Closure of the East–West Gondwana divide: The dawn of 'Cambrian Explosion'

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Next perhaps to the mass extinction that occurred in the wake of a meteorite impact ~65 million years ago (Ma), the burst of higher forms of animal life during the beginning of Cambrian (~543 Ma), better known as the 'Cambrian explosion' or Cambrian 'Big Bang', has remained a much discussed topic. Coincidences of several geological events with this 'big bang' during the Neoproterozoic–Early Palaeozoic (~650–542 Ma) period prompted several workers, particularly during the 1990s, to view these events as prime-triggers for this evolutionary spurt. Some of these geological events were the alternating spells of cold glacial and warm interglacial climates[1], plate reorganization induced by true polar wander[2] (TPW), fluctuations in ocean and atmospheric chemistry[3–5], decrease in the earth's tilt[6] (obliquity) precipitating rapid shifts in the earth's climatic zones, influence of a giant meteorite impact[7], introduction of genetic changes like gene doubling[3,8] and TPW-induced methane-release thermal-recycling events inflating biological diversity[9]. However, emerging data in subsequent years cast doubts on the major role attributed to them, particularly those based upon climate[10], extraterrestrial causes or earth's obliquity[11], and instead regarded the tectonically initiated environmental events of this period as immediate cause for the rapid evolution.

A recent study[12] has highlighted how the geological and the associated environmental changes following the amalgamation of two palaeocontinents – East Gondwana and West Gondwana, ~650 Ma onwards, could have led to the Cambrian explosion of life. These processes are claimed to have brought about the liberation of unprecedented amount of nutrient-rich sediment flux to the sedimentary basins of the period and creating right habitats for the proliferation of higher forms of multicelled and skeletonized animal life. This interpretation is based on results from correlation studies undertaken on the lithology and detrital-zircon age populations in the extensively spread rocks of Cambrian to early Devonian sedimentary systems in countries, which were once part of the two Gondwanas that had collided.

The new study has traced the intermittently active tectonic episodes of the Gondwana amalgamation resulting in uplifts, denudation of the uplifted rocks, transportation of the liberated detritus to the basins to form large sedimentary fans. The latter are seen today as extensively spread Cambrian age sedimentary rocks like quartz-rich sandstones, mudstones and conglomerates in all the countries which once lay adjacent to the converging East African - Antarctic orogen separating the East and West Gondwana. These countries were India (Tal Group), Arabian shield, Madagascar, S.E Australia, New Zealand, Antarctica, Africa, South America and North and South China. In the Cambrian sedimentary systems in all these countries, a consistent grouping of the detrital–zircon age (Pb–U ages) population into two age-groups, one at ~1200–900 Ma and the other at ~650–500 Ma are observed. These ages matched well with rocks of the same ages in Eastern Africa and this led to the logical conclusion that the provenance for these Cambrian sedimentary systems must be from the same east African cratonic margin.

Another supporting evidence for the changes induced by Gondwana convergence-tectonics during Cambrian to early Devonian is the sudden rise seen in the seawater $^{87}Sr/^{86}Sr$ ratio[13] of this period. A record rise of this ratio in the oceans, which is a good index of the magnitude of terrestrial weathering, points to unparalleled inputs of sediment flux to the marine basins. In conformity with this Sr-isotope increase, intermittent shifts in the $\delta^{13}C$ are also observed in the marine carbonates of this period. These $\delta^{13}C$ values are considered good proxies for monitoring the temporal fluctuations in climate and tectonic activity, and the observed values support the ecologic and biologic trends of this period[14]. The study further argues that such a huge bulk of detritus spread over many countries as a giant sedimentary fan – the Gondwana Superfan, could have materialized, only from a huge mountain range, which aptly has been named the 'Transgondwanan Supermountain'. Such a mountain is conceived to have developed along the earth's longest orogenic belt ever – the >8000 km long and >100 km wide East Africa-Antarctic orogen, uplifting an assortment of crustal blocks, accreted micro-continental fragments and juvenile island-arcs formed during the closure of the Mozambique Ocean between ~650–515 Ma (Figure 1).

This intense erosion and transportation by the river systems draining both sides of this supermountain lasted for about 260 million years (~650–390 Ma), aided by biota-assisted chemical weathering. This weathering must have been further accelerated by the absence of erosion-retarding vegetation cover as well as favourable location in the equatorial zone, probably in a region of very heavy rains, whose waters apparently were quite acidic due to enhanced atmospheric carbon dioxide from Neoproterozoic volcanism. The astoundingly high volume of >100 M.Cubic-km making up the Gondwana Superfan System is estimated to be large enough to pile up a 10 km thick sediment layer over all the 50 States of USA, and is about three times larger than the present day Bengal fan receiving the sediments from the uplifted Himalayan mountains. The waning of this superfan deposition during Ordovician (488–444 Ma) is reflected in the sudden reduction in the coverage of quartz-rich sedimentary rocks and a corresponding rapid fall in seawater $^{87}Sr/^{86}Sr$ ratio.

The Gondwana amalgamation, which raised the Transgondwanan Supermountain, is believed to have taken place in three stages over a time period spanning ~650 Ma to ~515 Ma. The initial collision of East African and Nubian Shield (650–590 Ma) was followed by two more pulses, between 580–550 and 525–510 Ma and these completed the convergence of the East and West Gondwana. Rapid plate motions accompanied by several increments of uplift, erosion and transportation of the eroded detritus to the basins that developed from subsiding foreland basins and sea level changes marked

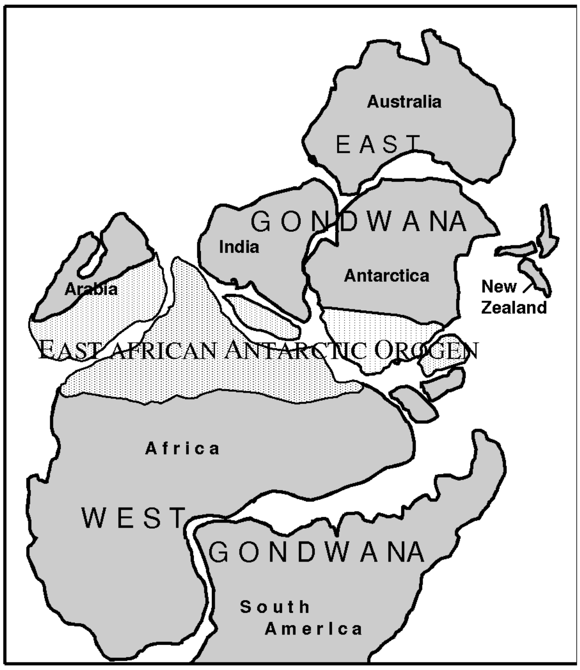

Figure 1. East and West Gondwana showing the countries that lay adjacent to the East Africa–Antarctica Orogen (convergence zone). The closure of the latter from ~650 Ma onwards uplifted an assortment of rocks to form the Transgondwana Supermountains (adapted from Figure 1, ref. 12).

each of these stages. These cyclic events which continued till the closing of the Mozambique Ocean by ~550 Ma, promoted recycling of the detritus. This recycling had obviously helped an efficient homogenization of the sediments, which is well reflected in the consistent presence of two dominant detrital-zircon age populations uniformly in all the countries exposing Gondwana Superfan succession.

The erosion of this Transgondwanan Supermountain had considerable implication for the explosion of animal life on the earth. The mountains contributed a record flux of dissolved P, Fe, Sr, Ca and bicarbonate ions to the oceans during Ediacaran–early Cambrian (~650–543 Ma) providing the vital nutrients and helping rapid rise in primitive life forms such as green algae. The latter served as food for the more complex life forms that evolved in the following Cambrian period. Also, the submergence of the shelves of the cratonic margin provided expanded marine habitats with P and other nutrient-rich waters and helped blooming of the diverse biota[15]. The high rise of P, Fe and $CaCO_3$, unique for the oceans of this period, formed the well-known phosphate deposits and had apparently helped the development of several new marine phyla with hard bodies and skeletons.

On the basis of Neoproterozoic–Palaeozoic geography and collisional tectonics, an earlier study had in fact, envisaged existence of a >7500 km long mountain range[16] contributing considerable sediment load to the oceans of this period. Another recent review[15] based on Sr and Nd isotope ratios, $\delta^{13}C$ records and lithofacies changes had also inferred inputs of large sediment-flux to the basins and had commented about their implications for the boost of biosphere of this period. The present study[12] has now validated these inferences through very detailed correlation of detrital–zircon age population in the Gondwana Superfan sedimentary system from several Gondwanan countries and also traced the palaeo-tectonic sequences and strengthened the claim for the existence of a megamountain – 'Transgondwanan Supermountain' as the precursor for the Cambrian big bang.

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