinia, from a Russian word meaning 'to beget'. Dalziel (1991), Hoffman (1991) and Powell et al. (2001) proposed configurations for Rodinia in which Laurentia (North America and Greenland)

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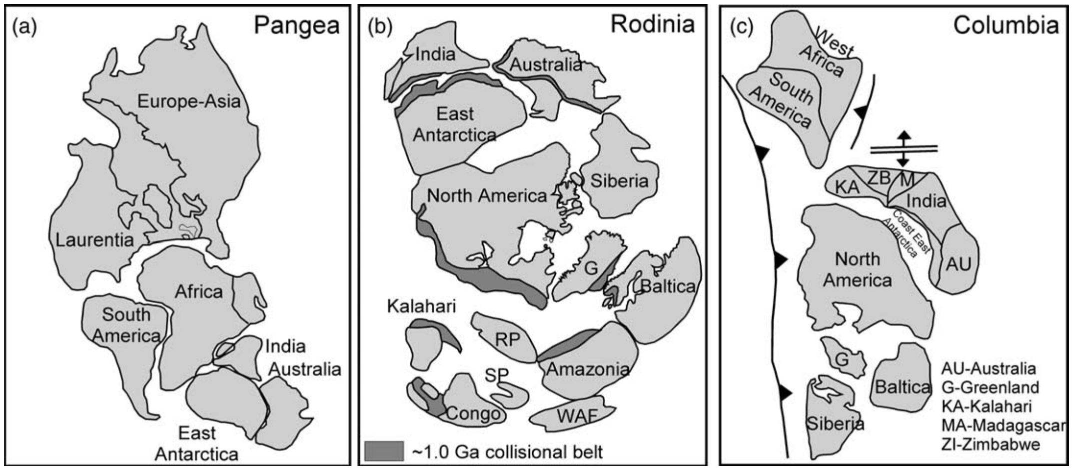

Fig. 1. Three supercontinents in Earth's history: Pangea (a) formed 300–250 million years ago (Rogers et al., 1995); Rodinia (b) formed ~1.0 billion years ago (Dalziel, 1997; Dalziel et al., 2000); and Columbia (c) formed ~1.8 billion years ago (Rogers and Santosh, 2002). Abbreviations: G, Greenland; RP, Rio de la Plata; SF, Sao Francisco; WAF, West Africa.

forms the core of the supercontinent with other continental blocks arranged around the edges (Fig. 1b). Piper (2000) uses the term 'Paleopangea' instead of Rodinia and proposes a significant different configuration. Now there is broad agreement that the assembly of Rodinia was completed by the global-scale orogenic events at approximately 1.0 Ga and its fragmentation 'begat' all subsequent continents that drifted and then coalesced into Pangea (Powell et al., 1993, 2001; Rogers, 1993; Rogers et al., 1995; Dalziel, 1995, 1997; Dalziel et al., 2000; Nast, 1997, 2002; Hoffman, 1999; Meert and Powell, 2001; Loewy et al., 2003; Pesonen et al., 2003; Pisarevsky et al., 2003; Torsvik, 2003; Li et al., 2004).

Recently, earth scientists have noted that many Rodinia's constituent fragments contain abundant evidence that they are a collage of earlier collision events, mostly occurring between 2.0 and 1.8 Ga (Rogers et al., 1995; Nast, 1997). This has led some geologists to reconsider Hoffman's (1989) early speculation that a Paleo-Mesoproterozoic supercontinent may have existed before Rodinia (e.g. Windley, 1995; Rogers, 1993, 1996; Condie, 1998, 2000, 2002; Zhai et al., 2000; Luepke and Lyons, 2001; Rogers and Santosh, 2002, 2003; Hartmann, 2002; Meert, 2002; Sears and Price, 2002; Rao and Reddy, 2002; Wilde et al., 2002; Zhao et al., 2002a, 2003a,b, 2004; Pesonen et al., 2003; Santosh, 2003; Santosh et al., 2003). Rogers and Santosh (2002) named this pre-Rodinian supercontinent 'Columbia' because they thought the critical evidence for its existence comes from matching patterns of ca. 1.5 Ga coeval rifts in the Columbia River region of western North America and eastern India. Fig. 1c is a preliminary configuration of Columbia proposed by Rogers and Santosh (2002), in which South Africa, Madagascar, India, Australia and attached parts of Antarctica are placed adjacent to the western margin of North America, whereas Greenland, Baltica (Northern Europe) and Siberia are positioned adjacent to the northeastern margin of North America, and South America is placed against West Africa. The available paleomagnetic data support the existence of the Paleo-Mesoproterozoic Columbia supercontinent (e.g. Symons, 1991; Elming, 1994; Smethurst et al., 1998; Zegers et al., 1998; Buchan et al., 2000; Ernst et al., 2000; Nomade et al., 2003; Pesonen et al., 2003).

The supercontinent Columbia is thought to have been produced by global-scale 2.0–1.8 Ga collisional events. Following its final assembly at ~1.8 Ga, this supercontinent underwent long-lived (1.8–1.3 Ga), subduction-related accretion along some of its continental margins, forming a 1.8–1.3 Ga large magmatic accretionary belt along the present-day southern margin of North America, Greenland and Baltica (Rogers and Santosh, 2002). It includes the 1.8–1.7 Ga Yavapai, Central Plains and Makkovikian Belts, 1.7–1.6 Ga Mazatzal and Labradorian Belts, 1.5–1.3 Ga St Francois and Spavinaw Belts and 1.3–1.2 Ga Elzevirian Belt in North America; the 1.8–1.7 Ga Ketilidian Belt in Greenland; and the 1.8–1.7 Transscandinavian Igneous Belt, 1.7–1.6 Ga Kongsberggian–Gothian Belt, and 1.5–1.3 Ga Southwest Sweden Granitoid Belt in Baltica (Gower et al., 1990; Åhäll and Gower, 1997; Karlstrom et al., 2001). Other cratonic blocks also underwent marginal outgrowth at about the same time. In South America, a 1.8–1.3 Ga accretionary zone occurs along the western margin of the Amazonia Craton, represented by the Rio Negro, Juruena and Rondonian Belts (Tassinari and Macambira, 1999). In Australia, 1.8–1.5 Ga accretionary magmatic belts including the Arunta, Mt. Isa, Georgetown, Coen and Broken Hill Belts, occur surrounding the southern and eastern margins of the North Australia Craton and the eastern margin of the Gawler Craton (Zhao and McCulloch, 1995). In China, a 1.8–1.4 Ga accretionary magmatic zone, called the Xiong'er belt (Group), extends along the southern margin of the North China Craton (Chen, 1992; Zhao et al., 2003b). Fragmentation of the supercontinent Columbia began ca. 1.5 Ga ago, associated with continental rifting along the western margin of Laurentia (Belt-Purcell Supergroup; Luepke and Lyons, 2001), southern margin of Baltica (Telemark Supergroup; Bingen et al., 2001), southeastern margin of Siberia (Riphean aulacogens; Khudoley et al., 2001), northwestern margin of South Africa (Kalahari Copper Belt; Green, 1992), and northern margin of North China (Zhaertai-Bayan

Obo Belt; Zhou et al., 2002). The fragmentation corresponded with widespread anorogenic magmatic activity, forming anorthosite–mangerite–charnockite–granite (AMCG) in North America, Baltica, South America and North China (Anderson and Morrison, 1992; Windley, 1989, 1993) and kimberlite–lamproite–carbonate suites in West Africa, South Africa, Western Australia, India and South America (Dawson, 1989). The fragmentation continued until the final breakup of the supercontinent at about 1.3–1.2 Ga, marked by the emplacement of the 1.27 Ga MacKenzie and 1.24 Ga Sudbury mafic dike swarms in North America and ecoval swarms in other cratonic blocks (Le Cheminant and Heaman, 1989; Ernst et al., 1995, 2001; Ernst and Buchan, 2003).

Unlike Pangea whose configuration is well known because it can be reconstructed from patterns of ocean opening, the pre-drift fit of modem continents and correlations of paleobiological fossils and whose fragmentation can be traced by magnetic stripes in the present oceanic crust, Proterozoic supercontinents (Rodinia and Columbia) are much less certain and more controversial in their configurations because of insufficient geological and paleomagnetic data. In this paper, we review and analyze a number of key issues regarding the relative positions of some constituent fragments in the proposed Proterozoic supercontinents (Rodinia and Columbia) and present our current understanding of some issues. We stress that although some geological and paleomagnetic data support the existence of a Paleo-Mesoproterozoic supercontinent, the quality and quantity of the available data are insufficient to provide rigorous constraints on the exact configurations of the proposed supercontinents.

2. How was Siberia matched with Laurentia?

An Archean to Paleoproterozoic connection between Siberia and Laurentia has been proposed for a long-time, based on both paleomagnetic and geological correlations (Sears and Price, 1978, 2000; Hoffman, 1991; Condie and Rosen, 1994; Frost et al., 1998; Rainbird et al., 1998; Smethurst et al., 1998; Ernst et al., 2000; Pisarevsky and Natapov, 2003; Pisarevsky et al., 2003). Paleomagnetic data indicate that during the Mesoproterozoic, Siberia was restricted to a $\pm 30°$ paleolatitude range (Piper, 1982; Smethurst et al., 1998; Ernst et al., 2000), broadly similar to latitudes determined for Laurentia and Baltica (Irving, 1979; Piper, 1982; Elming, 1994; Gala et al., 1998; Buchan et al., 2000). As paleomagnetic data cannot constrain longitude, various paleomagnetic reconstruction models for relative position of Siberia with Laurentia or Baltica have been postulated (e.g. Poorter, 1981; Piper, 1982; Scotese and McKerrow, 1990; Smethurst et al., 1998; Ernst et al., 2000; Pisarevsky et al., 2003). For example, Piper (1982) located Siberia adjacent to southwestern Laurentia, similar to the geological reconstruction by Sears and Price (1978). Scotese and McKerrow (1990) suggested that Siberia lay near eastern Greenland, but Smethurst et al. (1998) placed Siberia close to eastern Baltica rather than Laurentia. Ernst et al. (2000) obtained good-quality paleomagnetic data from the 1503 Ma Kuonanmka and 1384 Ma Chieress swarms. These data locate the Anabar Shield, and perhaps the whole Siberia, at low latitude during the early Mesoproterozoic (Fig. 2a), whereas well-constrained paleomagnetic data for Laurentia also place North America and Greenland at low latitudes at 1460–1420, 1320–1290, and 1267 Ma (Fig. 2b; Symons, 1991; Elming, 1994; Smethurst et al., 1998; Gala et al., 1998; Buchan et al., 2000). Thus, these new data further support the conclusion that Laurentia and Siberia drifted together during the Mesoproterozoic. However, these paleomagnetic data cannot discriminate between different models for Siberia and Laurentia (Sears and Price, 1978. 2000; Hoffman, 1991; Condie and Rosen, 1994; Frost et al., 1998; Rainbird et al., 1998).

Based on continuity of tectonic grain between Archean cratons and shape of the cratonic margins, Sears and Price (1978) suggested that Siberia was contiguous with western Laurentia, and that the two blocks drifted apart in the Mesoproterozoic. On the basis of available data on the age and tectonic significance of the Belt-Purcell basin and its presumed equivalents in the Cordilleran miogeocline, Sears and Price (1978) suggested that separation of Siberia and Laurentia began at ca. 1500 Ma. On the basis of improved geochronological and stratigraphic control in the Cordilleran miogeocline and in the northeastern Siberia Craton, Sears and Price (2000) a late Neoproterozoic or early Cambrian separation. In most recent Rodinia reconstructions, the Siberia–western Laurentia connection of Sears and Price (1978) has been largely neglected because (1) this model

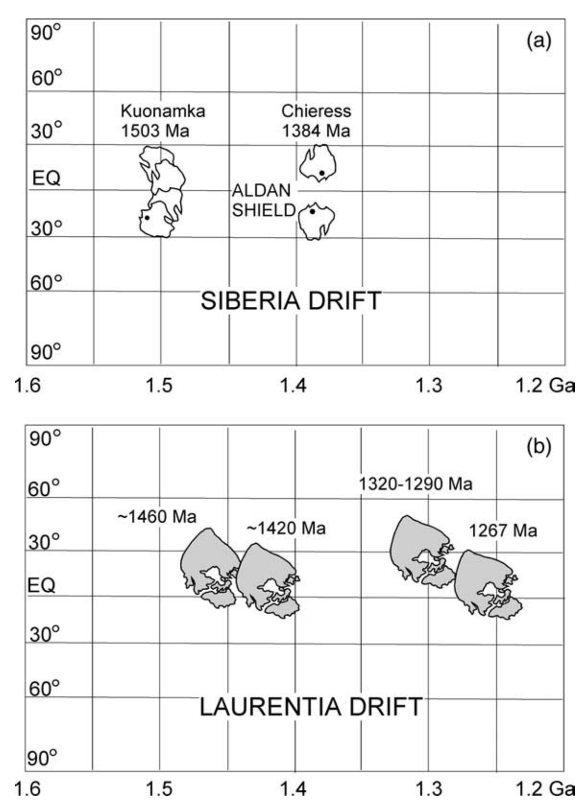

Fig. 2. Comparison of latitudinal drift and rotation of Siberia (a) and Laurentia (b) in the early Mesoproterozoic based on paleomagnetism (Ernst et al., 2000). See text for explanation.

does not provide a conjugate rifted margin of the western United States and adjacent Canada, where the U–Pb, Sm–Nd and stratigraphic data for the Belt basin (the Belt-Purcell Supergroup) imply a western continental source area composed largely of a 1.8–1.6 Ga Paleoproterozoic juvenile crust (Ross et al., 1992); and (2) no noticeable similarity is found between the geological history of the Aldan or Olekma terranes and that of the Wyoming province in western Laurentia (Frost et al., 1998; Pisarevsky and Natapov, 2003; Pisarevsky et al., 2003).

Since the 1990s, a number of reconstruction models place Siberia next to northern Laurentia (Hoffman, 1991; Condie and Rosen, 1994; Rainbird et al., 1998; Frost et al., 1998). In these models the Precambrian terranes of Siberia are broadly correlative with the major lithotectonic subdivisions of northwestern Laurentia, which from east to west are: the Archean Hearne/Rae province; 1.9–2.0 Ga Thelon magmatic zone; the Archean Slave province; and 1.95–1.85 Ga Coronation Supergroup of Wopmay belt. Hoffman (1991) noted that voluminuos 1.9–2.0 Ga magmatism in Siberia is rare in the Canadian Shield. Because the Thelon magmatic zone contains 1.9–2.0 Ga rocks, Hoffman (1991) correlated this zone with rocks of similar ages in the Anabar Shield. According to this reconstruction, the Thelon magmatic zone, Slave province and Wopmay belt of the Canadian Shield would be correlative with the Magan province, Daldyn terrane and Hapschan terrane, respectively, of the Anabar Shield (Fig. 3a). However, as pointed out by Frost et al. (1998), the Magan province have some 1.9–2.0 Ga plutons, but these rocks are anorthositic, charnockitic and monzonitic, unlike the calc-alkalic rocks of the Thelon magmatic zone, and other rocks in the Magan province are Archean granulite facies rocks whose counterparts cannot be found in the Thelon magmatic zone. Like the Slave province, the Daldyn terrane has rocks older than 3.0 Ga, but unlike the Slave, the Daldyn terrane underwent widespread granulite fades metamorphism. In addition, the Hapschan terrane underwent metamorphism at 1970 Ma, about 100 Ma before the Wopmay orogeny (Frost et al., 1998). Because of these, it seems unlikely that the Anabar and Thelon belts were originally connected.

Condie and Rosen (1994) proposed another possible Siberia–northern Laurentia reconstruction whereby the Aldan Craton and Akitkan belt were considered to be continuous with the Slave Craton and the Thelon belt, respectively (Fig. 3b). Evidence supporting this connection includes (1) zircon ages from both the Akitkan and Thelon belts that range from 2.0 to 1.9 Ga and appear to record additions of juvenile crust, and (2) >3.5 to 3.2, 3.1–2.9 and 2.8–2.6 Ga plutons present in both the Aldan and slave cratons. Condie and Rosen (1994) interpreted the Paleoproterozoic fold belts associated with the Aldan province as extensions of the Coronation Supergroup, a Paleoproterozoic rift to passive-margin succession deposited on the western margin of the Slave province. Frost et al. (1998)

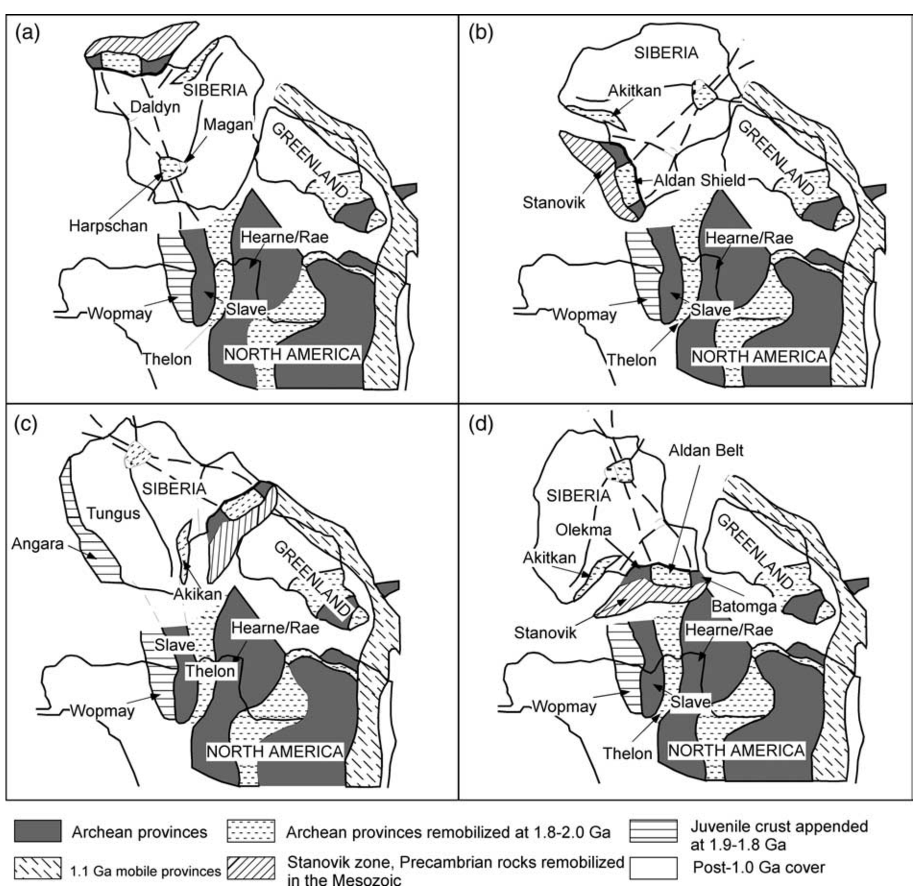

Fig. 3. Examples of Precambrian reconstructions involving Siberia and Laurentia: (a) Hoffman (1991); (b) Condie and Rosen (1994); (c) Rainbird et al. (1998); and (d) Frost et al. (1998).

pointed out three difficulties with this reconstruction. First, the Akikan fold belt crop out only around Lake Baikal and the connection is based upon its projection >1500 km from its outcrop using aeromagnetic anomalies. Second, in the Baikal region the Akikan fold belt consists of a folded 1835–1863 Ma sedimentary sequence which this reconstruction would correlate with the Thelon magmatic zone that comprises 1.9–2.1 Ga plutonic rocks. Finally, the Aldan craton shows a strong Proterozoic overprint that is not present in the Slave Province. Considering these difficulties, together with new SHRIMP U–Pb zircon data for the Riphean sandstones and gabbros from southeast Siberia, Rainbird et al. (1998) modified the reconstruction of Condie and Rosen (1994) by rotating (~100°) Siberia anticlockwise so that the Paleoproterozoic Angara fold belt, Archean Tungus Province, and Paleoproterozoic Akitkan fold belt in Siberia were contiguous, respectively, with the Paleoproterozoic Wopmay orogen, Archean Slave Province, and Paleoproterozoic Thelon–Taltson magmatic zone in Laurentia (Fig. 3c). A difficulty with this reconstruction is that unlike the Slave Province that was metamorphosed at amphibolite-facies, the Tungus Province underwent widespread granulite-facies metamorphism, forming voluminous granulites, charnockites and high-grade TTG gneisses and supracrustal rocks (Rosen et al., 1994).

The Aldan Shield in Siberia can be divided into the Archean Olekma and Batomga granite–greenstone terranes in the west and east, respectively, which are separated by the Paleoproterozoic (reworked) Aldan and Uchur high-grade terrane (Rosen et al., 1994; Frost et al., 1998). Considering similarities between the Olekma terrane and the Slave Province, and similarities between the Aldan–Uchur high-grade terrane and Thelon magmatic zone, Frost et al. (1998) postulated a reconstruction in which the Olekma and Batomga granite–greenstone terrains are continuations, respectively, of the Slave and Hearne/Rae Cratons, and the Aldan and Uchur high-grade terranes are a continuation of the Thelon belt (Fig. 3d). A further possible correlation in this reconstruction is the Coronation Supergroup in the Wopmay Orogen with the Akitkan fold belt in Siberia. Both groups involve weakly metamorphosed sedimentary and volcanic rocks and both sequences are of similar ages; 1.97–1.89 Ga for the Coronation Supergroup (Bowring and Grotzinger, 1992) vs. 1.90–1.84 Ga for the Akitkan (Rosen et al., 1994). This reconstruction is established on the assumption that the trends of the terrane boundaries in the Aldan Shield continued in the same orientation through the Stanovoy Belt prior to Mesozoic deformation. Rosen et al. (1994) show that there is a major terrane boundary within the Stanovoy Belt, which lies just to the east of the Olekma River and could be a displaced continuation of the boundary between the Aldan and Olekma terranes, but this evidence is permissive but not conclusive. Another difficulty with this reconstruction is that unlike the Akitkan fold belt that is considered to be a plate margin one (Condie and Rosen, 1994), the Taltson magmatic zone has recently been proposed to be intraplate rather than a plate margin based on the basis of the composition of the magmatic rocks (De et al., 2000).

Obviously, it is still controversial surrounding the fit of Siberia with Laurentia. As more geological and geophysical data, especially for Siberia become available, some important correlations can be applied to test the Siberia–Laurentia fit. For example, when detailed field studies and high-resolution magnetic anomaly data become available for Siberia, it will be possible to test whether the tectonic style of the Thelon–Taltson belt in Laurentia is similar to that of the Akitkan belt, as suggested by Condie and Rosen (1994) and Rainbird et al. (1998), or to that of the Aldan–Uchur high-grade gneiss belt, as suggested by Frost et al. (1998).

3. Laurentia vs. Australia–East Antarctica: SWEAT, AUSWUS or AUSMEX?

The early reconstruction of Rodinia was largely based on the SWEAT (Southwest US–East Antarctica) hypothesis, initially suggested by Jefferson (1978) and then named and advanced by Moores (1991), Hoffman (1991), Dalziel (1991) and Weil et al. (1998). This hypothesis proposes that the western US was matched with East Antarctica, western Canada with eastern Australia, and the truncated ~1.0 Ga Grenville Orogen of Texas was contiguous with a coeval belt in East Antarctica (Fig. 4a). The major piercing point of this fit is a match between the southwestern USA and Shackleton Range area of East Antarctica. Later, new geological and paleomagnetic data raise doubts about the main piercing points used for the ties between Australia and Laurentia in the SWEAT reconstruction, and then several modifications of the SWEAT hypothesis have proposed, resulting in a variety of fits of Laurentia against eastern Australia–eastern Antarctica (Ross et al., 1992; Young, 1992; Borg and DePalo, 1994; Li et al., 1995, 1996, 2004; Blewett et al., 1998). Ross et al. (1992) argued that the SWEAT configuration did not provide a continental counterpart to the rifted margin of the northwestern United States and adjacent Canada, where the U–Pb, Sm–Nd and stratigraphic data for the Belt basin (the Belt Supergroup) imply a western continental source area which was composed largely of a 1.8–1.6 Ga Paleoproterozoic juvenile crust. Alternatively, Ross et al. (1992) proposed a left-lateral displacement of about 1500 km between Australia and East Antarctica and Laurentia to bring the Gawler block in the Southern Australian Craton closer to the Belt basin in the northwestern United States and adjacent Canada. Borg and DePalo (1994) also suggested a similar displacement (Fig. 4b), but to a lesser extent, to obtain a reasonably good match of Nd isotopic provinces in Australia, Laurentia and East Antarctica. Blewett et al. (1998) suggested north Queensland as a possible source for this detritus. Li et al. (1995, 1996, 2004) further modified the SWEAT fit by placing South China between Laurentia and Australia, but Yang et al. (2004) placed South China against northwestern Australia. Most recently, Giles et al. (2004) proposed other alternative SWEAT-like reconstructions in which the South Australian Craton is rotated ~52° counterclockwise about a pole located at ~136°E and ~25°S (present-day coordinates), relative to its current position.

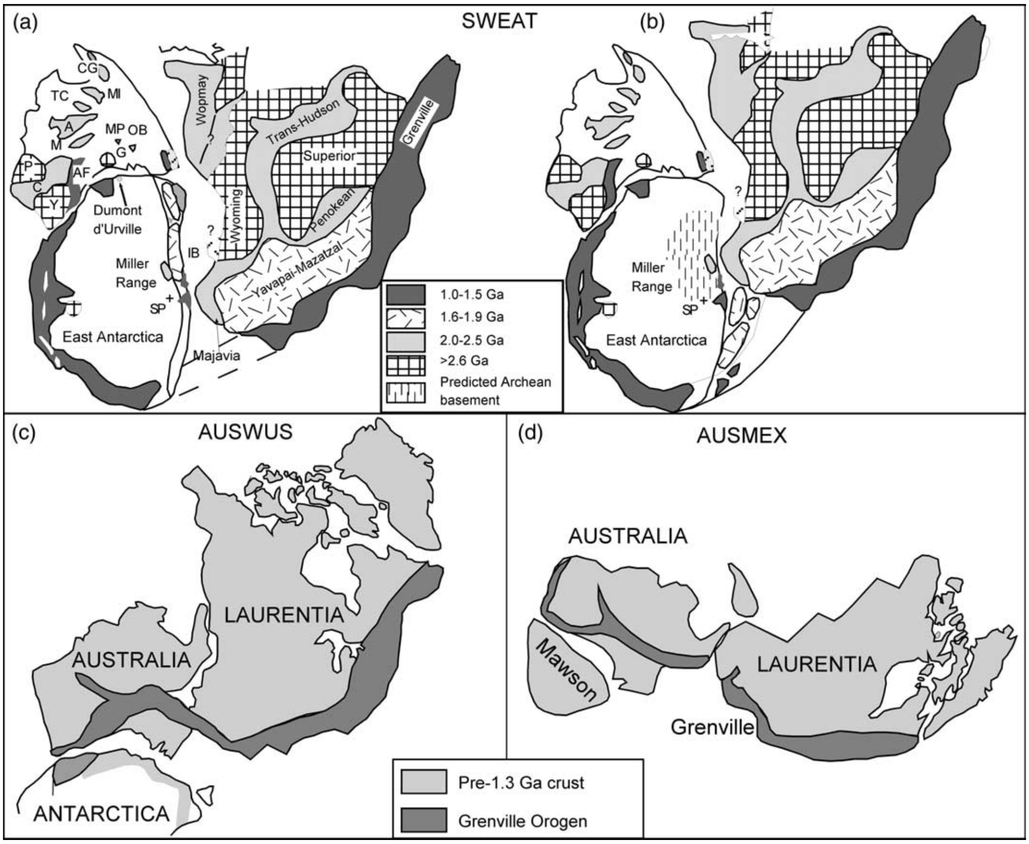

Fig. 4. Possible alternatives for the reconstructions of the North America–Australia–Antarctica connection (after Borg and DePalo, 1994). (a) Southwest US–East Antarctica (SWEAT) reconstruction of Moores (1991); (b) revised SWEAT reconstruction of Borg and DePalo (1994); (c) Australia–Western US (AUSWUS) reconstruction of Karlstrom et al. (1999); and (d) Australia–Mexico (AUSMEX) reconstruction of Wingate et al. (2002). Abbreviations: A, Arunta Inlier; AF, Albany-Fraser Orogen; C, Capricorn Orogen; CG, Coen-Georgetown Inlier; G, Gawler Craton; M, Musgrave Orogen, MI, Mt. Isa Inlier; MP, Mt. Painter Inlier; OB, Olary-Broken Hill Inlier; P, Pilbara Craton; TC, Tennant Creek Inlier; SP, South Pole; Y, Yilgarn Craton.

Brookfield (1993) proposed the Australia–Western United States reconstruction by matching inferred rift-transform segments of Proterozoic margins. In this reconstruction, the promontory of the Sr 0.706 line in Laurentia was matched with the re-entrant in the Tasman line of central Australia (Brookfield, 1993). Recently, Karlstrom et al. (1999) and Burret and Berry (2000) further extended this reconstruction and gave it the acronym AUSWUS (Australia–Western United States reconstruction), based on a comparison of the major geological provinces, belts, and lineaments of Paleo-Mesoproterozoic Laurentia and Australia (Fig. 4c). In these studies, major lineaments on both continents are viewed as part of the rift-transform fault system that was active during the supercontinent breakup (Karlstrom et al., 1999; Burret and Berry, 2000). For example, the NW-trending Mojave-Sonora lineament of Laurentia continues into Australia as the Koonenberry fault zone of the Tasman line, and the Great Falls tectonic zone is matched to the Diamantina Lineament (Burret and Berry, 2000a,b). The AUSWUS reconstruction can also explain tectonostratigraphic similarities between Australia and the southwestern US from 1.8 to 1.0 Ga, and similar 1.45–1.0 Ga paleomagnetic poles between Australia and Laurentia (Karlstrom et al., 2001; Burrett and Berry, 2000). Karlstrom et al. (2001) suggested that the southern margin of Laurentia was a long-lived (1.8–1.0 Ga) convergent continental margin that extended to Australia and Baltica; they all underwent an episodic southward accretionary growth along a margin of a supercontinent between 1.8 and 1.0 Ga.

Recently, however, Wingate et al. (2002) argued that most Australian paleomagnetic poles used for SWEAT nor AUSWUS are not reliable or are dated inadequately, and that new paleomagnetic results and high-precision isotopic ages support neither the SWEAT nor AUSWUS reconstructions. For example, the SWEAT reconstruction was constrained by optimizing the fit between Australian and Laurentian poles at ~1070 Ma and 700–750 Ma (Powell et al., 1993), but the 1070 Ma poles for Australia are unreliable, and the supposedly 700–750 Ma dykes poles for Australia (Giddings, 1976) may represent a younger (possibly Mesozoic) overprint (Halls and Wingate, 2001; Wingate et al., 2002). Paleomagnetic support for the AUSWUS reconstruction was based on matching Australian and Laurentian poles between ~1.75 and ~0.75 Ga (Karlstrom et al., 1999; Burret and Berry, 2000), but most Mesoproterozoic data for Australia are also dated inadequately (Wingate et al., 2002). Based on high-resolution SHRIMP U–Pb zircon ages and paleomagnetic results for a suite of mafic sills within the intracratonic Bangemall basin of Western Australia, Wingate et al. (2002) obtained a new 1070 Ma paleopole, which is separated by ~30° from the Laurentian path in the SWEAT fit and by at least 40° in the

AUSWUS fit. Moreover, Wingate et al. (2002) showed that a fit similar to SWEAT or AUSWUS cannot be achieved by matching the newly obtained paleopole with any part of the Laurentian path indicating that neither reconstruction is viable at 1070 Ma. Instead, based on their new paleomagnetic and isotopic results, Wingate et al. (2002) proposed the Australia–Mexico connection, referred to as AUSMEX (Fig. 4d), which places the Cape River Province of north-east Australia at similar latitude to the south-west end of the 1250–980 Ma Grenville Province of Laurentia. The AUSMEX connection is supported by a recent paleomagnetic study of the deep drillhole Empress 1A in the officer Basin, which indicated low paleolatitudes for Australia between ~810 and 750 Ma (Pisarevsky et al., 2001, 2003). Wingate et al. (2002) claim that the most compelling geological arguments used to generate the SWEAT and AUSWUS hypotheses, including correlation of Mesoproterozoic orogenic belts, Paleo- and Mesoproterozoic isotope age provinces, and Neoproterozoic rift-passive margin sedimentary successions, still remain robust in the AUSMEX reconstruction. However, this provocative fit needs further testing by key paleopoles of precisely the same age from Australia and Laurentia, and by detailed geological correlations.

4. Where was North China in the supercontinent Columbia?

The North China Craton is one of the oldest cratonic blocks in the world, with ~3.85 Ga rocks recognized in its basement (Liu et al., 1992; Song et al., 1996), but the craton is not shown in the Columbia reconstruction of Rogers and Santosh (2002) due to a lack of reliable paleomagnetic data. However, the available geological data suggest that the North China Craton preserves a full record for the assembly, accretion and fragmentation of Columbia. For example, like most other cratonic blocks, the North China Craton formed by the amalgamation of two discrete cratonic blocks (Eastern and Western Blocks) along the Paleoproterozoic Trans-North China Orogen at ~1.85 Ga (Fig. 5; Zhao, 2001; Zhao et al., 1999a, 2000a,b, 2001a,b, 2005; Liu et al., 2002; Guo et al., 2002; Kröner et al., 2005). Following the amalgamation, the North China Craton underwent a long-lived (1.8–1.4 Ga) subduction-related accretion along its southern margin, forming the Xiong'er volcanic belt (Fig. 5), which is petrologically and geochronologically similar to the 1.8–1.3 Ga magmatic accretionary belts along southern margin of North America, Greenland and Baltica (e.g. Gower et al., 1990). In the period 1.6–1.2 Ga, the North China Craton underwent widespread rifting and anorogenic magmatism, forming the Zhaertai–Bayan Obo rift zone along its northern margin (Fig. 5), and the Dachang-Damiao rapakivi granite–anorthosite–gabbro suites and Tuanshanzi alkaline volcanic assemblages, which are temporarily coincident with the fragmentation of the supercontinent Columbia.

The early Precambrian connection of the North China Craton with other cratonic blocks has long been controversial. Piper (1982) placed North China close to India, with the eastern margin of the North China Craton against the western margin of the India Shield, but he did not provide evidence for this reconstruction. Later, Li et al. (1996) proposed that the North China Craton was once connected to Siberia during the Paleo- and Mesoproterozoic, based on similarities of Paleo- to Mesoproterozoic sedimentary sequences between North China and Siberia, the prime example of which is the Changcheng (1.8–1.4 Ga) and Jixian (1.4–1.0 Ga) Formations on the North China Craton that can be correlated, respectively, with the Lower and Middle Riphean assemblages of Siberia. Condie (2002) extended this connection to the Paleoproterozoic by suggesting that the Trans-North China Orogen in the North China Craton was a continuation of the Akitkan Orogen

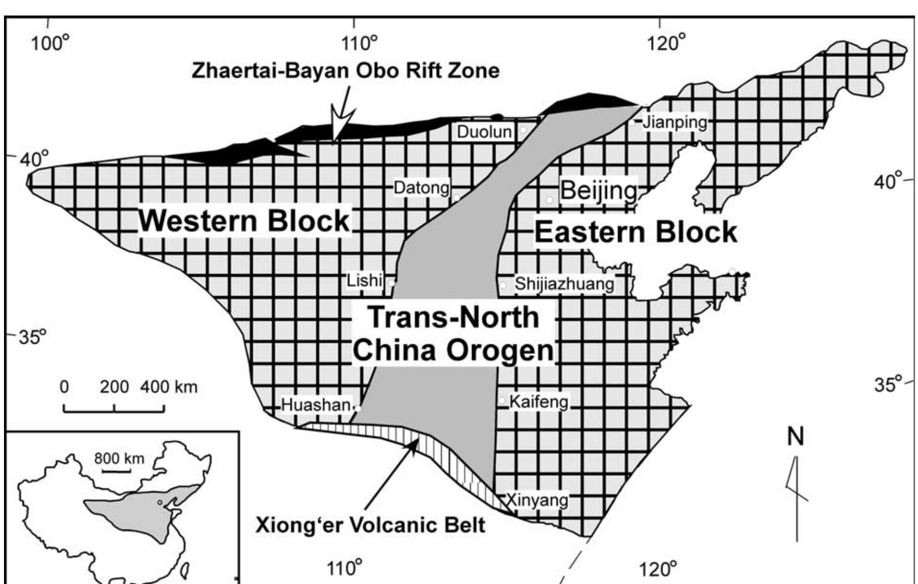

Fig. 5. Schematic tectonic map showing the spatial distribution of the ~1.85 Ga Trans-North China Orogen, 1.8–1.4 Ga Xiong'er accretionary complex, and 1.6–1.2 Ga Zhaertai-Bayan Obo rift zone in the North China Craton (revised after Zhao et al., 2002b).

in Siberia. Some paleomagnetic data seem to be consistent with the North China–Siberia connection (e.g. Zhang et al., 2000; Halls et al., 2000). However, striking geological differences in Archean basement rocks between the two continental blocks discourage these hypotheses.

Alternatively, Qian (1997) proposed a link between the North China Craton and the Fennoscandia Shield, based on lithological and geochronological correlations. According to this linkage, the North China Craton may have been located adjacent to either the eastern or western margin of the Fennoscandian Shield. Recent work has established the existence of Fennoscandian basement rocks from Baltica through Estonia, Belorussia and Poland to the western Ukraine (Bogdanova, 1993, 1999). Paleomagnetic studies by Elming (1994) suggest that the Ukrainian Shield had not separated from Fennoscandia until ∼1.3 Ga ago, implying that the North China Craton did not lay adjacent to the eastern margin of the Fennoscandian Shield. Another possible fit adjacent to the western margin of Baltica contravenes the already established connection of Baltica and South Greenland (e.g. Gower et al., 1990; Windley, 1995) and is also considered unlikely (Wilde et al., 2002).

Kröner et al. (1998) noticed a remarkable similarity between the ∼2.5 Ga granulite belt of the North China Craton and the 2.55–2.51 Ga granulite belt in Southern India. Both the granulite belts have supracrustal assemblages and tonalite–trondhjemite–granodiorite (TTG) and K-rich granite plutons that formed less than about 50 Ma prior to their deformation and high-grade metamorphism. As all other Archean crustal blocks of the world experienced main crust-forming events before ∼2.6 Ga (Condie, 1989), Kröner et al. (1998) postulated that the North China Craton and Southern India may have constituted part of one single active continental margin at the Archean-Proterozoic boundary along which juvenile crust was accreted onto an older landmass.

Most recently, Zhao et al. (2003a) extended the North China-India connection to Early Archean and Paleoproterozoic, on the basis of geological similarities between the Eastern Block (EB) of North China and the South India Block (SIB) of India. For example, the early Archean Caozhuang Group in the EB can be well correlated with the Older Metamorphic Group in the SIB; both comprise 3.6–3.4 Ga (fuchsite) quartzite, pelitic gneiss, calc-silicate rock, marble, banded magnetic quartzite and amphibolite (Wu et al., 1991, 1998; Mishra et al., 1999). The middle Archean 3.4–3.3 Ga Chentaigou supracrustal rocks and orthogneisses in the EB are broadly comparable to the 3.4–3.3 Ga Holenarsipur supracrustal rocks and the Gorur orthogneisses, and the 3.1–2.9 Ga Qianan supracrustal rocks and Yangyashan orthogneiss in the EB are comparable to the 3.1–2.9 Ga the Sargur Group and the Peninsular Gneiss in the SIB (cf. Wu et al., 1991; Nutman et al., 1992; Peucat et al., 1995; Song et al., 1996). The late Archean (2.8–2.6 Ga) Taishan Group and its equivalents in the EB and the Dharwar Supergroup in the SIB have similar lithologies that consist of a lowermost ultramafic (komatiitic) and mafic volcanic-rich sequence through a mafic-intermediate volcanic sequence to uppermost shale and economically important BIF (Chadwick et al., 1985; Kumar et al., 1996; Bai and Dai, 1998). In both blocks, the emplacement of ∼2.5 Ga granitoid plutons was followed shortly (less than 50 Ma) by a granulite facies metamorphic event, with anticlockwise P–T paths and associated with the development of dome-and-basin structures (Zhao et al., 1998, 1999b; Jayananda et al., 2000). The Paleoproterozoic Liaohe Group in the EB consists of lower clastic-rich, middle volcanic-rich and upper clastic + carbonate sequences (Li et al., 1997; Li and Yang, 1998), similar to the adjoining Singhbhum, Dhanjori and Kolhan Groups in the SIB (Naqvi and Rogers, 1987). These remarkable magmatic, sedimentary and tectonometamorphic similarities lead Zhao et al. (2003a) to propose that the EB and SIB are dispersed remnants of what was once a single continent from Archean to Paleoproterozoic. However, this North China–India link has not been paleomagnetically tested.

5. South America and West Africa: divorced and re-married or a long-lasting relationship?

Controversy has surrounded the timing and history of the amalgamation and fragmentation of South America and Africa for a long-time. The amalgamation of the cratonic blocks in South America and West Africa has long been considered to occur during the Brasiliano/Pan-African event at 0.6–0.5 billion years ago (Ga), leading to the final assembly of Gondwana (Fig. 6; Unrug, 1992, 1996; Hoffman, 1999). This is further supported by recent reconstructions of Rodinia, as shown in Fig. 1b, where the Amazonia, São Francisco and Rio de la Plata Cratons in South America and the Congo and West African Cratons in Africa were still separated by large oceans about 1.0 Ga ago.

On the other hand, however, both geological and paleomagnetic data suggest that the São Francisco and Amazonia Cratons were once joined, respectively, with the Congo and West African Cratons along the 2.1–2.0 Ga Transamazonian/Eburnean orogens (McElhinny and McWilliams, 1977; Onstott and Hargraves, 1981; Onstott et al., 1984; Onstott and Dorbor, 1987; Bertrand and Jardim de Sá, 1990; Ledru et al., 1994; D'Agrella et al., 1996; Rogers, 1996; Nomade et al., 2003). On the map of the classical Bullard et al. (1965) fit of Africa and South America, the structural trend of the Transamazonian orogen along the eastern margin of the São

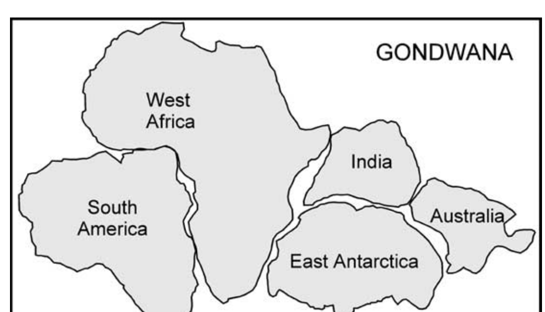

Fig. 6. South America, West Africa and other continental blocks in Gondwana (after Unrug, 1996).

Francisco craton is consistent with that of the Eburnean orogen along the western margin of the Congo craton; both are north–south trending (Fig. 7). The evolution of both the orogens is characterized by early compressive tectonics, marked by large-scale thrusts and sinistral strike-slip faults, followed by later transcurrent tectonics (Ledru et al., 1994), suggesting that they may have belonged to the same orogen joining the São Francisco and Congo cratons. Similarly, the structural trend of the Transamazonian Orogen in the northeastern part of the Amazonia Craton is consistent with that of the Eburnean Orogen along the southern margin of the Western African Craton, and both orogens are characterized by early large-scale thrusts followed by later transcurrent tectonics (Bertrand and Jardim de Sá, 1990; Ledru et al., 1994). Thus, the Transamazonian-Eburnean orogens may represent a Paleo-proterozoic transcontinental collisional superbelt suturing the cratonic blocks in West Africa and South America (Bertrand and Jardim de Sá, 1990; Boher et al., 1992). In addition, Ledru et al. (1994) noted that ∼2.0 Ga fluvio-deltaic formations are exposed in nearly every craton in South America and West Africa (Fig. 7) and show a similar structural and metamorphic evolution. These formations are considered to have deposited in foreland basins that were deformed and metamorphosed during the collisional orogeny at 2.1–2.0 Ga (Ledru et al., 1994). Therefore, comparison of the tectonic evolution on either side of the South Atlantic shows that the major convergence of the cratonic blocks took place at 2.1–2.0 Ga.

Paleomagnetic and isotopic data also suggest that South America (São Francisco and Amazonia Cratons) and West Africa (Congo and West African Cratons) may have existed as a single landmass after the Transamazonian/Eburnean orogenic events (McElhinny and McWilliams, 1977; Onstott and Hargraves, 1981; Onstott et al., 1984; Onstott and Dorbor, 1987; D'Agrella et al., 1996; Nomade et al., 2003). In the late 1970's and early 1980's, the consensus of opinion by most paleomagnetists was that the Congo and West African Cratons collided, respectively, with the Amazonia and São Francisco Cratons about 2.0 Ga ago (McElhinny and McWilliams, 1977;

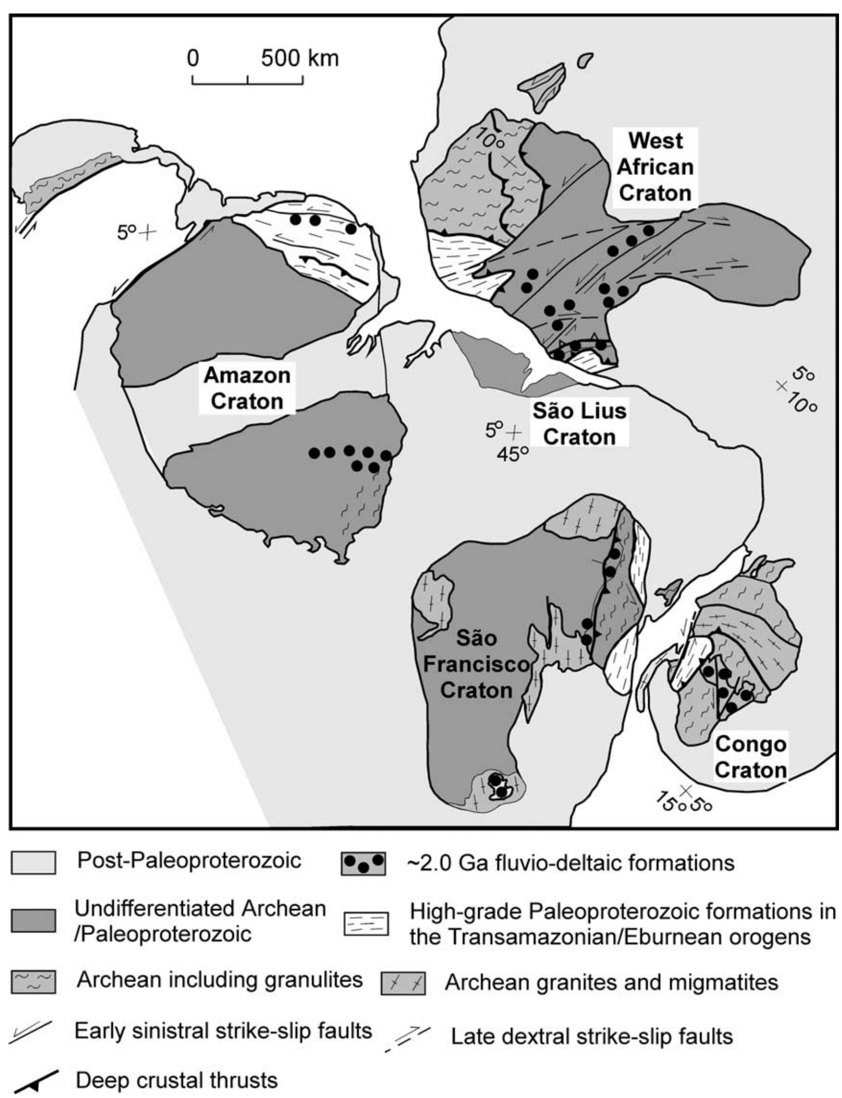

Fig. 7. A fit of circum-South Atlantic Archean-Paleoproterozoic provinces, showing assumed links for the Archean cratons and Paleoproterozoic Transamazonian-Eburnean orogens in West Africa and South America (after Ledru et al., 1994).

Onstott and Hargraves, 1981; Onstott et al., 1984). Onstott and Hargraves (1981) and Onstott et al. (1984) show that coeval rocks between 2.1 and 1.5 Ga in the Amazonia and West African Cratons record similar paleomagnetic polar wander paths if a subsequent ∼1000 km right-lateral strike–slip movement is assumed to have occurred between the two cratons. Furthermore, Onstott et al. (1984) showed that the 2.0–1.9 Ga paleomagnetic poles of the Amazonia and West African Cratons are distinctly different from the coeval poles of the Kalahari Craton, suggesting that relative motion has occurred between the West African and Kalahari Cratons since that time, implying that the Amazonia–West African Craton and the Kalahari Craton were not contiguous at that time. Although the early paleomagnetic reconstruction of South America and West Africa was questioned because of the poor quality of the paleomagnetic and isotopic data, recent paleomagnetic data from single cratons or terranes support the conclusion that South America (São Francisco and Amazonia Cratons) and West Africa (Congo and West African Cratons) belonged to a single continent at ∼2.0 Ga (D'Agrella et al., 1996; Nomade et al., 2003). For example, D'Agrella et al. (1996) obtained a paleomagnetic pole (Plat = 19°N and Plong = 44°E) from the 2.0 Ga rocks in the Ogoouè Formation of the Congo Craton in West Africa, and a paleomagnetic pole obtained for coeval granulites from the Jequie complex of the Sao Francisco craton supports a close affiliation for Sao Francisco and Congo Cratons, suggesting that both cratons belonged to the same landmass at that time. Similarly, based on the results of four virtual palaeomagnetic poles (two for French Guiana and two for the Ivory Coast), Nomade et al. (2003) proposed that the Amazonia (Guiana) Craton and the West African Craton belonged to the same block at about 2.00 Ga but separated prior to 2.02 Ga.

If South America (São Francisco and Amazonia Cratons) and West Africa (Congo and West African Cratons) were indeed amalgamated at 2.1–2.0 Ga, two possibilities that need to be further evaluated are that (1) South America and West Africa were divorced before the ca. 1.0 Ga formation of Rodinia and then re-married to form part of Gondwana; or (2) South America and West Africa remained largely coherent from their amalgamation at 2.1–2.0 Ga until their incorporation into Gondwana. The first possibility is consistent with the current reconstruction of Rodinia, but it is hard to explain why an old continent could have been fragmented into blocks that traveled widely around the earth and then were reassembled into the same configuration that they had before fragmentation. Whether the second possibility exists depends on how the tectonic nature of the Brasiliano/Pan-African orogens is interpreted. As these orogens do not show evidence of consumption of significant amounts of oceanic crust and major motions between the cratonic blocks (Hurley, 1973), Rogers (1996) suggests that they may represent only intracontinental rifts that opened briefly and then closed on themselves, rather than the major sutures that mark the sites of a vast ocean between two continents. Recently, Pedrosa-Soares et al. (2001) demonstrate that the Brasiliano-Araçuaí belt in South America and the Pan-African West-Congo belt in West Africa are counterparts of the same Neoproterozoic continental rift system that was opened during the breakup of the Rodinia supercontinent and closed during the formation of Gondwana (Fig. 8). The spatial distribution of the Araçuaí and West-Congo belt belts shows that this rift system was only limited to the embayment outlined by the São Francisco and Congo cratons (Fig. 8), which implies that the rifting did not result in the complete fragmentation of the adjoining South America–West Africa continent. Pedrosa-Soares et al. (2001) suggest that although minor amounts of oceanic crust may have developed in some areas in the central zone of the rift, the São Francisco and Congo paleocontinental regions were still connected by some cratonic bridges. Aspler and Chiarenzelli (1998) proposed a similar origin for the Trans-Hudson orogen. Thus, it is most likely that South America and West Africa had existed as a single megacontinent during most of the Proterozoic period. Condie (2002) suggested that the adjoining South America and West Africa continent may have survived as an intact landmass from the ∼1.5 Ga incomplete fragmentation of a Paleoproterozoic supercontinent until its collision with other cratonic blocks to form Rodinia.

6. One or two pre-Rodinia supercontinents?

As discussed above, geological and paleomagnetic data suggest that South America and West Africa were once amalgamated along the Transamazonian/Eburnean Orogen to form a coherent continental block at 2.1–2.0 Ga. However, it still remains unclear whether the adjoining South America and West Africa continent, named 'Atlantica' by Rogers (1996), was connected with or separated by a large ocean from the rest part of Columbia, named 'Arctica', which comprises Laurentia, Siberia, Baltica, North Australia and North China (Rogers, 1996; Condie, 2002). In the current reconstruction models of the supercontinent Columbia, the adjoining South America and West Africa continent was not positioned contiguous to any other continental blocks (see Fig. 2; Rogers and Santosh, 2002; Zhao et al., 2002a, 2004). Condie (2002) proposed a possibility that there were two pre-Rodinia supercontinents, rather than one, which formed 2.1–1.8 Ga ago, with Atlantica and Arctica forming the core of each of these supercontinents.

On the other hand, some geologists have noted similarities in the Paleo-Mesoproterozoic geology between South America, Laurentia and Baltica (Park, 1992, 1995; Sadowski and Bettencourt, 1996; Dalziel, 1997; Geraldes et al., 2001; Sadowski, 2002; Tohver et al., 2002; Meert and Torsvik, 2003). As reviewed by Sadowski and Bettencourt (1996) and Sadowski (2002), Amazonia (South America), Laurentia and Baltica all underwent two major episodes of magmatism between 1.8 and 1.3 Ga, forming temporally and petrologically similar volcanogenic sequences and granitoid suites along the present southern margin of Laurentia and Baltica and the western margin of Amazonia. The first episode of magmatism occurred between 1.8 and 1.5 Ga ago, forming the Yavapai, Mazatzal, Central Plains, Makkovikian, Labradorian and Ketilidian belts in Laurentia; the Konigsbergian, Gothian and

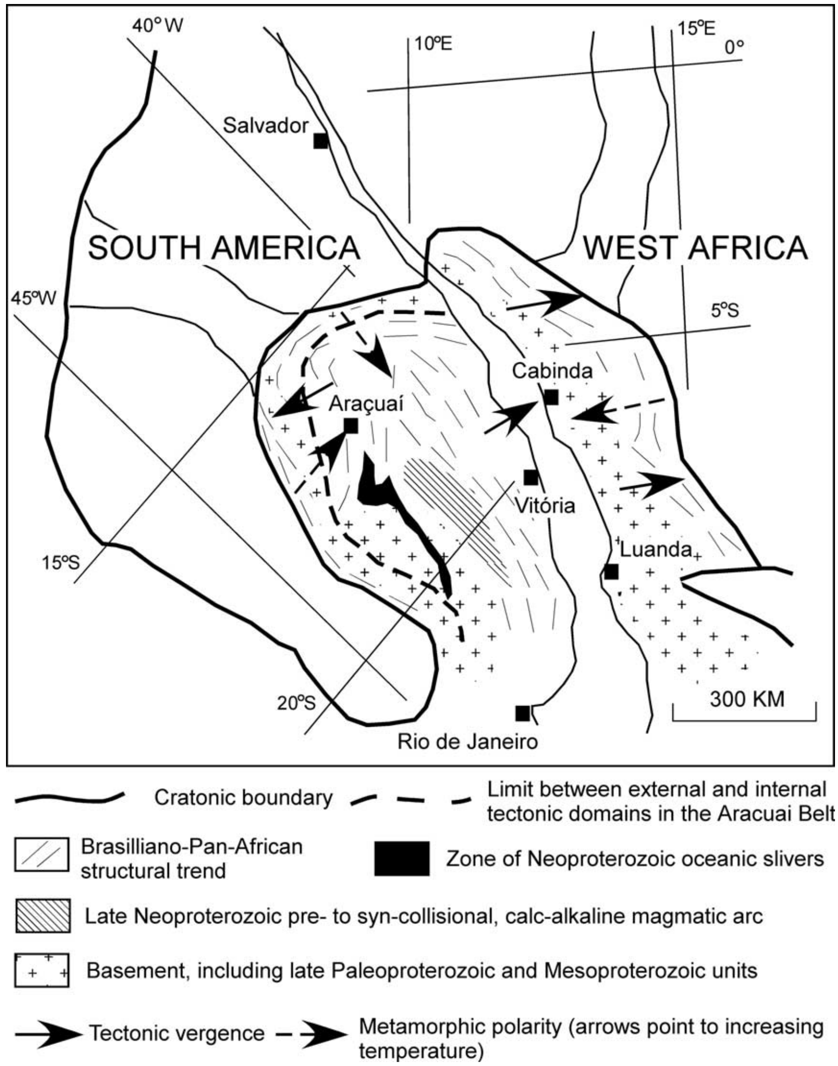

Fig. 8. Sketch of the Araçuaí-West-Congo Orogen in a pre-rift reconstruction (after Pedrosa-Soares et al., 2001).

Transscandinavian Igneous belts in Baltica; and Rio Negro-Juruena belt in western Amazonia. The second one occurred between 1.5 and 1.3 Ga ago, forming the St Francois and Spavinaw Granite–Rhyolite belts in Laurentia, the Southwest Sweden Granitoid belt in Baltica; and the Rondonian belt in western Amazonia. Petrological and geochemical data indicate that these juvenile volcanogenic sequences and granitoid suites along the present southern margin of Laurentia and Baltica and the western margin of Amazonia resemble those of present-day active continental margins, representing long-lived, subduction-related, outgrowth along the margins of these continents (Nelson and DePaolo, 1985; Bennet and DePaolo, 1987; Sadowski and Bettencourt, 1996). In addition, the 1.6–1.2 Ga anorogenic anorthosite–mangerite–charnockite–granite (AMCG) plutonic suites and 1.4–1.2 Ga mafic dyke swarms in Laurentia and Baltica also show ecoval analogues in western Amazonia (Sadowski and Bettencourt, 1996; Geraldes et al., 2001). These similarities led to a speculation that Laurentia, Baltica and Amazon were once continuous, forming a superlarge accretionary margin of a Paleo-Mesoproterozoic supercontinent (Park, 1992, 1995; Sadowski and Bettencourt,

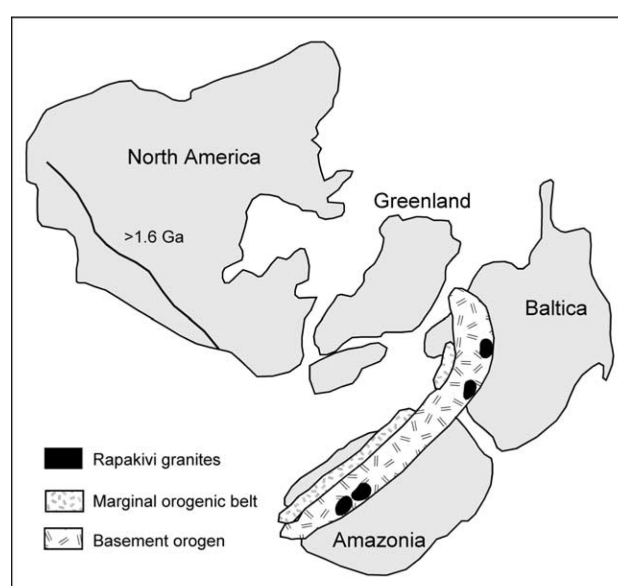

Fig. 9. A possible early to middle-Neoproterozoic configuration of Laurentia, Baltica, and Amazonia (Geraldes et al., 2001).

1996; Dalziel, 1997; Geraldes et al., 2001; Sadowski, 2002). However, the geometric relationships between Laurentia, Baltica and Amazonia are still controversial (Sadowski and Bettencourt, 1996; Dalziel, 1997; Geraldes et al., 2001; Sadowski, 2002; Tohver et al., 2002).

In their recent analysis of the geometric and geological relationships between Laurentia, Baltica and Amazonia, Geraldes et al. (2001) suggested a genetic relationship between 1.6 and 1.5 Ga rapakivi granites and orogenic suites within the Amazonia Craton and those exposed in Baltica (Åhäll et al., 2000), and proposed that a continuation of these belts indicates a close proximity between Amazonian and Baltica but not necessarily Laurentia. Geraldes et al. (2001) proposed an Amazonia–Baltica reconstruction as shown in Fig. 9, where the paired accretionary-rapakivi suites in both blocks represent parts of a major, laterally continuous continental margin at 1.6–1.5 Ga. Meert and Torsvik (2003) show that the Amazonia-Baltica connection is consistent with paleomagnetic data until ∼1200 Ma. Geraldes et al. (2001) also argue that the relationship of the adjoining Baltica–Amazonia to Laurentia at this time is not certain. Considering the well-established Laurentia–Baltica connection in the period of the Mesoproterozoic (e.g. Buchan et al., 2000, 2001) and a significant clockwise rotation (up to ∼80°) of Baltica away from Laurentia in the period between 1.2 and 1.1 Ga (Park, 1992), we think that the Geraldes et al. (2001) reconstruction of Fig. 9 may represent a configuration of Laurentia–Baltica–Amazonia at the end of the Neoproterozoic. Alternatively, we propose a possible Paleo-Mesoproterozoic Laurentia–Baltica–Amazonia reconstruction as shown in Fig. 10, whereby the present northwestern margin of Amazonia is positioned adjacent to the southern margin of Baltica so that the Rio Negro-Juruena and Rondonian accretionary belts in Amazonia represent continuations,

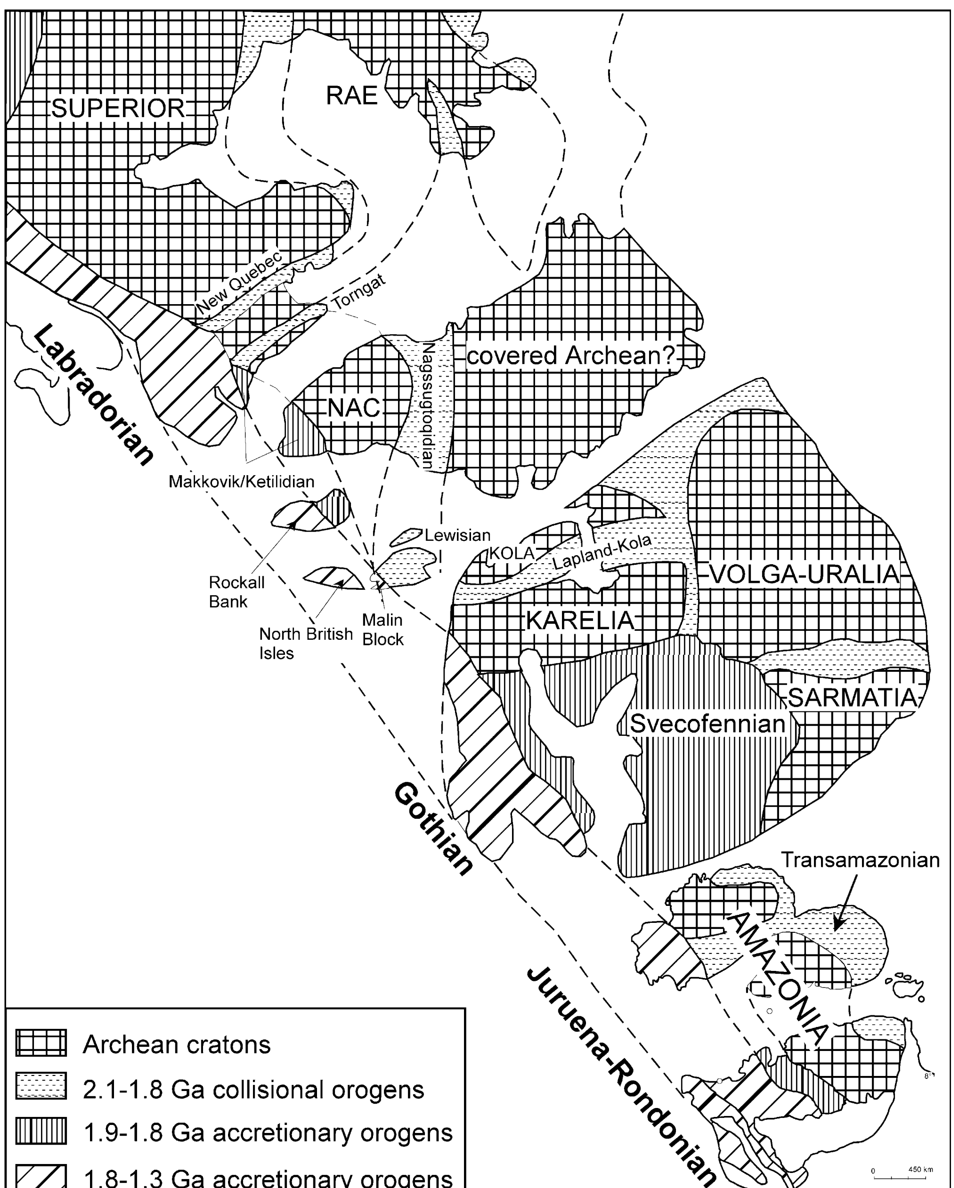

Fig. 10. A possible Mesoproterzoic configuration of Laurentia, Baltica, and Amazonia.

respectively, of the Konigsbergian–Gothian–Transscandinavian belt and Southwest Sweden Granitoid belt in Baltica. In this reconstruction, the fit of Baltica with Laurentia is the same as that of Buchan et al. (2000), whereas the reconstruction of Amazonia and Baltica is the same as their current models for the configuration of Rodinia (e.g. Fig. 1b; Dalziel, 1997; Powell et al., 2001), except that the adjoining Amazonia and Baltica were rotated ~80° clockwise relative to Laurentia, as suggested by Park (1992). This rotation may have resulted in the final collision between Laurentia and Baltica–Amazonia along the Grenville, Sunsas and Sveconorwegian belts at ~1000 Ma ago, which was coincident with the final assembly of Rodinia.

7. Summary and discussion

There is a coherent outline of the timing and processes involved in the assembly of Proterozoic supercontinents Columbia and Rodinia and also much increased knowledge of their subsequent accretion, fragmentation and final breakup, full configurations of these two supercontinents are not viable at present because of a number of unresolved issues concerning continental reconstructions, especially for Laurentia vs. Siberia, Laurentia vs. Australia–East Antarctica, North China vs. Siberia/Baltica or India, South America vs. West Africa, and Amazonia vs. Laurentia.

Paleomagnetic data support a Mesoproterozoic link between Laurentia and Siberia, both of which were at low latitudes restricted to a ±30° paleolatitude range and showed broadly similar APWP paths (Smethurst et al., 1998; Ernst et al., 2000), but geological data, especially for Siberia, are insufficient to provide rigorous constraints on the fit of the two blocks. An early reconstruction that considers the Aldan Shield as a continuation of the Wyoming Province (Sears and Price, 1978) has been largely abandoned because of their contrasting geological histories (Frost et al., 1998). At present, most reconstructions are in favor of models connecting Siberia to northern Laurentia, but a hot debate remains about whether the Paleoproterozoic Thelon Orogen in Laurentia is connected to the Paleoproterozoic Akitkan fold belt (Condie and Rosen, 1994; Rainbird et al., 1998); or to the Aldan–Uchur high-grade gneiss belt (Frost et al., 1998). Detailed field geological studies and high-resolution geophysical data (e.g. magnetic anomaly) are needed to test whether the tectonic style of the Thelon–Taltson belt in Laurentia is similar to that of the Akitkan belt or to that of the Aldan–Uchur high-grade gneiss belt.

Geological and paleomagnetic data are also supportive of the western Laurentia–Australia–East Antarctica connection, but the quality of the current paleomagnetic data is insufficient for determining the exact geometry of the Laurentia–Australia–East Antarctica reconstruction, in part because many of the early paleomagnetic studies were not tied to a precise isotopic age. More importantly, newer studies combining paleomagnetic and isotopic age data have called into question the validity of SWEAT, AUSWUS and other variants (e.g. Wingate et al., 2002; Torsvik, 2003; Meert and Torsvik, 2003). Therefore, more reliable paleomagnetic data combined with high-precision radiometric ages are an urgent need for further reconstructions of Laurentia and Australia–East Antarctica.

Because of a lack of paleomagnetic data, the North China Craton does not appear in most configuration diagrams of Rodinia and the newly proposed supercontinent Columbia of Rogers and Santosh (2002), although some workers have proposed possible connections with Siberia (Li et al., 1996; Condie, 2002), Baltica (Qian, 1997; Wilde et al., 2002), and India (Zhao et al., 2003a). Available paleomagnetic data seem to be consistent with the North China–Siberia reconstruction (e.g. Halls et al., 2000), but striking geological differences in basement rocks between the two blocks discourage this connection. The Eastern Block of the North China Craton and the Southern Indian Block of the India Shield show remarkable magmatic, sedimentary and tectonometamorphic similarities from Archean to Paleoproterozoic (Zhao et al., 2003a), but whether there was a link between the two blocks during this period is waiting for a paleomagnetic test.

Geological and paleomagnetic data suggest that the Amazonia and São Francisco Cratons in South America collided with the West African and Congo Cratons in Africa, respectively, along the 2.1–2.0 Ga Transamazonian and Eburnean Orogens (McElhinny and McWilliams, 1977; Onstott and Hargraves, 1981; Onstott et al., 1984; Onstott and Dorbor, 1987; Bertrand and Jardim de Sá, 1990; Ledru et al., 1994; D'Agrella et al., 1996; Rogers, 1996). However, whether South America and West Africa were divorced and then remarried to form part of Gondwana, or remained largely coherent from their amalgamation at 2.1–2.0 Ga until their incorporation into Gondwana is still controversial. We favor the latter interpretation because it is highly unlikely that the adjoining South America and West Africa could have been fragmented into blocks that drifted widely and then were reassembled into Gondwana as the same configuration that they had in the supercontinent Columbia. Thus, most Pan-African/Brasiliano belts may represent only intracontinental rifts that opened briefly and then closed on themselves (Rogers, 1996), although minor amounts of oceanic crust may have developed in the central zones of the intracontinental rift systems (Pedrosa-Soares et al., 2001). In addition, little consensus has been reached regarding the relative position of the combined South America and West Africa (Atlantica) with the rest part of the supercontinent (Arctica, Rogers, 1996). There remains the possibility that there were two Paleo-Mesoproterozoic supercontinents, with 'Atlantica' and 'Arctica' forming the core of each of these supercontinents, as suggested by Condie (2002). However, recent geological and paleomagnetic studies suggest that the 1.8–1.5 Ga Rio Negro-Juruena and 1.5–1.3 Ga Rondonian belts in western Amazonia may represent continuations of the 1.8–1.5 Ga Gothian and 1.5–1.3 Ga Southwest Sweden Granitoid belts in southern Baltica, respectively, (Sadowski and Bettencourt, 1996; Dalziel, 1997; Geraldes et al., 2001; Sadowski, 2002; Tohver et al., 2002; Meert and Torsvik, 2003). Therefore, Proterozoic supercontinents Columbia and Rodinia most likely contained nearly all of the earth's continental blocks at that time, although their exact geometries cannot be configured out at present due to the insufficiency of convincing geological correlations and high-resolution paleomagnetic results matched with reliable isotopic ages.

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