What's in a name? The Columbia (Paleopangaea/Nuna) supercontinent

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Abstract

Supercontinents play an important role in Earth's history. The exact definition of what constitutes a supercontinent is difficult to establish. Here the argument is made, using *Pangæa* as a model, that any supercontinent should include ~75% of the preserved continental crust relevant to the time of maximum packing. As an example, *Rodinia* reached maximum packing at about 1.0 Ga and therefore should include 75% of all continental crust older than 1.0 Ga. In attempting to 'name' any supercontinent, there is a clear precedent for models that provide a name along with a testable reconstruction within a reasonable temporal framework. Both *Pangæa* and *Rodinia* are near universally accepted names for the late Paleozoic and Neoproterozoic supercontinent respectively; however, there is a recent push to change the Paleo-Mesoproterozoic supercontinent moniker from "*Columbia*" to "*Nuna*". A careful examination of the "*Nuna*" and "*Columbia*" proposals reveals that although the term "*Nuna*" was published prior to "*Columbia*", the "*Nuna*" proposal is a bit nebulous in terms of the constitution of the giant continent. Details of "*Nuna*" given in the original manuscript appear to be principally based on previously published connections between Laurentia, Baltica and, to a lesser extent the Angara craton of Siberia (i.e. "the lands bordering the northern oceans"). Therefore the proposal is made that "*Columbia*" consists of several core elements one of which is "*Nuna*".

Keywords: Columbia, supercontinent, Pangaea, Rodinia, Nuna

1. *Introduction*

The recognition of continental drift by Wegener (1912) was of fundamental importance in the eventual acceptance of the plate tectonic revolution. One of the key concepts that helped Wegener document his case for continental drift was the idea of a large united landmass consisting of most of the Earth's continental regions. The late Paleozoic supercontinent of *Pangæa* (*cf.* Pangea, Wegener, 1915, 1922) stands alone as the most rigorously defined supercontinent in Earth history although arguments persist as to the exact relationships between the various elements of *Pangæa* (see discussion in Domeir et al., 2011). Wegener (1915) provided the first reconstruction for this supercontinent (Figure 1) that he dubbed "*Urkontinent*" and subsequently (Wegener, 1922) referred to the supercontinent as "*die Pangäa"* (the Pangea). Conversion of the German *Pangäa* to a proper English noun results in a more correct spelling of *Pangæa* (Rance, 2007).

A supercontinent can be simply defined as a quasi-rigid or rigid assembly of most of the Earth's continental landmasses (Hoffman, 1999; Rogers and Santosh, 2004). Defining what constitutes 'most' of the Earth's continental crust is problematic (see Bradley, 2011), but the size of *Pangæa* can serve as basis for comparison as it consisted of between 75-90% of the Earth's continental crust. There are of course problems with defining a simple metric for establishing what does/does not constitute a supercontinent, especially in the Precambrian even using the 'proxy approach' advocated by Bradley (2011). Although it is not critical to the argument presented in this paper, a proposition that 75% of the Earth's preserved crust (of the relevant age) should be present in any reconstructed supercontinent seems reasonable (for example 75% of Archean nuclei should be part of any Archean supercontinent).

2. *Supercontinents in Earth History*

Early hints that older supercontinents existed prior to *Pangæa* were based on 'common' isotopic ages observed in various places around the globe (Gastil, 1960; Runcorn, 1962; Sutton, 1963). Runcorn (1962) proposed 4 phases of 'orogenesis' at 200 Ma, 1000 Ma, 1800 Ma and 2600 Ma. Sutton (1963) suggested seven orogenic cycles of 200-400 Ma duration. Remarkably, a recent compilation by Campbell and Allen (2008) of U-Pb detrital zircon ages almost precisely mimics the 4 phases of orogenesis advocated by Runcorn (1962; Figure 2). In the early to mid-1970's, on the basis of geologic, paleontologic and paleomagnetic data, researchers began to posit the existence and outline possible reconstructions for an older supercontinent that formed around 1.1-1.0 Ga and broke apart during the late Neoproterozoic (Valentine and Moores, 1970, 1972; Burke and Dewey, 1973; Irving et al., 1974; Piper, 1976; Sawkins, 1976). The initial name for this supercontinent was given by Valentine and Moores (1970) as *Pangea-I* and later Sawkins (1976) referred to the supercontinent as "*proto-Pangea*" although no reconstructions were provided in either paper. Piper (1976) referred to his reconstruction as simply 'The Late Proterozoic supercontinent" although he later refers to the Neoproterozoic supercontinent as "*Paleopangaea*" (Piper, 2000; 2007). Bond et al. (1984) also noted that there were significant tracts of rifted margins surrounding Laurentia and proposed a reconstruction for the Neoproterozoic supercontinent, but did not give it a name.

The first to provide a name (*Rodinia*), a temporal framework (Neoproterozoic) and a reconstruction for the supercontinent were McMenamin and McMenamin (1990; Figure 3). The reconstruction provided by McMenamin and McMenamin (1990) was based on earlier reconstructions of McMenamin (1982), Piper (1987), Donovan (1987) and Sears and Price (1978). The name *Rodinia* is derived from the Russian infinitive "*rodit*" that means 'to beget or 'to grow' and was chosen because it was then thought that *Rodinia* gave birth to all subsequent continents and its edges served as loci for the development of complex animals (McMenamin and McMenamin, 1990). Although several seminal papers on the Late Neoproterozoic supercontinent were published in the early 1990's none specifically referred to the supercontinent as *Rodinia* (Moores, 1991; Dalziel, 1991, 1992; Hoffman, 1991). In 1993, two papers appeared in the peer-reviewed literature referring to the Neoproterozoic supercontinent as *Rodinia* (Powell et al., 1993a,b). Since that time, the name *Rodinia* is the dominant name used to refer to a wide variety of Neoproterozoic supercontinental reconstructions (see also Li et al., 2008; Meert and Torsvik, 2003; Weil et al., 1998; Torsvik et al., 1996)

During the late 1980's, Paul Hoffman suggested that the 1.8-1.6 Ga amalgamation of the cratonic elements of Laurentia may have occurred contemporaneously with the formation of an even larger supercontinent (Hoffman, 1988, 1989a,b). Global reconstructions for this hypothetical supercontinent were not shown in those publications although the time frame of its assembly was detailed. Gower et al. (1990) argued for a tight reconstruction of cratonic northern Europe against North America that they called *Nena*. Williams et al. (1991) gave a list of "fictitious" supercontinental names for use in describing the origin of cratonic elements of Laurentia. Three of these fictitious supercontinents can be temporally linked to the 1.8-1.6 Ga interval and include "*Hudsonland*" (1.9-1.8 Ga), "*Central Plainsland*" (1.7 Ga) and "*Labradorland"* (a.k.a *Mazatzaland* at 1.6 Ga). No reconstructions of these fictitious supercontinents were given by Williams et al. (1991) and no specific continental configurations were implied.

Piper (2010) proposed a reconstruction based Archean-Paleoproterozoic supercontinent that he calls "*Protopangaea*". It differs from the other Paleo-Mesoproterozoic supercontinent configurations in that the reconstruction is valid from about 2.7-2.2 Ga. The transition from the *Protopangaea* to a *Paleopangaea* reconstruction consists of minor rotational adjustments among the constituent elements. According to Piper et al. (2011), *Paleopangaea* remained essentially unchanged until its breakup in the Neoproterozoic (see figure 4a,b). If true, it means that *Paleopangaea* remained intact for nearly 1200 million years. It is worth noting that a more appropriate spelling of Piper's supercontinents would be *protoPangæa* and *paleoPangæa* (following the etymology of the term *Pangæa*).

Rogers (1996) showed a reconstruction of "*Arctica*" linking Laurentia and Siberia and argued that Mesoproterozoic collisions brought together *Arctica* with Antarctica and Baltica. Rogers (1996) called this assembly of continental crust "*Nena*" after Gower et al. (Figure 5a; 1990). Although, Baltica, Siberia, Laurentia and Antarctica make up a large percentage of the preserved continental crust of Mesoproterozoic and older ages, large tracts of continental crust are not included the model (i.e. the West Gondwana cratons, India, Australia and the smaller cratonic elements now incorporated into Asia) such that *Nena* (*sensu* Rogers, 1996) is not a supercontinent.

Hoffman (1997) published a short chapter in a structural geology textbook in which he discussed the progressive welding of cratonic nuclei into the core of North America. In that paper (1st edition; reference figure 19.9.1), the Proterozoic core of Laurentia is referred to as "*Nuna*" (eskimo name for lands bordering the northern oceans). The paper then continues to give multiple definitions of *Nuna* first by including Baltica as a continuation of the Proterozoic core. That configuration is essentially no different from *Nena* as proposed by Gower et al. (1990) and thus the *Nena* moniker would have precedence over *Nuna* for the Baltica-Laurentia Paleoproterozoic connection (figure 5b).

Hoffman later describes *Nuna* as consisting of Laurentia, Baltica and, more speculatively, the Angara craton (Siberia) along with northern and western Australia. Lastly, *Nuna* is mentioned as one of five giant continents. Hoffman (1997) provided no testable reconstruction for *Nuna* (other than previously published connections between Baltica and Laurentia), but conceptually it appears to differ little from the published reconstructions of *Nena* (*sensu* Gower et al., 1990 and Rogers, 1996; figures 5a,b). The argument made here is that the name *Nuna* has no precedence in the literature insofar as it mimics the aforementioned earlier proposals. It seems more reasonable to retain the name *Nena* as a core assembly of Baltica and Laurentia. *Nuna* would be apropos for the combination of Siberia, Baltica and Laurentia as the name would then properly honor "*the lands bordering the northern oceans*" and more closely follow the loosely defined connections given by Hoffman (1997). *Nuna* would then be one of the core elements in *Columbia* (see dashed outlines in figures 6a,b).

Rogers and Santosh (2002) produced the first tentative global reconstruction of a Paleo-Mesoproterozoic supercontinent that they named "*Columbia*" (figure 6a,b,c see also Meert, 2002). The name for the supercontinent was derived from a proposed connection between eastern India and the Columbia region of North America (NW Laurentia). Their paper marks the first attempt to provide a name, a temporal framework and a testable reconstruction for the supercontinent that preceded *Rodinia* (see also Meert, 2002; Sears and Price, 2002; Rao and Reddy, 2002). In the same volume Meert (2002) published a set of euler rotation poles for the *Columbi*a supercontinent and discussed an initial paleomagnetic test of the proposed configuration. At the same time, Zhao et al. (2002)

proposed that the assembly of this pre-*Rodinia* supercontinent was completed by global-scale collisional events during 2.1–1.8 Ga.

G. Zhao (personal communication) provided an interesting historical perspective on the naming of the supercontinent. It turns out that Zhao and colleagues had submitted a paper to Earth Science Reviews in which they referred to the supercontinent as "*Hudson*". The paper had a difficult time during the review process, but ultimately the publications from the Gondwana Research (2002) volume allowed the ESR paper to move forward. Zhao et al. (2002) changed *Hudson* to *Columbia* after the Rogers and Santosh (2002) paper was published ahead of their own contribution. Subsequent works detailed geological linkages between the various cratonic elements of the proposed Paleo-Mesoproterozoic supercontinent of *Columbia* (in particular see the compilations by Zhao et al., 2002, 2003, 2004, 2011; Pesonen et al., 2003; Betts et al., 2011; Kusky, 2011; Yakubchuk, 2010; Goldberg, 2010, Cordani et al., 2009; Rogers and Santosh, 2009; Zhai and Santosh, 2011; Meert et al., 2011; Pradhan et al., in press).

Both *Rodinia* and *Pangæa* are widely accepted terms for the Neoproterozoic and Paleozoic supercontinents, but there is some recent debate regarding the name of the Paleoproterozoic-Mesoproterozoic supercontinent with "*Nuna*", "*Columbia*" and "*Protopangaea*" appearing in the literature (Reddy and Evans, 2009). In particular, *Nuna* has worked its way into the literature by making the argument that the name appeared in print prior to *Columbia*. There are several reasons why *Columbia* should be preferred ahead of other choices and why *Columbia* is more commonly cited in the literature. (1) All previously adopted names of supercontinents (or large landmasses) appeared in the literature with a suggested name, a temporal framework and a testable reconstruction.

These supercontinents include *Pangæa* (alt. Pangea/Pangaea, Wegener, 1915)*, Gondwanaland* (alt. Gondwana, Suess, 1904)*, Laurasia* (du Toit, 1937) and *Rodinia* (McMenamin and McMenamin, 1990). A testable reconstruction is important as it conveys specific information about the geometry of the supercontinent. Any reconstruction should be reasonably detailed based on the information available, but should also be flexible as there are constant refinements to the models even for the more recent supercontinents of *Pangæa* (see Domeir et al., 2011 for a review) and *Rodinia* (see Torsvik et al., 1996; Weil et al., 1998; Meert and Torsvik, 2003; Li et al., 2008; Evans, 2009). The temporal framework for the amalgamation and breakup of the supercontinent should also be reasonably approximated. (2) The *Nena* (*sensu* Gower et al., 1990) and *Nuna* (Hoffman, 1997) published reconstructions are essentially identical and thus *Nena* has precedence over *Nuna* when referring to the Proterozoic connections between Baltica and Laurentia (3) The name *Nena* (*sensu* Rogers, 1996) was also used for a larger landmass consisting of Baltica, Siberia, Laurentia and Antarctica and is therefore nearly identical to the hypothetical *Nuna* later proposed by Hoffman (1997) that consisted of Baltica, Laurentia, the Angara craton (Siberia) and perhaps parts of Australia (and unnamed extensions).

Based on the history of providing *both a name* and a *testable reconstruction* in a temporal framework, we argue that *Columbia* should be preferentially adopted as the name for the late Paleoproterozoic-Mesoproterozoic supercontinent (Rogers and Santosh, 2002). While the term *Nuna* appeared in a textbook insert prior to *Columbia*, no testable global reconstruction was provided other than previously noted connections between Baltica and Laurentia (*Nena sensu* Gower et al., 1990). Although possible links with Siberia and Australia were mentioned by Hoffman (1997), this represents only a slight modification of the earlier published *Nena* model (*sensu* Rogers, 1996). Other Paleo-Mesoproterozoic supercontinental names including *Hudsonland*, *Central Plainsland* and *Labradorland* (Williams et al., 1991) were proposed as *fictitious* parental supercontinents that gave birth to specific regions within Laurentia and should be dropped from the literature as formal names. We also reject the term *Protopangaea* on the grounds that it was first used as a name for the Neoproterozoic supercontinent (Sawkins, 1976) and secondly because *Columbia* has precedence in the literature.

3. *The Supercontinent Cycle*

Accepting the premise that supercontinents in any particular configuration amalgamated around 1.8, 1.1 and 0.30 Ga (*Columbia*, *Rodinia* and *Pangæa*), we can conjecture that there may be other supercontinents during Earth history (Bradley, 2011; Reddy and Evans, 2009; Santosh et al., 2009; Meert and Tamrat, 2003). If we further define a supercontinent as a rigid (or quasi-rigid) assembly of most (>75%) of the Earth's continental blocks, then the smaller (but still extensive) continents of *Gondwana* and *Laurasia* cannot factor into the calculation of supercontinent cyclicity. Campbell and Allen (2008) use detrital zircon age peaks as a proxy for constraining the ages of previous supercontinental assemblies (see figure 2; Hawkesworth et al., 2010). *Columbia*, *Rodinia* and *Pangæa* are clearly defined in the age spectra as are hints of either a late Archean supercontinent (labeled *Superia*/*Sclavia* in their diagram). Hawkesworth et al. (2010) also discuss the possibility that the ~2.7 Ga peak more accurately reflects development of new continental crust with or without a supercontinent. There is also an important peak in the detrital zircon population at about 0.5 Ga that correlates well with the assembly of the very large *Gondwana* continent (Meert and Lieberman, 2008; Meert, 2003). Hartnady (1991) and Dalziel (1997) proposed a short-lived supercontinent called *Ur-Gondwana* or *Pannotia* during the Ediacaran time frame; however paleogeography for that particular interval of time is highly contentious (see discussions in Meert et al., 2007; Meert and Lieberman, 2004). The time separation between *Columbia* assembly (~1.8 Ga), *Rodinia* assembly (~1.1 Ga) and *Pangæa* assembly (~0.3 Ga) averages to a 750 million year supercontinental 'cycle' between the assembly phases. A late Archean supercontinent at ~2.5-2.6 Ga would fit in this cycle and a future supercontinent might be predicted in another 400-500 million years.

A complete supercontinental cycle should include not only time of formation, but also the length of time the supercontinent remained in a quasi-rigid or rigid configuration. This is a more difficult number to evaluate as it appears that *Rodinia* was particularly long-lived (~400 Ma) whereas *Pangaea* was relatively short-lived (~120 Ma; Guttierez-Alonso et al., 2008) and details on the duration of *Columbia* have yet to be reliably established.

4. Conclusions

There are at least three periods in Earth history during which most (>75%) of the Earth's continental crust were assembled in a rigid (or quasi-rigid) supercontinent. These three supercontinents are named *Columbia* (Rogers and Santosh, 2002), *Rodinia* (McMenamin and McMenamin, 1990) and *Pangaea* (Wegener, 1912, 1915). In addition, there are other Phanerozoic 'named' large continental landmasses such as *Gondwana* and *Laurasia* along with a more tenuous Neoproterozoic *Pannotia* (*Ur-Gondwanaland*). Each of the 'named' supercontinents or large continents was published in a temporal framework with a testable reconstruction. Although the names *Nuna* and *Paleopangea* have been used synonymously with *Columbia*, the *Nuna* configuration is essentially no different from two earlier *Nena* reconstructions (*sensu* Gower et al., 1990 and Rogers, 1996) and *Paleopangaea* has no precedence. The maximum packing of the three supercontinents occurred at ~1.8, 1.0 and .3 Ga indicating an approximate 750 Ma interval between supercontinental assembly.

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Figure Legends

Figure 1: The supercontinent *Pangæa* during the Late Paleozoic (~260 Ma). The supercontinent was composed of two large halves (Gondwana in the south and Laurasia in the north). The 'pac-man' shaped Paleotethyan ocean was located to the west of the supercontinent and separated from the larger Panthalassan ocean by the North China (NCB) and South China (SCB) blocks. Approximate locations of the strong zonal climatic zones are also shown in the figure. The locations of the Appalachian, Caledonian and Uralian Mountains are shown within Laurasia. AI=Armorica, Avalonia and Iberia.

Figure 2: Detrital zircon spectra as given in Hawkesworth et al. (2010) in comparison with those in Runcorn (1962). The key supercontinents apparent in the spectra include *Columbia*, *Rodinia* and *Pangæa.* Other peaks may reflect an earlier amalgam of Archaean nuclei and *Gondwana/Ur-Gondwanaland/Pannotia* in the latest Neoproterozoic.

Figure 3: Rodinia according to McMenamin and McMenamin (1990). The reconstruction is based on a Siberia fit proposed by Sears and Price (1978) with Kazakhstania positioned off present-day SW Laurentia. Baltica is fit close to Bullard (1965) and just north of Australia. Gondwana was treated as a single landmass.

Figure 4: (a) Paleoproterozoic *Paleopangaea* according to Piper et al. (2011) and (b) Neoproterozoic *Paleopangaea* according to Piper (2000). CRM= Cambrian rifted margins for which there appear to be no conjugates.

Figure 5: (a) The "*Nena*" *sensu* Rogers (1996) configuration including Siberia and the Laurentian nuclei (*Arctica* of Rogers, 1996) coupled to Baltica and Antarctica. (b) The "Nuna" configuration of Hoffman (1997) with a tight fit between Baltica and Laurentia. This is equivalent to Gower et al.'s (1990) "*Nena*" reconstruction.

Figure 6: (a) Archetypal "*Columbia*" fit of Rogers and Santosh (2002). The reconstruction was an attempt to show the approximate relationship between the various elements comprising the supercontinent without taking into account a specific map projection such that the continents are distorted. The dashed outline shows the "*Nuna*" core within the Columbia supercontinent (b) A simplified image of the "*Columbia*" supercontinent according to Zhao et al. (2004) and (c) "Columbia" at 1.5 Ga using slightly modified rotation parameters (Laurentia fixed) originally given in Meert (2002) to approximate the Rogers and Santosh (2002) archetypal fit. Laurentia, along with all the other elements are then rotated according to the ~1.5 Ga St. Francois mountains pole of Meert and Stuckey (2002).

Figure 1
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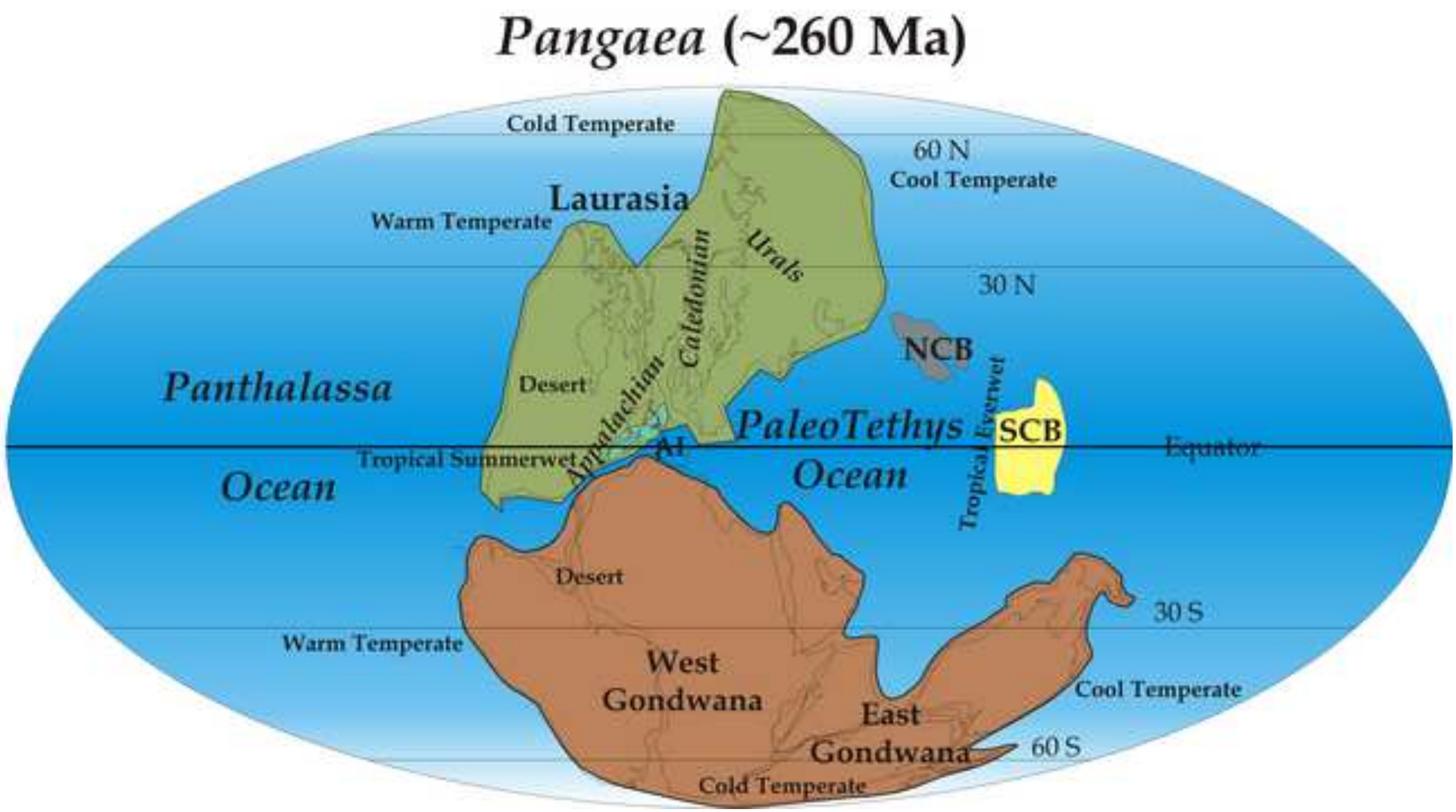

Figure2
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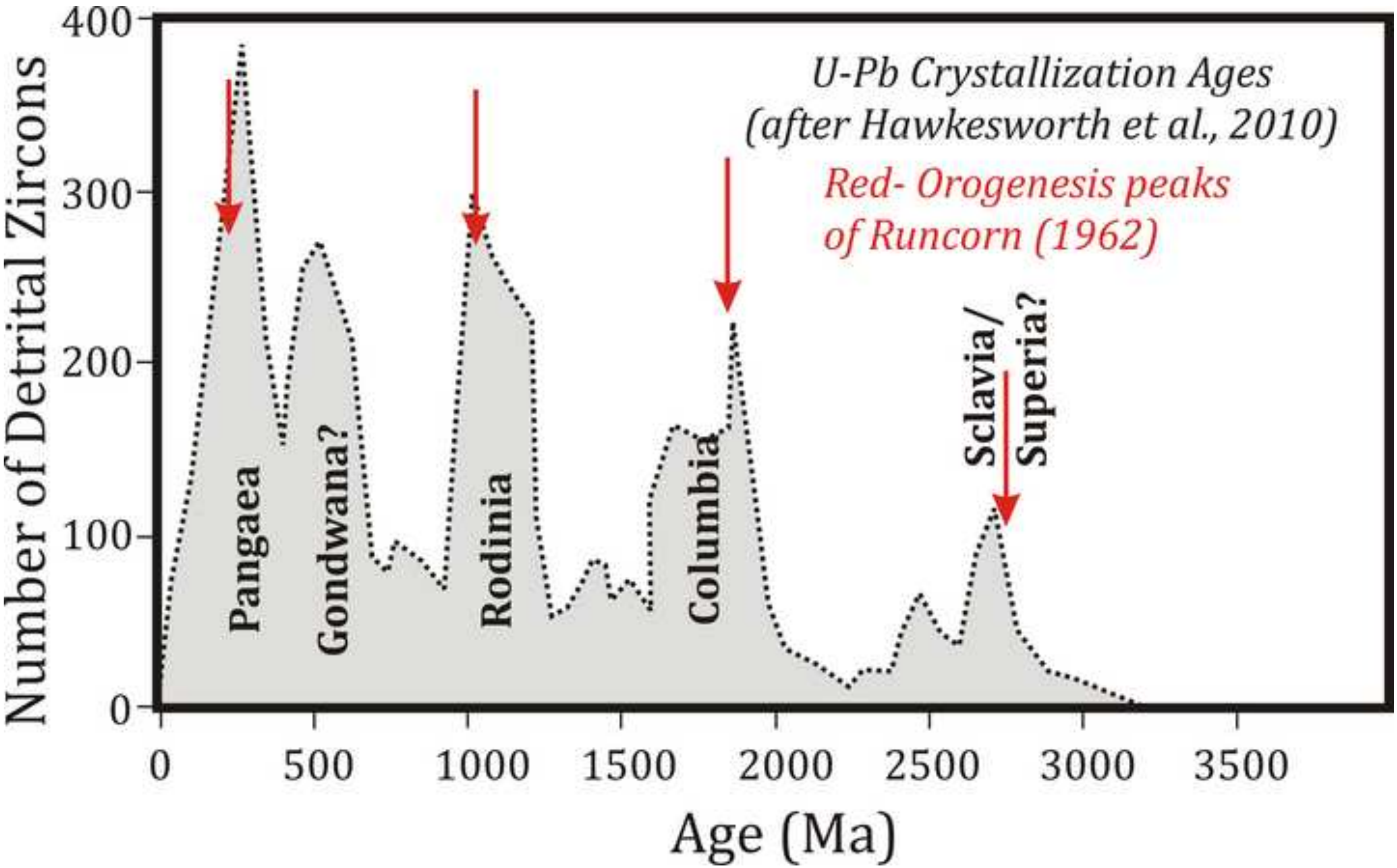
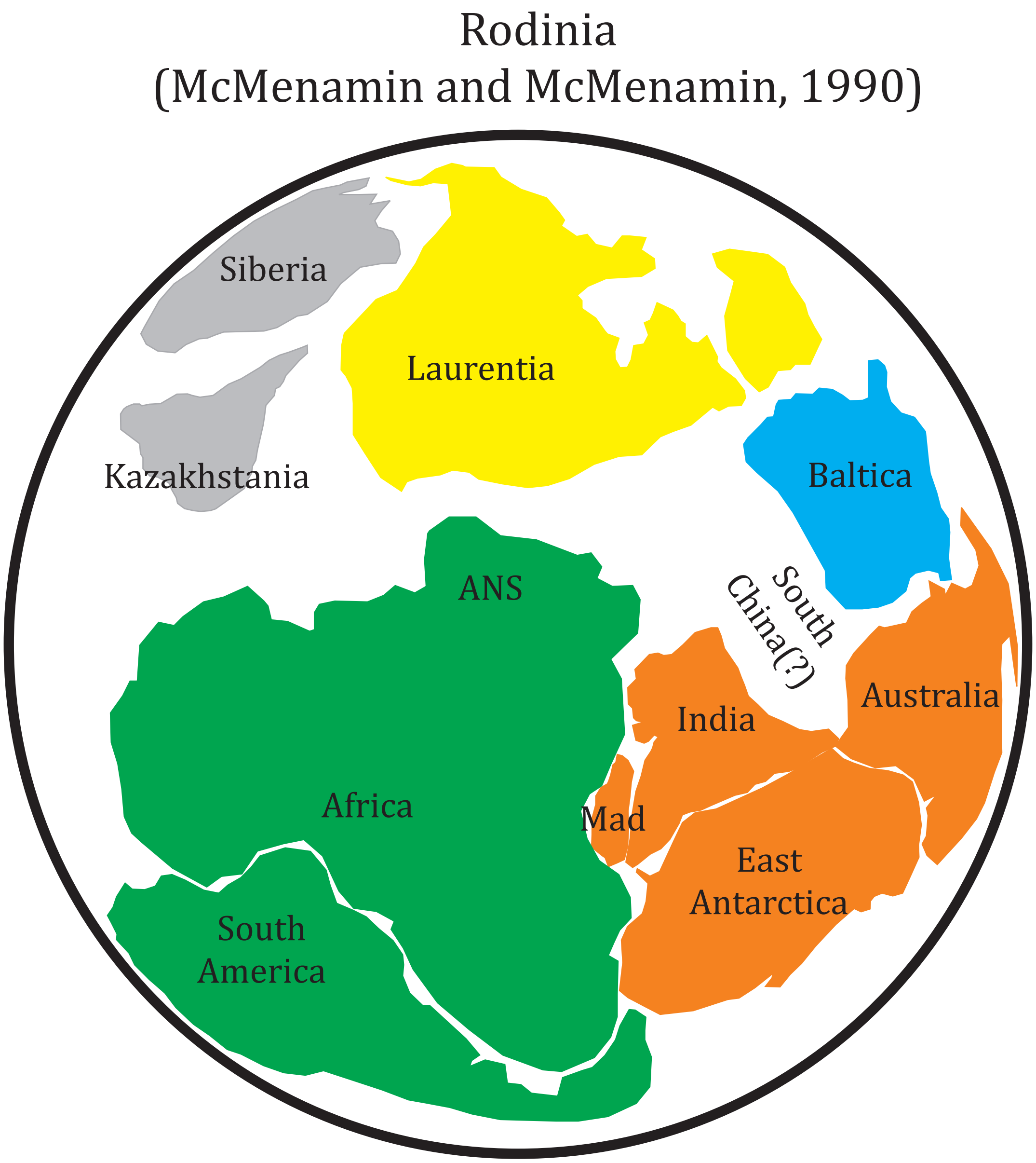


Figure3



Rodinia
(McMenamin and McMenamin, 1990)
Siberia
Laurentia
Kazakhstania
Baltica
ANS
South
China(?)
Australia
India
Africa
Mad
East
Antarctica
South
America

Figure4

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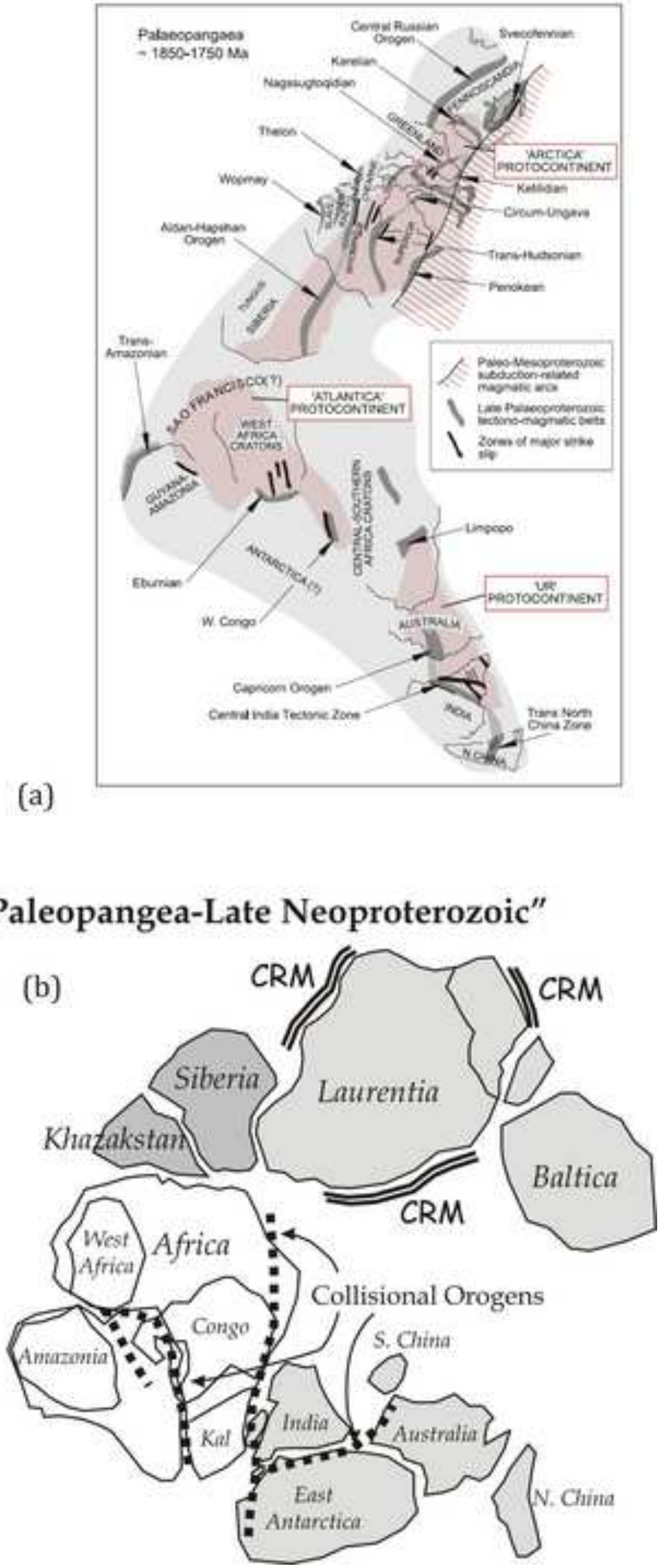

Figure5

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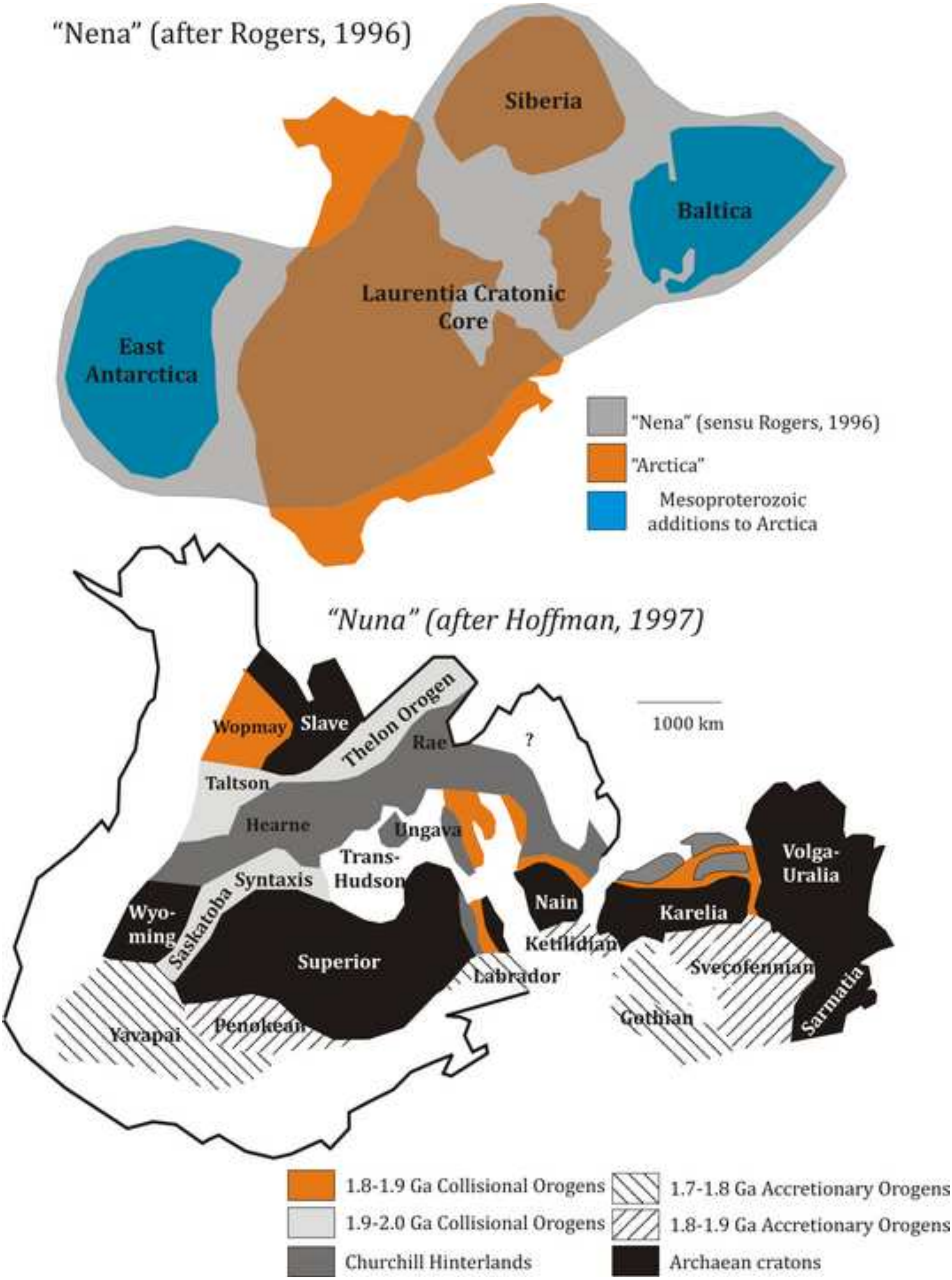

Figure6
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