Reply to JDA Piper on "The making and unmaking of a supercontinent: Rodinia Revisited"

Joseph G. Meert[1] *and Trond H. Torsvik*[2]

[1]University of Florida, Department of Geological Sciences, 274 Williamson Hall, Gainesville, FL 32611 USA e-mail:jmeert@geology.ufl.edu
[2]Academy of Sciences (VISTA), c/o Geodynamics Center, Geological Survey of Norway, Leif Eirikssons vei 39, Trondheim, 7491, Norway

We appreciate the opportunity to discuss the points raised by JDA Piper in his comment on our recent contribution to Tectonophysics (Meert and Torsvik, 2003). We begin by noting several important points neglected by JDA Piper. The first is that our paper focused on paleomagnetic evidence for/against *Rodinia*. Although we mentioned Piper's contributions (Piper, 1976, 2000) briefly in the introduction, we spent no time evaluating the evidence for or against his Paleopangea reconstruction. The bulk of his comment and analysis seem nothing more than an attempt to publish further details of his model and circumvent the normal peer-review process.

Piper seemed drawn to the comment in our introduction briefly describing his early work and the fact that his proposal relied heavily on the uncertainties in the ages and positions of the paleomagnetic poles used to create his Proterozoic supercontinent (Van der Voo and Meert, 1991). He is absolutely correct in stating that the database has blossomed in the 24 years since his original hypothesis, but we also note that these datapoints are not of uniformly high-quality. Thus, we are faced with several options in how we evaluate continental reconstructions. We acknowledged the issues related to pole selection in our introduction:

"*We wish to note, at the outset, that each reconstruction discussed below is based on a particular set of paleomagnetic poles and polarity options. At times, there are not so subtle differences between our choices of poles and those chosen by earlier authors...At the same time, we recognize that the limited dataset creates a host of problems for previous interpretations. Because of the limitations of the paleomagnetic data, we highlight these problems for further consideration rather than attempting to rescue any particular reconstruction*"

Another approach that one can use to evaluate a paleomagnetic dataset that is not of uniform quality is to apply the 'quasi-rigid' premise. In reading through various comments discussing the 'quasi-rigid' premise by Piper (e.g. Piper 1991, 2000), it is obvious that high-quality data are considered equally alongside poor quality data. The argument put forth to support this sort of data selection is that "if conformity to a single path is not evident through all the imperfections of the data, then the case for the model disappears". However, as Van der Voo and Meert (1991) showed, the single paths generated via this method are so tortuous and accommodating, that any pole, good or bad, can be placed somewhere on the path. The 'quasi-rigid' premise is basically stating that if two high quality poles (e.g. well constrained spatially and temporally) indicate that two cratons cannot exist in their proposed configuration, the configuration can be rescued by adding noise (e.g. poorly defined poles) to the dataset. In short, the 'quasi-rigid' premise is nothing more than an exercise that guarantees the success of the model by adding noise into the system until the model becomes acceptable. This is certainly one approach to use in generating reconstructions, but we feel that paleomagnetism and geochronology have matured to the point where we can demand more from our models.

We offer a point by point rebuttal to several other criticisms of our paper offered by Piper:

(1) Piper suggests that we 'correct' our model and change the breakup of Rodinia from 700-800 Ma to 580-560 Ma based on the thermal subsidence studies by Bond et al. (1984). We wish to remind Piper that we discussed the breakup in the context of current *Rodinia* models. We note several problems with the proposed configurations for *Rodinia* and conclude with the observation that the breakup models are controversial. Piper correctly notes that thermal subsidence data by Bond et al. (1984) indicate rifting in W, NW NE and E North America, Australia, South America (Precordillera), Norway, Turkey, Pakistan and Iran during the Cambrian. He then criticizes the Rodinia models for their failure to account for all of these rifted margins. However, Paleopangea fares no better. Piper's model (Figure 1) accounts for a portion of the length of rifted margin along western Laurentia with Siberia as the conjugate. Piper shows no conjugate for the NW margin of Laurentia. Much of the E-NE-margin of Laurentia is without a conjugate in Piper's model along with portions of the eastern coast of Greenland (Figure 1). We acknowledge that the thermal subsidence data needs to be reconciled with paleogeographic models proposed for the Neoproterozoic, but we fail to see any distinct advantage in this regard using the Paleopangea model.

(2) Piper claims that the $^{87}Sr/^{86}Sr$ curve of Veizer (1989) supports his scenario for rifting between 560-580 Ma. A more recent compilation by Walter et al. (2000) concludes that $^{87}Sr/^{86}Sr$ values begin a steady rise (to some of the highest values in Earth history!) starting at 610 Ma (Figure 2a). This rise in the Sr-ratio is usually ascribed to collisional orogenesis during the final stages of Gondwana assembly. Thus, rather than a clear rift signal, the Sr-isotopic data are more compatible with a major interval of Himalyan type continental collision. This accords well with the model presented in Meert and Torsvik (2003). Meert (2003) also discussed the wealth of evidence for major orogenesis in Gondwana during this interval. In contrast, the Paleopangea model proposes a rotation of East Gondwana and all orogenesis is deemed 'ensialic'. Furthermore, we note that the available $^{87}Sr/^{86}Sr$ isotopic data are much lower in the 700-800 Ma interval suggesting a less radiogenic input of strontium (figure 2a). This signal is in agreement with models positing a major rift episode, accompanied by voluminous mafic magmatism, beginning at 800 Ma or slightly earlier. Piper notes; "*any model…which fails to address these key observations, lacks credibility*". We agree with the statement, but disagree

about the model to which the statement applies!

(3) Regarding our pole selection: Piper takes us to task for 'using' a 1236 Ma pole from Africa in our model. A careful inspection of our Figure 5a (and the text) shows that this pole was not used in the analysis other than to show a large gap in the African dataset. Piper also takes us to task for not using the Sveconorwegian dataset in Stearn and Piper (1984). This is not strictly correct as the Bamble mean pole is based (at least in part) on data found in Stearn and Piper (1984). It's true that we did not use all the data, but we have adequately explained our selection criteria and note that our selection of poles is quite similar to that used by Pesonen et al. (2003). Piper also complains about our use of an Indian pole with a Q=1. Apparently Piper did not read our discussion of the Indian poles where we concluded "*Because the data are so poor, no direct comparison to any APWP is attempted* (Meert and Torsvik, 2003; Section 2.6, page 278)".

The remainder of the comment is a re-hash of the Paleopangea model and an argument for why this model better fits the geologic and paleomagnetic data. We conclude by reminding Piper that Paleopangea does not:

(1) Account for the Neoproterozoic rifted margins any better than does the Rodinia model.

(2) Account for the rise in $^{87}Sr/^{86}Sr$ ratios during the late Neoproterozoic or the low ratio during the 800-700 Ma interval whereas Rodinia models do offer a consistent explanation for both observations.

(3) Account for the presence of active margins along the East African orogen including a prolonged period of arc-related magmatism in Madagascar, India, Seychelles and elsewhere (see Meert, 2003; Ashwal et al., 2002).

(4) Account for the sedimentologic, petrographic, structural and geochronological evidence for the Brasiliano ocean between the South American and African cratons.

(5) Survive when more rigid paleomagnetic selection criteria are used. The existence of Paleopangea from a paleomagnetic perspective depends more on noise than on signal. A single example illustrating the failure of Piper's model should suffice. In figure 2b (adapted from Piper, 2004 figure 1a) we show poles from Laurentia, Africa, India and Australia for the interval from ~800-723 Ma. We specifically choose this interval because many of the poles have good spatial and temporal resolution. The Paleopangea model would predict that the poles should show a coherent grouping and also that any apparent polar wander should be of similar magnitude and direction. Clearly, this is not the case. The apparent polar wander path for Laurentia shows limited motion whereas the motion of India and the Congo craton are in nearly opposite directions. Similar age poles fall far from each other (e.g. Mundine dykes, the Mbozi Complex and the Malani paleomagnetic poles). One can find little support in this diagram for Paleopangea even assuming a 'quasi-rigid' model. Certainly, contouring of the pole positions does not help resolve the ambiguities shown in our Figure 2b.

Lastly, we wish to note that our paper was not written in defense of the Rodinia model. It was written in a volume dedicated to the work of Chris Powell. Chris spent many years working on the Rodinia model and testing it against geologic and paleomagnetic observations. We wanted to show the many degrees of freedom allowed by the paleomagnetic and geologic data and highlight these problems for future research. We made this point clear at several places in the manuscript including the abstract and conclusion. We find it difficult to believe that anyone could conclude from our paper that we find the Rodinia model unassailable. We repeat here our goal in writing the paper: "*Our intent in this paper was to highlight the current status of paleomagnetic reconstructions for this time interval and to point out the extremely weak case for the Neoproterozoic supercontinent of Rodinia from those data*".

References Cited

Ashwal, L.D.A., Demaiffe, D, Torsvik, T.H., 2002. Petrogenesis of Neoproterozoic granitoids and related rocks from the Seychelles: evidence for an Andean arc origin, J. Petrol., 43, 45-83.

Bond, G.C., Nickeson, P.A., Kominz, M.A. 1984. Breakup of a supercontinent between 625 and 555 Ma: new evidence and implications for continental histories, Earth Planet. Sci. Lett., 70, 325-345.

Meert, J.G., 2003. A synopsis of events related to the assembly of eastern Gondwana, Tectonophys, 362, 1-40.

Meert, J.G. and Torsvik, T.H., 2003. The making and unmaking of a supercontinent: Rodinia revisited, Tectonophys., 375, 261-288.

Stearn, J.E.F. and Piper, J.D.A., 1984. Paleomagnetism of the Sveconorwegian mobile belt of the Fennoscandian shield, Precam. Res., 23, 210-246.

Pesonen, L.J., Elming, S.A., Mertanen, S., Pisarevsky, S., D'Agrella-Filho, M.S., Meert, J.G., Schmidt, P.W., Abrahamsen, N., Bylund, G., 2003. Paleomagnetic configuration of continents during the Proterozoic, Tectonophys., 375, 289-324.

Piper, J.D.A., 1976. Paleomagnetic evidence for a Proterozoic supercontinent, Philos. Trans. R. Soc. Lond, A280, 469-490.

Piper, J.D.A., 1991. The quasi-rigid premise in plate tectonics, Earth Planet. Sci. Lett., 107, 559-569.

Piper, J.D.A., 2000. The Neoproterozoic supercontinent: Rodinia or Paleopangea?, Earth Planet. Sci. Lett., 59, 61-89.

Piper, J.D.A., 2004. Comment: The making and unmaking of a supercontinent:Rodinia revisited, Tectonophys, this issue.

Van der Voo, R. and Meert, J.G. 1991. Late Proterozoic paleomagnetism and tectonic models: A critical appraisal, Precam. Res., 53, 149-163.

Veizer, J., 1989, Strontium isotopes in seawater through time, Ann. Rev. Earth Planet. Sci., 17, 141-187.

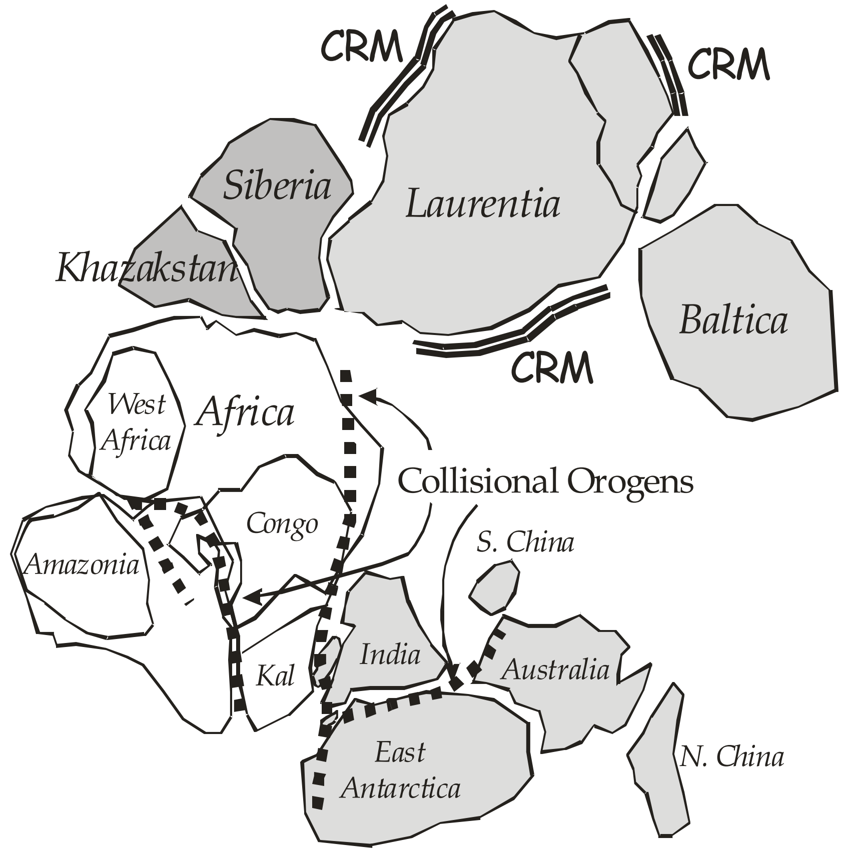
Walter, M.R., Veevers, J.J., Calver, C.R., Gorjan, P. and Hill, A.C., 2000. 840-544 Ma Neoproterozoic interval by isotopes of strontium, carbon and sulfur in seawater and some interpretative models, Precam. Res., 100, 371-433.

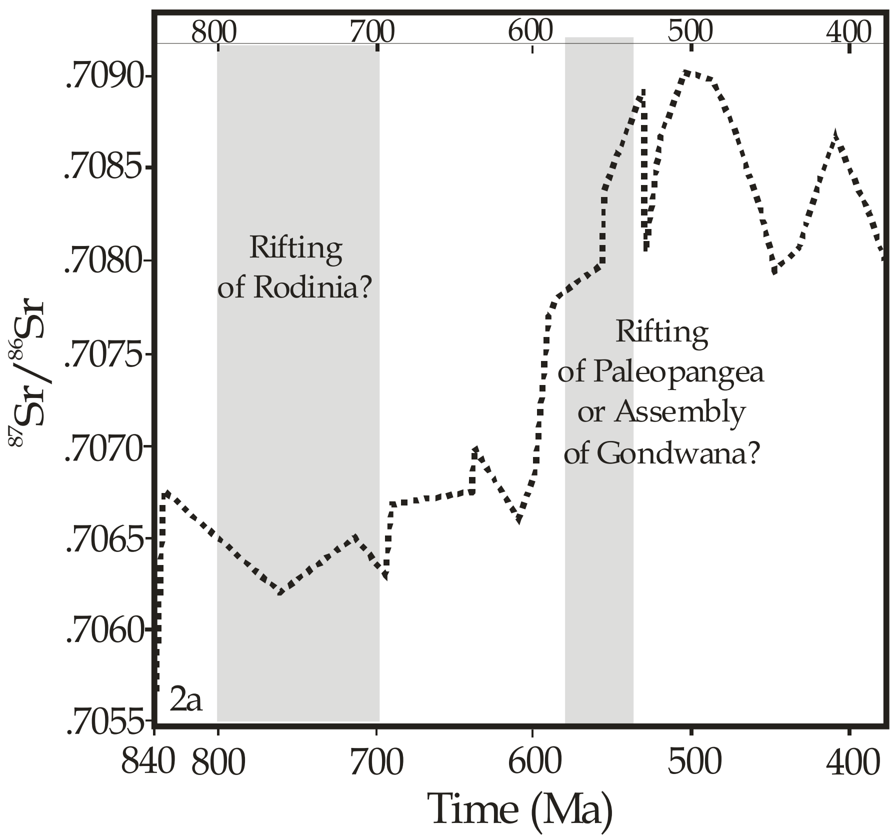
Figure Legends:

Figure 1: Paleopangea based on Piper (2000). We have sketched in the Cambrian rifted margins described in Bond et al. (1984) and elsewhere for which there are no apparent conjugates in the Paleopangea model (CRM's). We also sketched (dotted lines) the approximate locations of Neoproterozoic to Cambrian age collisional orogens we believe are related to arc collisions and the final assembly of Gondwana. In contrast, the Paleopangea model ascribes much of this high-grade metamorphism and deformation to ensialic orogenesis.

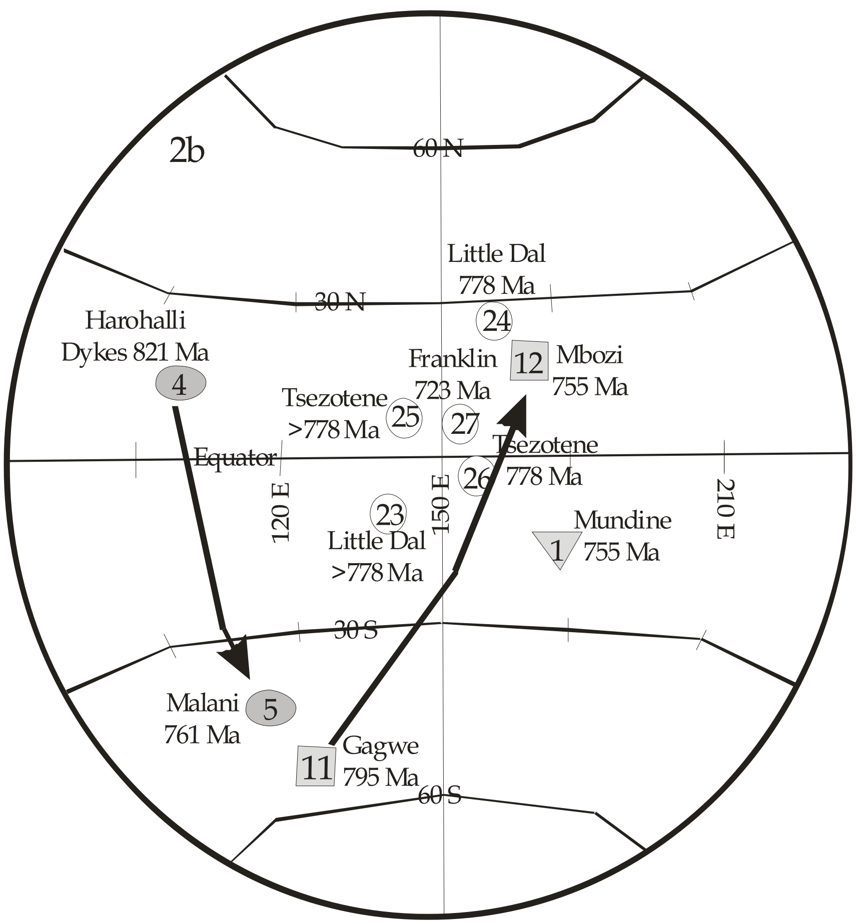
Figure 2: (a) $^{87}Sr/^{86}Sr$ curve for the interval from 840-400 Ma after Walter et al. (2000). Datapoints used to make the curve are unevenly spaced, but the general trend is towards higher ratios at the end of the Neoproterozoic. (b) Modified from Figure 1a of Piper (2004). The legends and numbering are identical to that of Piper (2004). Note the severe discrepancies between poles and their ages and the direction of the APWP's. These observations negate the Paleopangea reconstruction for the interval from 800-700 Ma.

“Paleopangea”





800
700
600
500
400
.7090
.7085
.7080
.7075
.7070
.7065
.7060
.7055
Rifting
of Rodinia?
Rifting
of Paleopangea
or Assembly
of Gondwana?
2a
840
Time (Ma)



2b
60 N
30 N
Equator
30 S
60 S
120 E
150 E
210 E
Little Dal
778 Ma
24
Harohalli
Dykes 821 Ma
4
Franklin
723 Ma
12
Mbozi
755 Ma
Tsezotene
>778 Ma
25
27
Tsezotene
778 Ma
26
23
Little Dal
>778 Ma
Mundine
755 Ma
1
Malani
761 Ma
5
11
Gagwe
795 Ma