The Supercontinent Cycle and the Proxy Case for Pannotia

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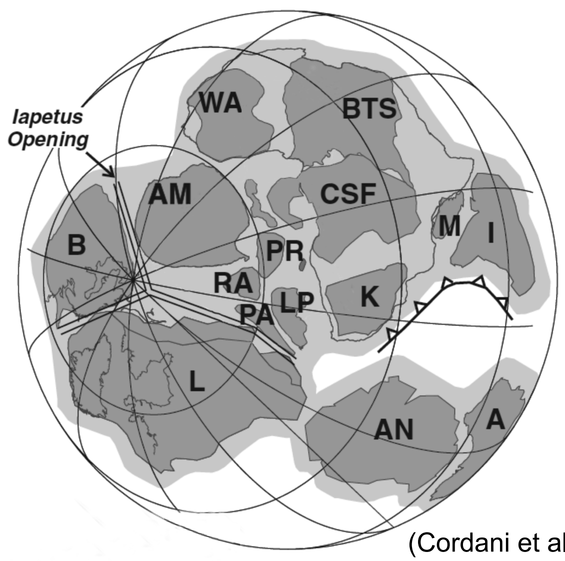
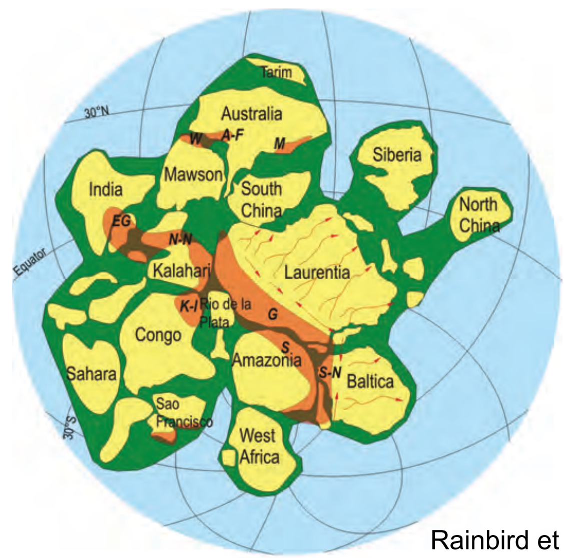
Pannotia
ca. 590 Ma



(Cordani et al. 2003)

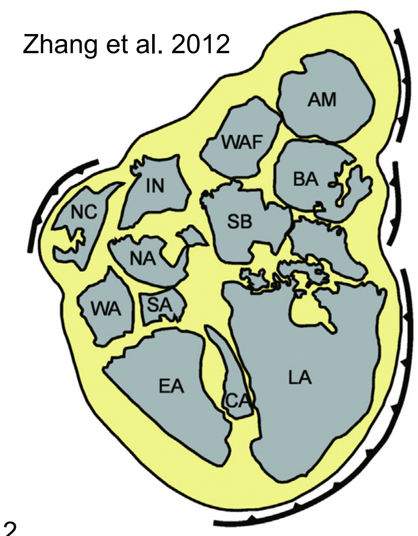
Rodinia
(ca. 900 Ma)



Rainbird et al. 2012

Columbia (Nuna)
(ca. 1.7-1.5 Ga)

Zhang et al. 2012



Origin of Debate

Comes from the two sources upon which the existence of past supercontinents usually hinge

1. Paleomagnetic Data

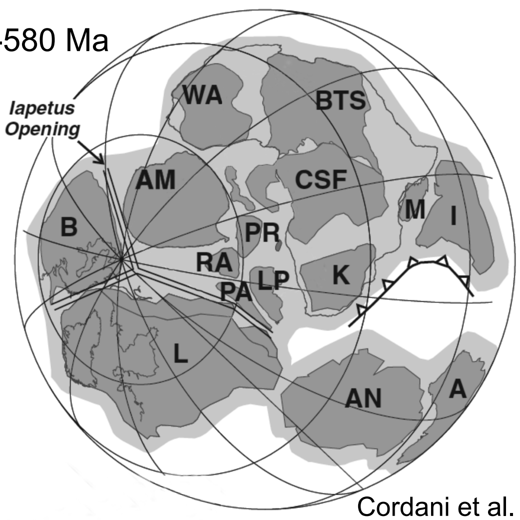
- Permissive of an Ediacaran supercontinent but by no means conclusive

2. Absolute Age Constraints

- Suggest breakup was well underway before the supercontinent was fully assembled

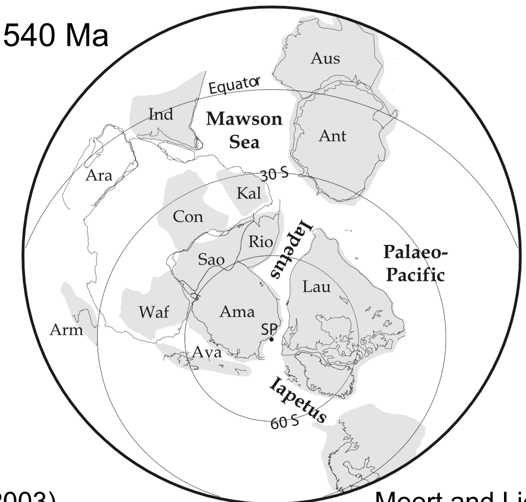
Paleomagnetic Data

600-580 Ma



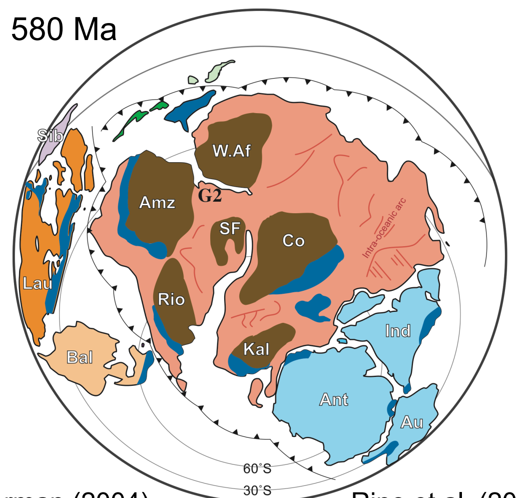
Cordani et al. (2003)

540 Ma



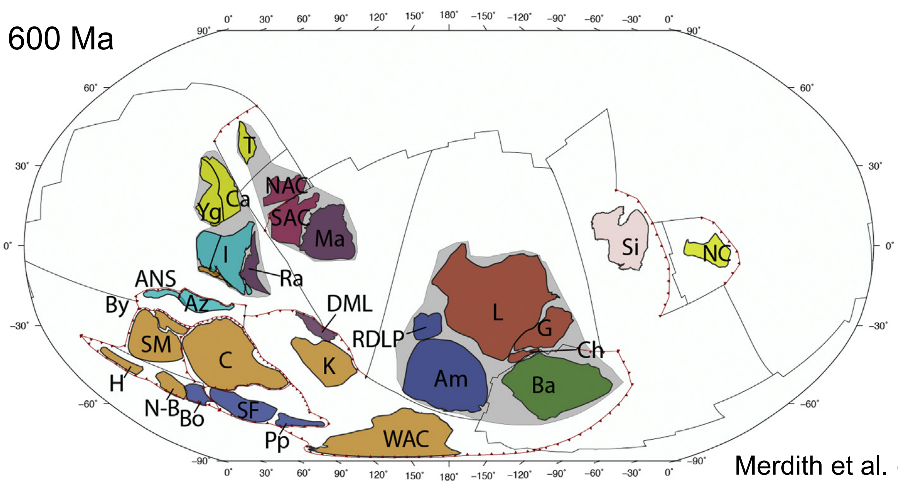
Meert and Lieberman (2004)

580 Ma



Rino et al. (2008)

600 Ma



Merdith et al. (2017)

- Some reconstructions broadly supportive of Pannotia, others are more equivocal

Data for Ediacaran sufficiently uncertain that Pannotia cannot be verified paleogeographically

Absolute Age Constraints

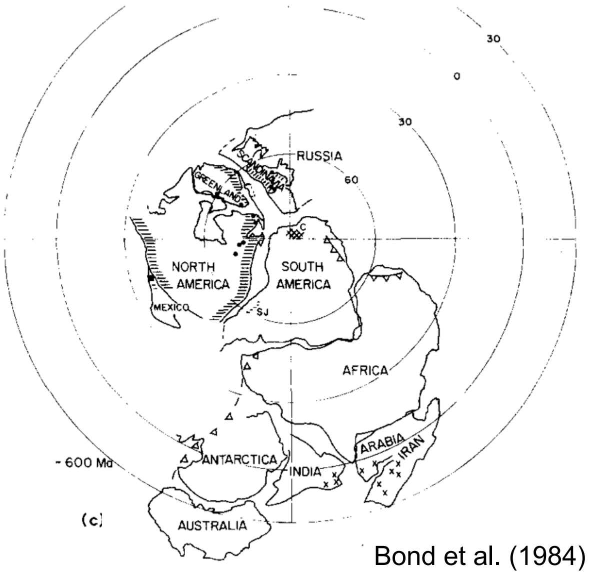
1. Timing of Orogenesis

- Timing of Pan African-age orogenesis, though to have been responsible for the assembly of Pannotia, spans the interval ca. 650-550 Ma based on age of orogenic magmatism, collisional metamorphism and detrital zircon and monazite in modern African rivers

2. Timing of Breakup

- Time span entirely encompasses 625-555 Ma breakup interval documented by Bond et al. (1984) on basis of tectonic subsidence curves for early Paleozoic passive margins in North and South America, Australia and Middle East

Pannotia ephemeral if it existed at all



Bond et al. (1984)

Caveats

age data is not as damning as it might appear

1. Timing of Orogenesis

- Timing of continental collision, and hence supercontinent amalgamation, is recorded by the onset of collisional orogenesis rather than its termination
- Bulk of Pannotia was likely assembled by ca. 620 Ma

2. Timing of Breakup

- Changes to time scale since Bond et al. (1984) revise breakup interval to 605-520 Ma
- Revised timing permissive of a short-lived supercontinent at ca. 620-580 Ma.

Supercontinent Proxies

- Within context of the supercontinent cycle, supercontinents mark the end of one cycle and the beginning of next and their recognition can be taken beyond paleomagnetic reconstructions to include a wide variety of proxies

- Proxies for supercontinent assembly and breakup include:

    - Global-scale orogeny and granitoid magmatism
    - Detrital zircon and monazite peaks
    - Ultrahigh P and ultrahigh T metamorphism
    - Major changes in climate, atmospheric composition, ocean chemistry and sea level
    - Major extinctions and biotic radiations
    - Reversals in crustal recycling
    - Widespread continental rifting, mafic dike swarms and LIPs
    - Extensive passive margin development

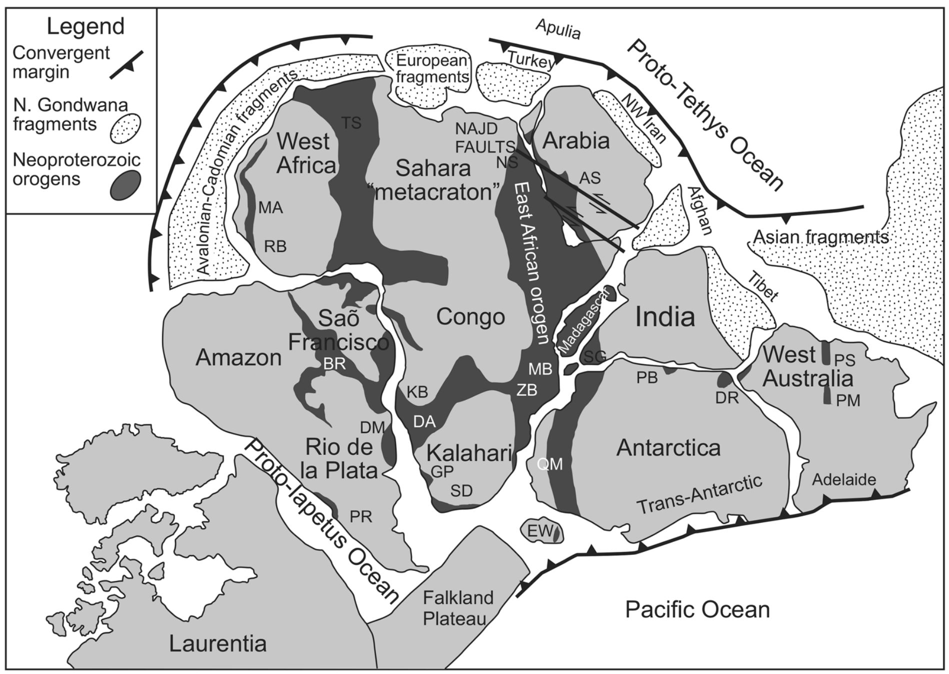
- Applied to the Ediacaran, proxy signals for Pannotia are unmistakable

Pannotia Assembly

Proxy = Global Orogeny

Since supercontinent assembly requires continents to collide an obvious proxy for their amalgamation is world-wide orogeny.

- For Pannotia, the orogeny was one of the largest in Earth history – the Pan African-Cadomian-Baikalian (Timanide), collisional belts of which date to 650-550 Ma



Murphy et al. (2018)

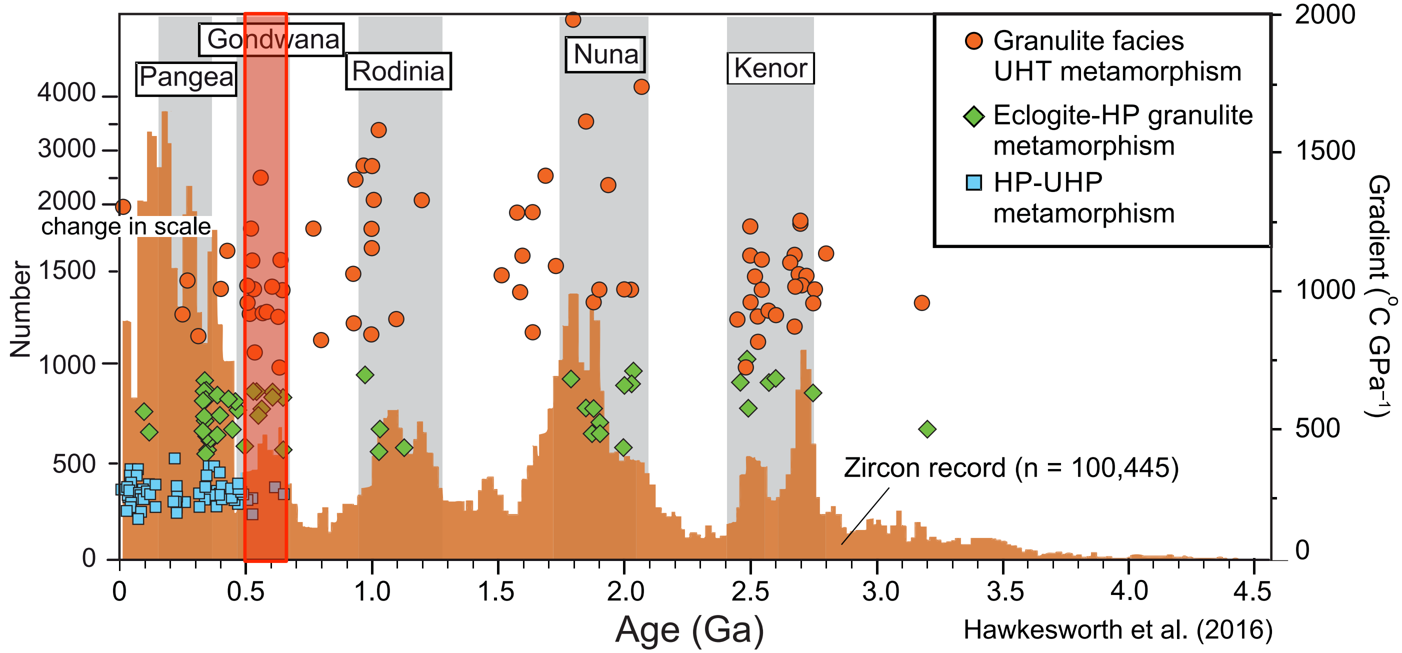
Pannotia Assembly

Proxy = Zircon Age Distribution and Extreme Metamorphism

Amalgamation coincides with peaks in detrital zircon/monazite ages – document increased continental arc activity and granitoid magmatism

Widespread extreme (ultrahigh P/ultrahigh T) metamorphism

- All are hallmarks of the Ediacaran

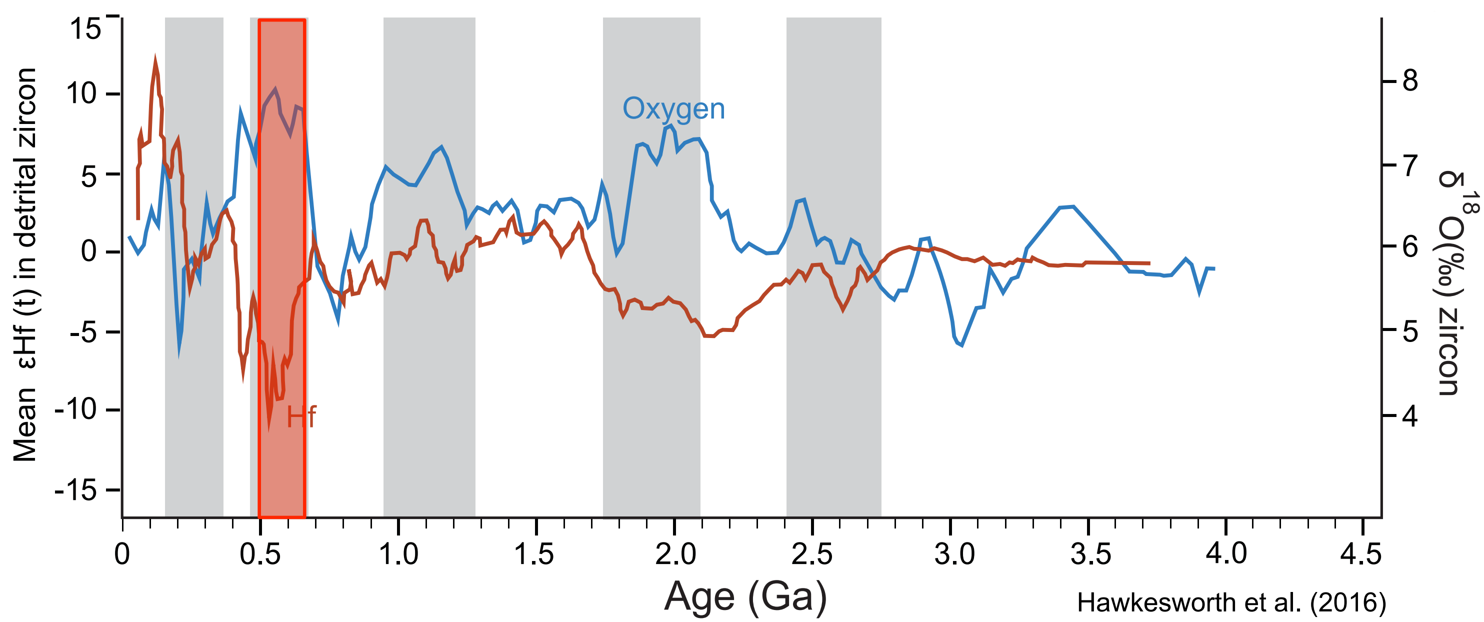


Pannotia Assembly

Proxy = Geochemical Trends

Amalgamation may also correspond to negative εHf values in zircons (indicating enhanced crustal recycling) and elevated $\delta^{18}O$ values (indicating reworking of sedimentary material)

- Especially true of the Ediacaran – consistent with continental collision and crustal thickening of supercontinent assembly



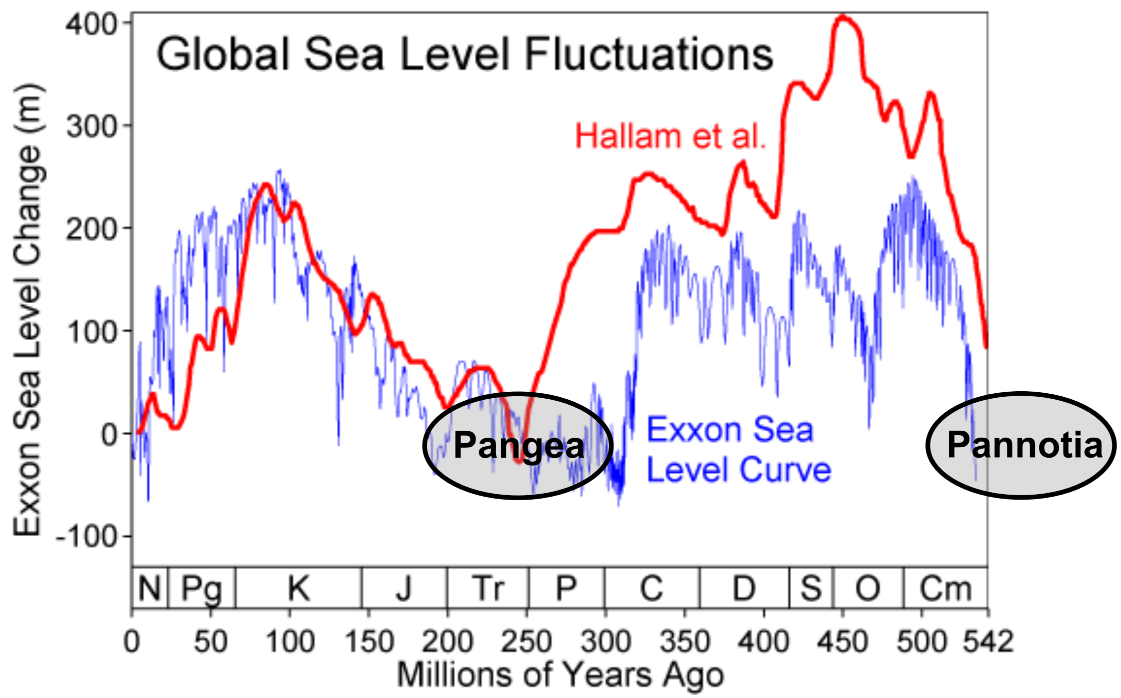
Hawkesworth et al. (2016)

Pannotia Assembly

Proxy = Sea Level

Supercontinents correspond to periods of very low global sea level – their epeirogenic uplift likely a consequence of continental insulation (traps mantle heat) and the formation of a slab graveyard (fosters mantle upwelling)

- True for Pangea and also the case for the Ediacaran

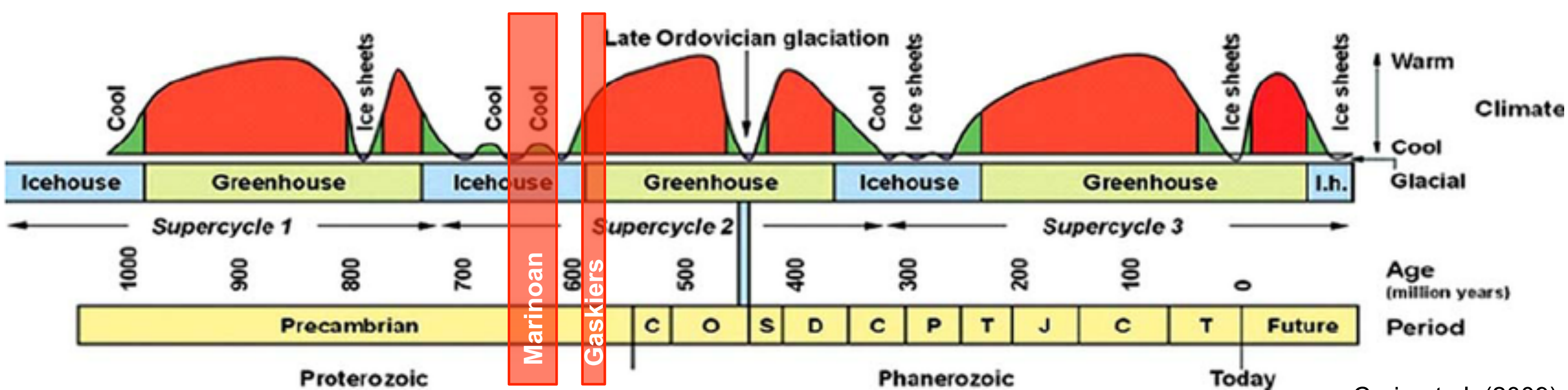


Pannotia Assembly

Proxy = Climate Change

Amalgamation often coincides with climatic deterioration due to drawdown of atmospheric CO_2 through enhanced chemical weathering of orogens of supercontinent assembly and an epeirogenically uplifted supercontinent

- Ediacaran changes to environment among most profound in Earth history
- Two major glaciations, the Marinoan (>639-635 Ma) and the Gaskiers (ca. 580 Ma) coincide with assembly of Pannotia and onset of its rifting



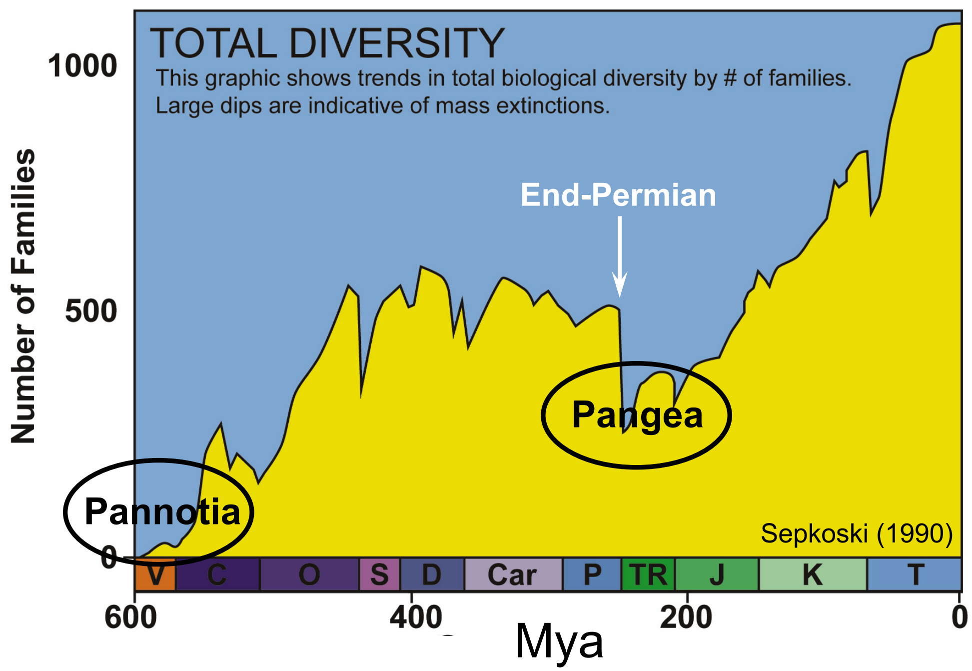
Craig et al. (2009)

Pannotia Assembly

Proxy = Extinctions

Amalgamation also tends to coincide with major extinctions, in part as a consequence of low sea level and the loss of shallow marine habitat

- True for Pangea and also the case for the Ediacaran, which witnessed a decline in stromatolites and extinctions among acritarchs and palynoflora

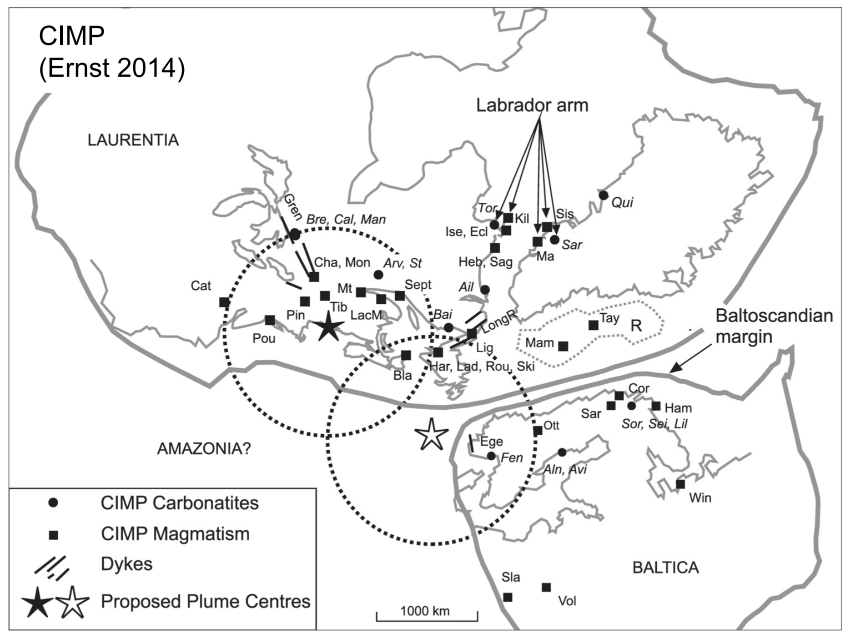


Pannotia Breakup

Mafic Dike Swarms and LIPs

Since supercontinent breakup requires continents to rift an obvious proxy lies in evidence for mafic dike swarms and LIPs

- For Pannotia, widespread continental rifting at 620-530 Ma is documented by mafic dyke swarms (notably in Laurentia and Baltica) and by the Central Iapetus Magmatic Province (615-530 Ma) and Wichita LIP (540-530 Ma)

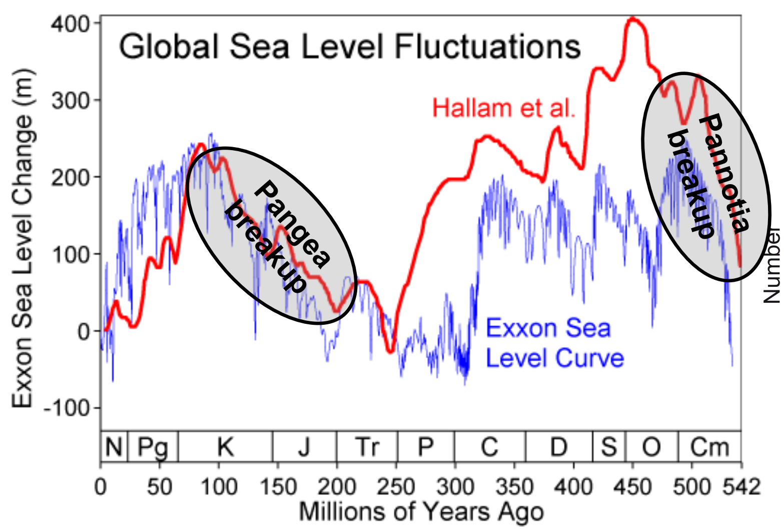


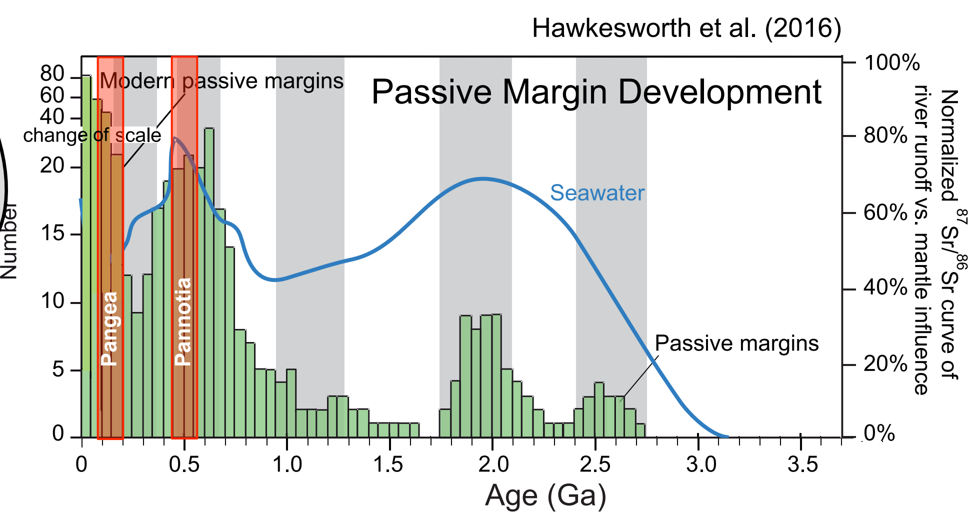
Pannotia Breakup

Sea Level

Supercontinent breakup coincides with onset of major rise in global sea level and accompanying passive margin development in response to thermal subsidence of dispersing continental fragments coupled with increased ridge volume due to opening of new ocean basins (e.g. Iapetus)

- True of Pangea in Mesozoic and also for Pannotia in early Paleozoic



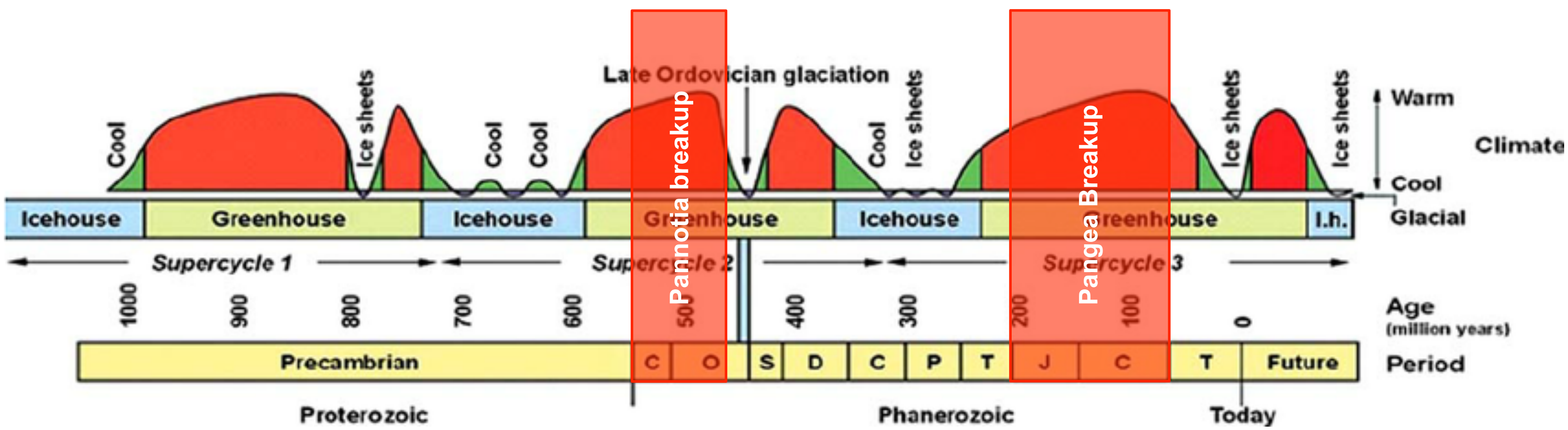


Pannotia Breakup

Proxy = Climate Change

Breakup tends to coincide with climatic warming due to a progressive buildup of atmospheric CO_2 in response to decreased continental weathering with sea level rise and consequent continental flooding

- Just as Mesozoic (following Pangea breakup) was a period of greenhouse climate, so too was the Early Paleozoic (following Pannotia breakup)



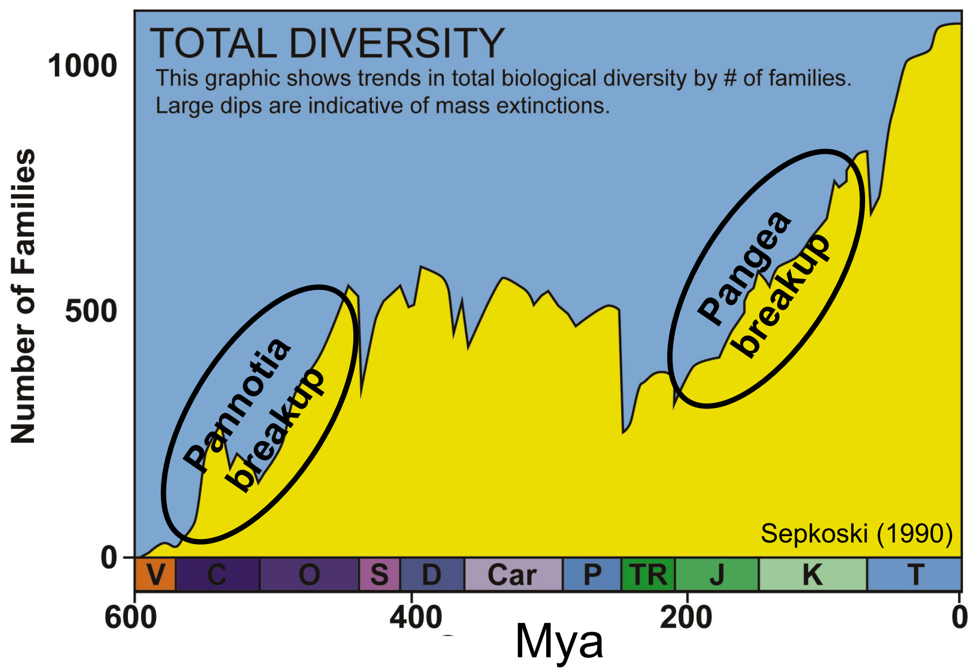
Craig et al. (2009)

Pannotia Breakup

Proxy = Evolutionary Radiation

Breakup also coincides with major evolutionary radiation, in part as a consequence of rising sea level and creation of new shallow marine habitat

- True for Pangea in the Mesozoic and also the case for Pannotia – breakup followed by Cambrian explosion (appearance of most major animal phyla)

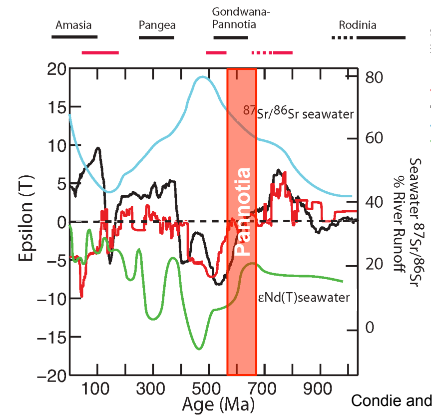


Pannotia Breakup

Geochemical Proxies

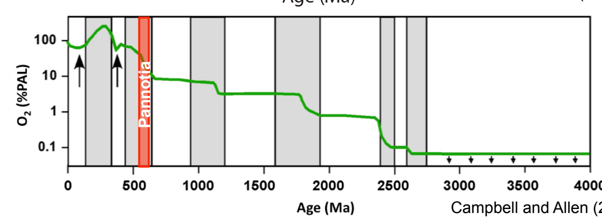
Pannotia breakup accompanied by a variety of geochemical proxies:

- Abrupt rise in the sea water $^{87}Sr/^{86}Sr$ ratio (and negative εNd excursion), suggesting erosional release to oceans of radiogenic strontium from weathering of uplifted supercontinent



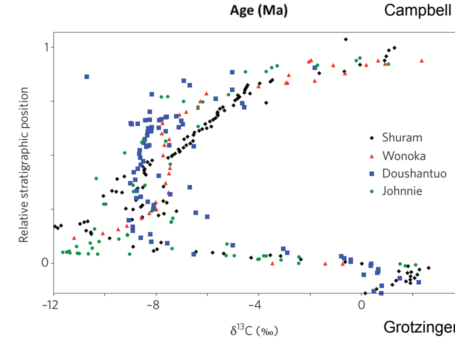
Condie and Aster (2013)

- Sharp rise in atmospheric O_2 levels, possibly due to enhanced marine productivity resulting from an increase in the erosional release of nutrients



Campbell and Allen (2008)

- Largest negative $\delta^{13}C$ anomaly in Earth history (Shuram at 560-550 Ma), suggesting even larger reorganization of Earth's carbon cycle than that which accompanied recovery from end-Permian extinction following amalgamation of Pangea



Grotzinger et al. (2011)

Conclusions

Ediacaran proxies for the amalgamation and breakup of a supercontinent are unmistakable and collectively provide strong support for existence of Pannotia

Ramifications:

- Breakup of Rodinia was not followed by the assembly of Pangea but by the assembly of Pannotia and Iapetus was a consequence of Pannotia breakup not the tail end of Rodinia breakup

- It was Pannotia, not Gondwana, that was formed by Pan African orogenesis and Gondwana only came into existence with the breakup of Pannotia at the dawn of the Paleozoic

- Gondwana was never a supercontinent in the context of the supercontinent cycle because it formed as a consequence of breakup, not assembly, and its own breakup coincides with that of Pangea