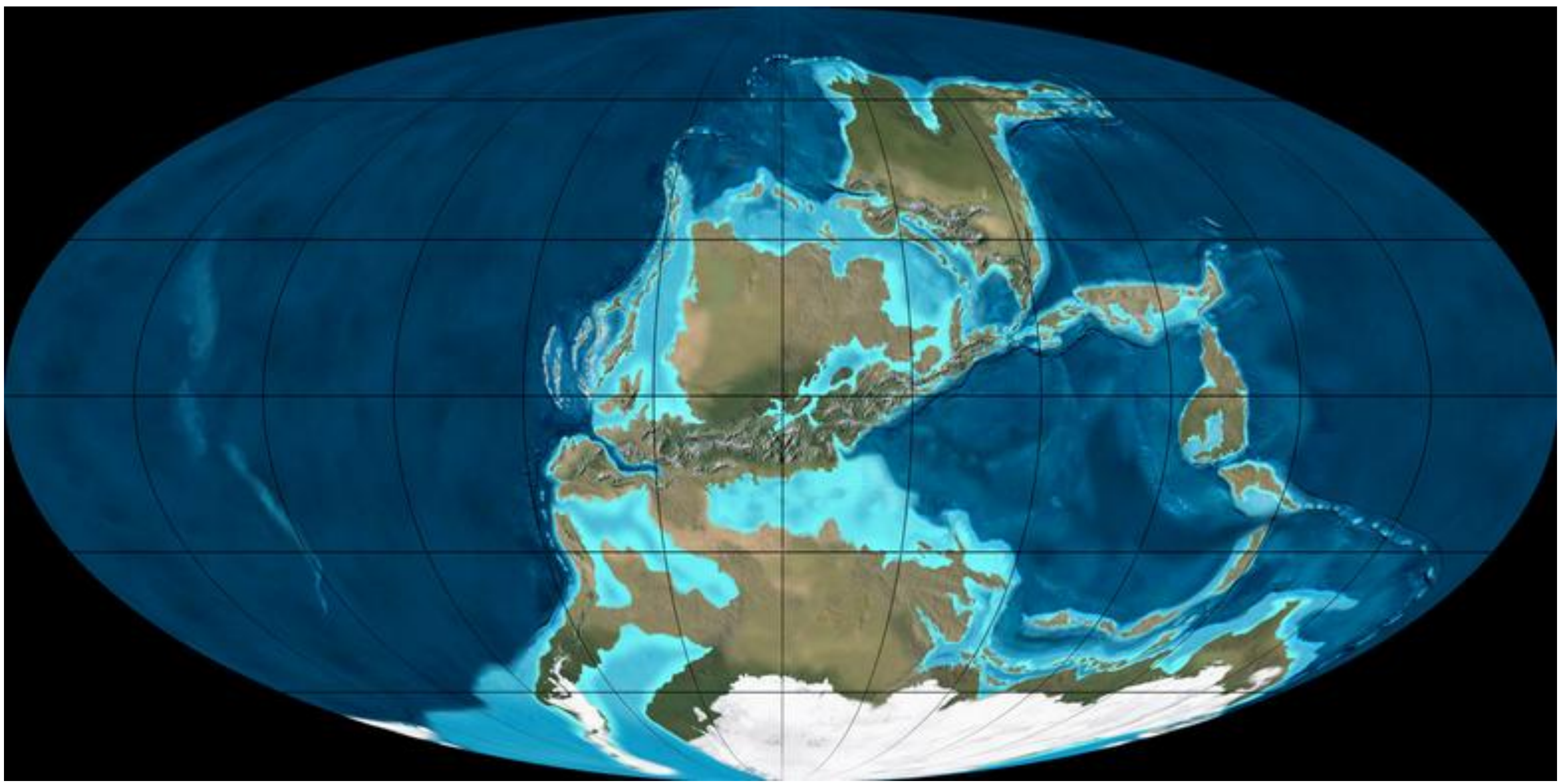
Geological origins of the Devonian, Carboniferous-Permian and Cenozoic Glaciations



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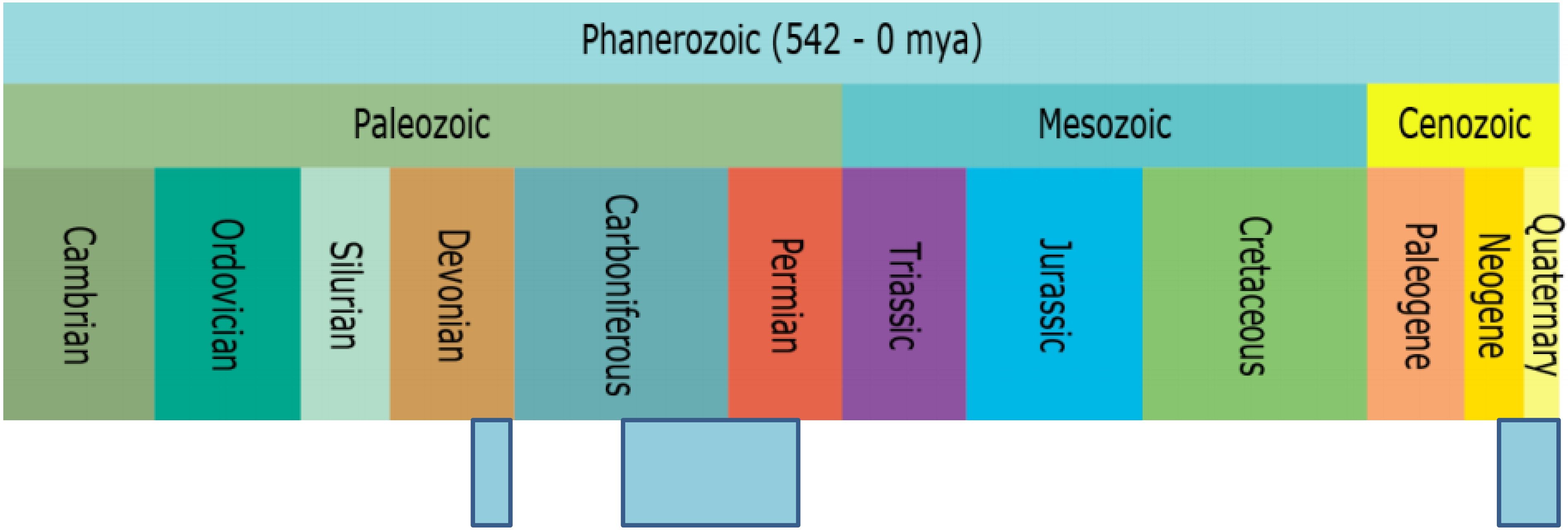

Glacio-epochs and the supercontinent cycle after ~3.0 Ga: Tectonic boundary conditions for glaciation

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8. Late Devonian ice c. 374 Ma

8.1. Brief cooling triggered by continental collision

Uplift related cooling along the active margin of the South American plate spawned shortlived Late Devonian ice covers in what is now Bolivia and parts of Brazil (Caputo, 1998; Isaacson et al., 1999; Fig. 6). The suggested cooling role of a possible bolide impact at this time has been argued by Streel et al. (2001) and evidence from fossil lycopsids suggests lowered levels of atmospheric CO_2 (Beerling, 2002). Kaiser et al. (2006, p. 157) refer to Late Devonian ice volumes as being similar to that of Quaternary glaciations. A 3–4 °C cooling across the Frasnian–Famennian boundary has been linked to weathering-related consumption of $C0_2$ during collisional events leading to the building of *Pangea* resulting in ‘one of the greatest crises of the biosphere recorded during the Phanerozoic’ (Averbuch

9. Late Paleozoic Gondwanan glacio-epoch (c. 350–250 Ma)

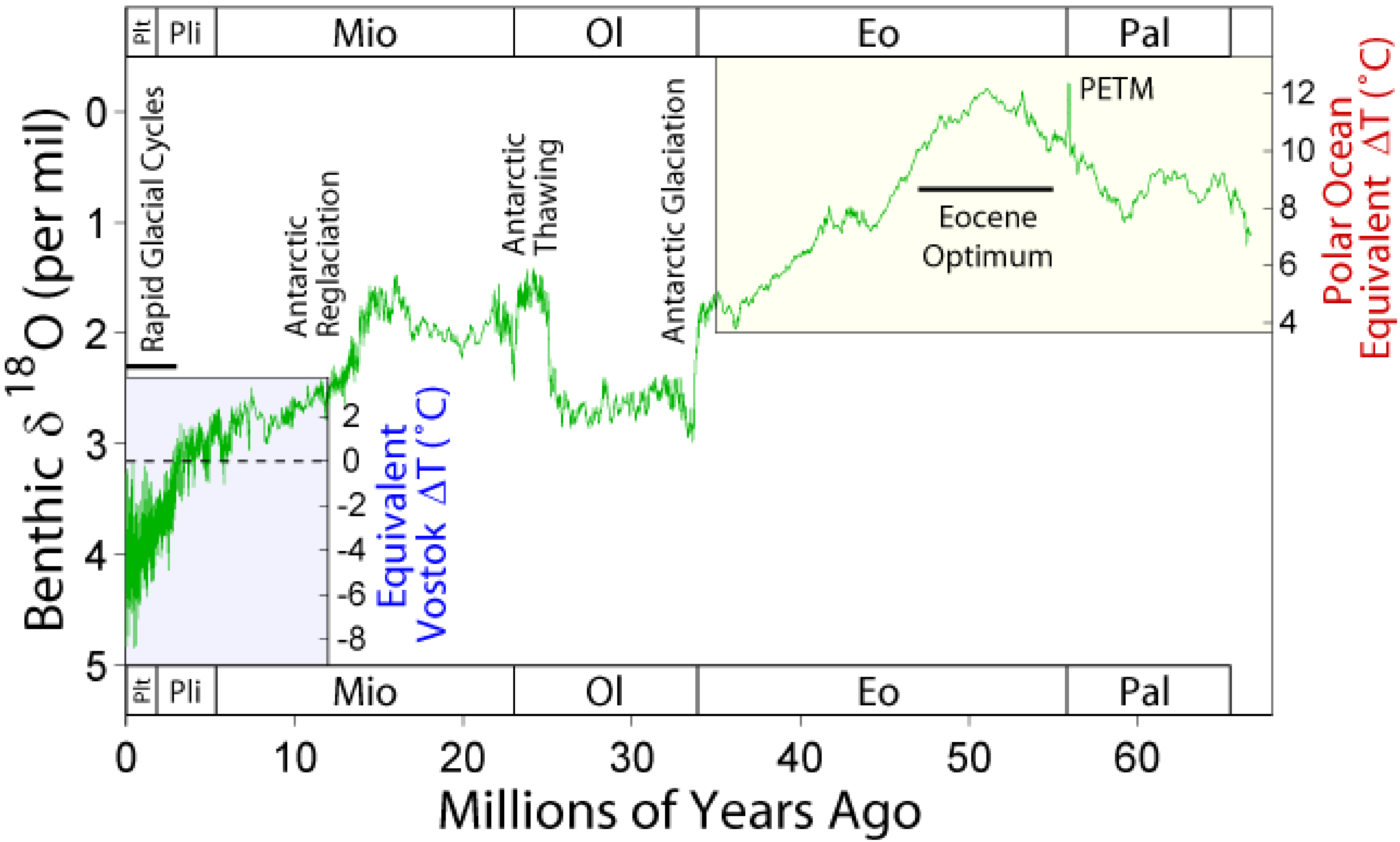
9.1. Long lived cooling triggered by continental collision

Pujol et al. (2006) concluded that tectonic processes drove global paleoclimates of the Late Paleozoic. This is clearly evident after 350 Ma when large ice sheets formed across India, South America, Southern Africa, Australia and Antarctica (Crowell 1999; Veevers 2004). Veevers and Powell (1987) and Powell and Veevers (1987) showed that ice growth was a direct response to extensive uplift at high southerly paleolatitudes during the mid-Carboniferous Variscan and late Carboniferous Alleghenian collisions of Gondwana with Laurasia. These collisions coincided with large-scale thermal doming and uplift across Pangea (Speed et al., 1997; Veevers, 2000) in conjunction with lowered atmospheric CO_2 levels (Beerling 2002). In general, the locus of ice covers progressively moved across Gondwana from South America to Australia (Crowell, 1999) tracking Gondwana's transpolar trajectory. The lack of

11. Cenozoic glacio-epoch (<55 Ma)

Earth began to cool after the Paleocene-Eocene Thermal Maximum* at around 55 Ma (Figs. 2 and 7) and a range of tectonic influences are apparent on the formation of glacial ice covers. Plate tectonic modification of continental elevation, ocean configuration and oceanic gateways are recognised as keys to understanding the transition from a long warm Mesozoic to a cooler Cenozoic (e.g., Poulsen et al., 1998; Hay et al., 2002; Prothero et al., 2003; Meijer et al., 2004).

*He means the Eocene Optimum. The PETM was a short-lived event (~150 ka) that was followed by much warmer conditions during the Eocene.



Plt
Pli
Mio
Ol
Eo
Pal
Benthic δ 18O (per mil)
0
1
2
3
4
5
Rapid Glacial Cycles
Antarctic Reglaciation
Antarctic Thawing
Antarctic Glaciation
PETM
Eocene Optimum
Equivalent Vostok ΔT (°C)
2
0
-2
-4
-6
-8
Polar Ocean Equivalent ΔT (°C)
12
10
8
6
4
0
10
20
30
40
50
60
Millions of Years Ago

11.1. Coupled tectono-climate models: the effects of plate collision and dispersal

Cooling after 55 Ma is increasingly being related to the tectonic and bathymetric evolution of the oceans as *Pangea* continued to disintegrate (Scher and Martin, 2006; Via and Thomas, 2006) in combination with shorter term, orbitally forced ocean circulation changes (Shevenell et al., 2004). The dispersal of Pangea moved large continental blocks (Eurasia and North America) to higher latitudes (Turekian, 1996; Wolfe, 1978) where climatic effects of Milankovitch variations were amplified by uplift. The northward obduction of India against Eurasia built the glaciated Himalayas and released large volumes of easily weathered sediment, changed upper atmosphere flow patterns, planetary albedos (Ruddiman et al., 1989; Kutzbach et al., 1989, 1993), monsoon intensity (and thus mechanical and chemical weathering) and atmospheric CO_2 (Raymo and Ruddiman, 1992

13. Concluding remarks

A review of Earth's glacial record over the last 3 Ga indicates a close relationship between glacio-epochs and times of enhanced crustal extension during the Proterozoic and Phanerozoic; most of Earth's glacial record appears to be preserved in extensional basins. Tectonically generated topography produced by crustal extension may be an important control on cooling in conjunction with increased availability of moisture. Clearly there are times in Earth history of rifting with no ice, and ice with no rifting but the marked association between the two for most ancient glacio-epochs cannot be simply coincidental. This association could simply reflect better preservation of glacial strata in extensional basins and the tendency for glacial deposits to be entirely reworked by large rivers in compressional settings. Having recognised the importance of tectonic

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The last three glacial periods (Devonian, Carboniferous-Permian and Cenozoic) are all at least partly or largely related to continental convergence, with little evidence of contribution from rifting. We can see it, and Eyles can see it! These are the glaciations that we know the most about.

The Proterozoic glaciations might show evidence of rifting but even Eyles admits that that might be a product of enhanced preservation in rift sediments.