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# From Rodinia to Gondwana with the 'SAMBA' model—A distant view from Baltica towards Amazonia and beyond

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ABSTRACT

A refined model of the late Mesoproterozoic to Neoproterozoic supercontinent Rodinia is presented, with Baltica, Amazonia and West Africa attached to eastern Laurentia as in the SAMBA model (Johansson, 2009), and East Antarctica, Australia and India to western Laurentia in a SWEAT configuration (Moores, 1991). In such a model, the Proto-Andean margin of South America would form the conjugate margin of Laurentia's Grenville margin. With the Kalahari craton attached to SW Laurentia and East Antarctica, as proposed by Loewy et al. (2011), followed by the Congo and Tanzania cratons in Africa and the São Fransisco and Rio de la Plata cratons in South America, all these cratons would be part of Rodinia, but would still be separated from Amazonia by a wide Brasiliano (Clymene) ocean embayment. By rotating the African and eastern South American cratons ca. 90° counterclockwise around a pole located close to the Laurentia–Kalahari junction, and East Antarctica, Australia and India ca. 120° counterclockwise around a pole located inside the Kalahari craton, all relative to a fixed Laurentia, these cratons will move from a Rodinia to a Gondwana configuration. These rotations will open up the Proto-Pacific ocean, close the Brasiliano (Clymene) ocean, and both open and close the intervening Adamastor and Mozambique oceans, creating the various Brasiliano and Pan-African fold belts in the ensuing collisions. The maximum plate velocity, ca 7.5 cm/year (15,000 km in 200 m.y.), will occur along the outer periphery of this rotation, thereby explaining the formation of large amounts of juvenile Neoproterozoic continental crust within the oceanic Arabian–Nubian sector of the Pan-African Orogen. Rather than being an example of 'introversion' or 'extroversion', the change from Rodinia to Gondwana in this model would be more like the 90° 'orthoversion' model proposed by Mitchell et al. (2012).



## 1. Introduction

In plate tectonic reconstructions of supercontinents, as in many other tasks, there is sometimes the problem of not seeing the forest because of all the trees, as the English (or Swedish) proverb goes. Although there were few trees in the Precambrian to obscure the geological views, there are many details within the geological record that may sometimes hamper a broader view. This contribution is an attempt to take a step back to look at the broader picture of Proterozoic supercontinent configurations, and in particular the configuration of Rodinia and the change from a Rodinia to a Gondwana configuration, and ultimately to Pangaea. Using my distant northerly lookout from Baltica, many 'trees' (details, facts, publications...) may have been overlooked in the process, but it is hoped that the ideas and models presented here nevertheless may serve as a framework for further discussions and reconstructions. Also, the models presented here are not completely new, but could be seen as refinements of already published models, e.g. by Gower et al. (1990), Hoffman (1991), Moores (1991), Dalziel (1997), and Li et al. (2008a). They also build on the previously published 'SAMBA' (South America – Baltica) model (Johansson, 2009).

In the latter model, it was proposed on geological grounds that Baltica, Amazonia and West Africa formed a single coherent landmass from at least 1800 Ma to at least 800 Ma, and perhaps until 600 Ma, with the (present-day) northwest side of Amazonia attached to the southwest side of Baltica (along the Trans-European Suture Zone), and the west coast of West Africa attached to the southern (Black Sea–Caspian Sea) margin of Baltica. In such a configuration, the geology of the three now-dispersed cratons forms a coherent pattern, with Archaean nuclei surrounded by early Palaeoproterozoic (2.0–2.2 Ga) orogenic belts in the 'east', and successively younger orogenic belts that can be followed from Baltica to Amazonia in the 'west' (all directions refer to present-day coordinates, if not otherwise stated). As parts of the late Palaeoproterozoic to Mesoproterozoic supercontinent, SE Laurentia, SW Baltica and SW Amazonia formed a curved active margin facing an open ocean from 1900 Ma to 1250 Ma. From c. 1250 Ma to 1000 Ma, Baltica, together with Amazonia and West Africa, rotated c. 75° clockwise

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relative to Laurentia according to this model, and collided with the present-day southeast margin of Laurentia forming the Grenville, Sveconorwegian and Sunsas orogens, as part of the process leading to the formation of Rodinia.

## 2. Baltica–Laurentia relations from 1.8 Ga to 1.3 Ga

A long-lasting connection between Baltica and Laurentia, sometimes termed the NENA connection (Northern Europe–North America; Gower et al., 1990), has generally been assumed in most Proterozoic supercontinent reconstructions (e.g. Gorbatschev and Bogdanova, 1993; Karlstrom et al., 2001), although the detailed configurations have varied (see e.g. maps in Kalsbeek, 1995). The reconstruction used by Johansson (2009) for the time period 1.8–1.3 Ga, during the mid-Proterozoic supercontinent Nuna or Columbia (Hoffman, 1997; Rogers and Santosh, 2002; cf. Meert, 2012), closely followed earlier reconstructions by e.g. Hoffman (1989), Bridgwater et al. (1990), and Gorbatschev and Bogdanova (1993), with a relatively tight fit between SE Greenland and NW Fennoscandia (northern Norway; Fig. 1A). However, relatively consistent palaeomagnetic data instead seem to favour a fit with the present-day Arctic margin of Baltica attached to eastern Greenland (Fig. 1B; Buchan et al., 2000; Salminen and Pesonen, 2007; Evans and Pisarevsky, 2008; Pisarevsky and Bylund, 2010; Evans and Mitchell, 2011; Mertanen and Pesonen, 2012; Pesonen et al., 2012; Zhang et al., 2012; Salminen et al., 2013), similar to the original NENA configuration of Gower et al. (1990). Although both of these reconstructions imply a Laurentia–Baltica connection via Greenland, there is an 85° difference in the orientation of Baltica relative to Laurentia (Greenland) between the configurations shown in Fig. 1A and B, which is a highly significant difference from a palaeomagnetic point of view (cf. Evans, 2013). Below, these two reconstructions are evaluated briefly.

The tight fit between SE Greenland and NW Fennoscandia in Fig. 1A yields a close connection between the early Proterozoic Nagssugtoqidian mobile belt of Greenland ("Nag" in Fig. 1A) and the Lapland-Kola Belt (LKB) in northern Fennoscandia, as discussed by Bridgwater et al. (1990). It also allows a close connection between the 1.9–1.75 Ga Svecofennian orogen and 1.8–1.65 Ga Transscandinavian Igneous Belt (TIB) in Fennoscandia, and the Ketilidian (Ket) and Makkovikian (M) orogens in Laurentia, as well as the 1.7–1.5 Ga Gothian orogen in SW Fennoscandia and the Labradorian orogen in eastern Laurentia. Whereas the Archaean Lewisian gneiss terrane of NW Scotland could be placed adjacent to the Archaean rocks of the North Atlantic Craton in SE Greenland, the rest of the northern British Isles (NBI) probably had to be located somewhere further to the south, and juxtaposed with the Lewisian terrane much later. In this configuration, an elongated Archaean craton stretching from Labrador and southern Greenland (Nain or North Atlantic Craton) via the Lewisian complex of NW Scotland and the Lofoten-Vesterålen and Western Troms basement complexes of NW Norway to the Karelian Craton of NE Fennoscandia seems likely. The Lewisian, Lofoten-Vesterålen and Western Troms complexes are critical stepping stones between Baltica and Laurentia in such a configuration, but detailed attempts to correlate the Archaean and Palaeoproterozoic rocks of these areas are not fully conclusive (Bergh et al., 2012). With Amazonia attached south of Baltica (Johansson, 2009), this configuration leads to a long curved Laurentia–Baltica–Amazonia active margin, facing an ocean towards the southwest throughout the late Palaeoproterozoic and most of the Mesoproterozoic.

Towards the other direction, this configuration leaves a triangular gap between northern Baltica and eastern Greenland. This gap could have been filled by another continental block, or by an oceanic embayment, bordered by passive margins both towards northern Baltica and eastern Greenland.

In the alternative configuration depicted in Fig. 1B, the Laurentia-Baltica-Amazonia active margin would be much straighter. Correlation between the Nagssugtoqidian mobile belt of Laurentia and the Lapland-Kola Belt in Baltica, the Ketilidian belt in Laurentia and the Svecofennian orogen in Baltica, as well as the Labradorian orogen in Laurentia and the Gothian orogen in Baltica, would still be possible, but involve much longer distances. Even with the northern British Isles and Rockall plateau located outboard of SE Greenland, a substantial gap is left to Fennoscandia, inviting the question whether there has been an intervening continental block with an inverse sequence of orogenic belts filling that area.

On the other hand, there is no gap between northern Baltica and eastern Greenland, as the Kola block and its buried continuation east of the White Sea would be directly attached to eastern Greenland. In such a configuration, the buried (and hence little known) N-S-trending (in present-day coordinates) late Palaeoproterozoic collision zone between Fennoscandia and Volgo-Uralia would be approximately aligned with the northern margin of Greenland. If Siberia was located north of Laurentia and Greenland, as in many Proterozoic plate tectonic reconstructions (see below), the present-day eastern (Uralian) margin of Volgo-Uralia would either be attached to the present-day western or eastern margin of the Siberian craton, depending on its orientation.

However, direct matching of the geology of northern Baltica and eastern Greenland is difficult. Most of the Kola block consists of Archaean rocks, including the Murmansk terrane along the north coast of the Kola peninsula, which strikes E-W (parallel to the continental margin) and probably continues in the buried basement east of the White Sea (cf. Bogdanova et al., 2005, 2008). On the Greenland side, Archaean and Palaeoproterozoic rocks have been overprinted by late Grenvillian and Caledonian tectonothermal activity, and now form part of the Caledonian nappe pile on eastern Greenland. Further inland, they are buried by inland ice. In the southern part of the East Greenland Caledonides, the basement rocks predominantly consist of Archaean gneisses, but in most of this area they consist of 1.9–2.0 Ga calc-alkaline granitoids intruded by c. 1.75 Ga post-tectonic granites (Kalsbeek, 1995). No exact counterparts to these rocks appear to exist on the Baltica side, but it remains possible that the older granitoids on Greenland form part of a Palaeoproterozoic collision zone between the Murmansk terrane and an Archaean block buried under the Greenland ice sheet. If so, this collision zone would parallel the E-W-trending part of the Lapland-Kola Belt, as well as the future rift between Baltica and Laurentia/Greenland.

The tight fit between northern Baltica and eastern Greenland depicted in Fig. 1B, and in many recent palaeomagnetic reconstructions, leaves little room for the at present rather wide continental shelves on both sides, or the Barentsia microcontinent, which includes present-day Svalbard and surrounding shelf areas. However, the Barents Sea shelf north of the Timan fold belt probably did not exist at this time, and it is unclear how wide the Greenland shelf might have been, considering that it has undergone several episodes of rifting and orogeny subsequently. Barentsia in Mesoproterozoic time probably only consisted of the Ny Friesland terrane, composed of c. 1.75 Ga granitids (cf. Johansson et al., 1995), which was probably located somewhere along the east Greenland margin, or close to the Greenland–Baltica–Siberia triple junction in this configuration.

The geological evidence for one configuration or the other is thus not conclusive. However, palaeomagnetic key pole data from Laurentia and Baltica seem to consistently favour a configuration