Journal of Advanced Research in Geo Sciences & Remote Sensing
Volume 10, Issue 1&2 - 2023, Pg. No. 29-39
Peer Reviewed Journal

Research Article

Supercontinent Dynamics and Biogeochemical Cycles: The Vital Interplay of 'Life and Death'

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How to cite this article:
Sharma A, Ahmed MM. Supercontinent Dynamics and Biogeochemical Cycles: The Vital Interplay of 'Life and Death'. *J Adv Res Geo Sci Rem Sens* 2023; 10(1&2): 29-39.

Date of Submission: 2023-03-12
Date of Acceptance: 2023-04-22

ABSTRACT

Supercontinents have significantly impacted mantle dynamics, solid Earth processes, surface environments, the biogeochemical cycle. In the early history of Earth, the collision of parallel intra-oceanic arcs was crucial for building embryonic continents. Super downwelling along Y-shaped triple junctions may have contributed to the rapid assembly of continental fragments into closely packed supercontinents. The reassembly of supercontinents after breakup and ocean closure occurs through "introversion", "extroversion" or a combination of both. The assembly of supercontinents also had a significant impact on life evolution, with the Cambrian Gondwana assembly playing a role in promoting biodiversity. Recent models suggest a relationship between superplumes, supercontinent breakup, mass extinction. The assembly and dispersal of continents appear to have influenced the biogeochemical cycle, but whether these stages are closely linked to solid Earth processes remains to be investigated.

Keywords: Supercontinents, Mantle Dynamics, Superplume, Life Evolution, Extinction

Introduction

Island arcs dominated the early Earth's oceanic domain, but once the proto-continents were formed through arcearc collision and accretion, continental crust was constructed into substantial land masses. Throughout the second part of Earth's history, these were once more broken up and put back together in newer configurations. (Worsley et al., 1986; Worsley and Nance, 1989; Condie, 2001; Condie et al., 2001; Santosh, 2010, among others) The formation and dissolution of supercontinents have had a substantial impact on the mantle dynamics, solid earth processes, surface ecosystems, the biogeochemical cycle. The well-known connection between supercontinents and sea level variations is one of the surface environmental changes. Sea level is typically lower when continents are clustered together than when they are separated (Parsons and Sclater, 1977). The continents are flooded by rising sea levels, whereas the continental shelves are exposed when the sea level is low. The creation and fragmentation of supercontinents has a significant impact on global climatic patterns. An icehouse climate prevails when continents are grouped together, a greenhouse climate prevails when they are spread out. While isolated oceanic settings during continental separation speed up broad diversity, life evolution is less extensive when continents are fused together (Maruyama and Santosh, 2008).

Large land masses formed when continents come together cause more CO2 to be removed from the atmosphere by weathering processes. This extra CO2 is then eroded into the oceans. More nutrients are released due to increased weathering and erosion, which encourages greater biological productivity. In addition to colder climates, the increased CO2 sequestration also causes increased nutrient upwelling, marine productivity, phosphate deposition. Widespread glaciation would eventually occur because to the abrupt drop in CO2 concentration and the rising albedo brought on by the high land/ocean ratio. The creation of rift basins, on the other hand, results from the breakup of supercontinents, the restricted circulation in these basins encourages anoxic conditions in their deeper regions.

Escarpments that are actively eroding along newly formed rift margins add sediment to the rift basins, while marine transgressions speed up the burial of organic and carbonate carbon on solid continental shelves.

During the breakup of the supercontinents, an expansion of the ocean ridge system would also encourage mantle degassing and the emission of CO2 into the atmosphere (Condie, 2001). Climates become warmer as a result of rising CO2 levels and rising sea levels. As a result, the Earth's tectonic development of climate has been marked by alternating times of "greenhouse" drowning and "icehouse" emergence. These icehouse intervals might also line up with biotic innovation and phosphate deposition periods. Continental differentiation, enzyme productivity, atmospheric oxygen levels, solar luminosity are thought to indicate growing secular patterns, according to Worsley et al.'s 1986 summary of recurrent and non-recurring events in the evolutionary history of the Earth. The four phases of a supercontinent cycle described by Worsley (ibid.) are supercontinental stasis, maximum continent dispersal, continental assembly, fragmentation. These occur every 500 Ma or so and are related to tectonic activity, the preservation of cratonic sediment, the evolution of the atmosphere and hydrosphere, the distribution of stable isotopes from marine platforms. Periods of rapid geochemical adaptation to biospheric evolution can be seen in non-recurring and irreversible events like the emergence of photosynthesis, the production of banded iron formations, the deposition of detrital uraninite.

This article offers a summary of some of the current speculative models on the tectonics of the formation and dissolution of supercontinents, as well as their effects on the biosphere of Earth.

Conceptual models on the assembly and disruption of supercontinents

Parallel intra-oceanic arc collisions had a significant role in the formation of early continents during the Earth's history. Recent research on Archean terranes from many locations around the globe has provided significant insights into the process of composite arc amalgamation (Komiya et al., 2002; Santosh et al., 2009, references therein). The western Pacific domain, where 60%–70% of island arcs are concentrated, might be thought of as a modern equivalent to the Archean process. Maruyama et al. (2009) studied the characteristics and procedures of subduction zone magma factories in the western Pacific region in relation to the age of the subducting plate and the method of subduction. Santosh et al. (2009) identified two unique groups of subduction zones on the planet: the Tethyan subduction zone and the Circum-Pacific subduction zone, based on the topology of Y-shaped triple connections in significant supercontinental assemblies. When subduction occurs on both sides, the Y-shaped structure of the triangular sections preferentially cools the mantle beneath and lowers the temperature in these domains relative to the surrounding areas. In addition, the Y-shaped domains accelerate refrigeration through greater subduction, which strengthens downwelling in comparison to other mantle regions. Once this process starts, cold downwelling grows at an uncontrollable rate and finally expands into a sizable zone of super-downwelling. According to Santosh et al. (2009), this type of super-downwelling may be one of the primary mechanisms dragging the scattered continental fragments through mantle convection and packing them tightly together to form a supercontinent assembly. Numerous studies (e.g., Gurnis, 1988; Lowman and Jarvis, 1993; Yoshida et al., 1999; Coltice et al., 2007; Phillips and Bunge, 2007; Zhang et al., 2009) have examined the implications of supercontinents on the dynamics and structure of the mantle. These findings show that the construction of supercontinents may not be facilitated by a mantle convection planform with short-wavelength structures and numerous downwellings. This is because various downwellings would capture continental chunks, preventing collision. It would take more time for a supercontinent to form if the number of continental blocks floating on Earth were to increase and their size were to be smaller than the wavelength of mantle flow (Phillips and Bunge, 2007; Zhang et al., 2009).

The "Wilson cycle" refers to the opening and closure of vast oceans, whereas the "supercontinent cycle" refers to the periodic assembly and breakup of land masses. The processes involved with the assembly, dispersal, reorganisation of supercontinents are more complex even though both are thought of as complementary. Hoffman (1991) put out the idea of a "inside-out" process as a means of putting together crustal pieces following the disintegration of a former supercontinent. The opposite side becomes a devouring boundary along the continents, such as in the case of the Pacific margin, if the supercontinent was rifted on one side to support a passive margin, as in the case of the Atlantic Ocean.

The Pacific Ocean would eventually close as a result of the passive collision of two continents over time, creating a substantial continental mass. In the case of the Atlantic, both continental edges begin as passive margins but later change to active margins; the ocean gets smaller and could even disappear entirely. On the other hand, the Indian Ocean simultaneously hosts two distinct types of margins, active and passive, which combine the rifted continents to form the southern margin of Asia and transport the northern continental margin of Gondwana via an

Atlantic-type process. Therefore, the Indian Ocean-type process exemplifies the "inside-in" mechanism by showing simultaneous continental fracture and merger (Murphy and Nance, 2005). Rogers and Santosh (2002, 2004) presented a similar simultaneous rifting and accretion scenario for the Paleoproterozoic supercontinent Columbia. The Tethyan process began at least in the Permian to Triassic period and ran concurrently to the east with the Pacific process. The future supercontinent's boundary was subsequently defined by double-sided subduction (Maruyama et al., 2007). While the Pacific region is associated with the "inside-out" arrangement, the Tethyan region serves as an example of the "inside-in" reassembly of supercontinents (Hoffman, 1991; Murphy and Nance, 2003; Murphy and Nance, 2005; Murphy et al., 2009). As a result, a combination of introversion and extroversion would be required to complete a supercontinent. This combination was present during the construction of Rodinia and is anticipated to occur during the merger of the next supercontinent Amasia (see Maruyama et al., 2007; Santosh et al., 2009). Murphy et al. (2009) talked about the two geodynamically distinct oceanic lithosphere tracts that are produced during the breakup of supercontinents: a relatively young interior ocean floor that forms between the dispersing continents and a relatively old exterior ocean floor that surrounded the supercontinent prior to breakup. Supercontinents may arise via two end-member mechanisms: introversion, in which the inner ocean floor is preferentially subducted, extroversion, in which the outer ocean floor is preferentially subducted. This is supported by the geologic and Sm/Nd isotopic record that was combined in their study. According to Murphy et al. (2009), superplumes, possibly caused by slab avalanche events, may occasionally overwhelm top-down geodynamics, imposing a geoid high over an already-existing geoid low and causing the dispersing continents to reverse course to form an introverted supercontinent. A somewhat modified model by Silver and Behn (2008) postulated the P-type (Pacific-type) and A-type (Atlantic-type) mechanisms of ocean closure during the creation of supercontinents (Fig. 1). In an A-type closure, the internal ocean starts to close as the subduction process starts at a passive margin. The internal ocean keeps expanding and develops into a larger ocean basin in P-type closure. When a supercontinent is formed by an A-type closure, the interior ocean closes, stopping subduction zones there while the external ocean continues to experience subduction and sea-floor spreading.

Figure 1 Two types of ocean closure following supercontinent breakup as proposed by Silver and Behn (2008). Orange-shaded regions e supercontinents; black lines with dark blue triangles e subduction zones; thick red lines e internal ocean; blue rectangles in (d) and (f) e oceanic crustal materials including ophiolites trapped in the suture zone. See text for discussion.

The intricacy of "introversion" and "extroversion," as well as the P-type and A-type processes linked to supercontinent cycles outlined above, also takes into account the eradication and construction of diverse settings that have an effect on the extinction or survival and diversification of life. Future research should use these conceptual models to unravel the history of life on the planet in order to gain a deeper understanding of the influence of geology on environmental and biological processes.

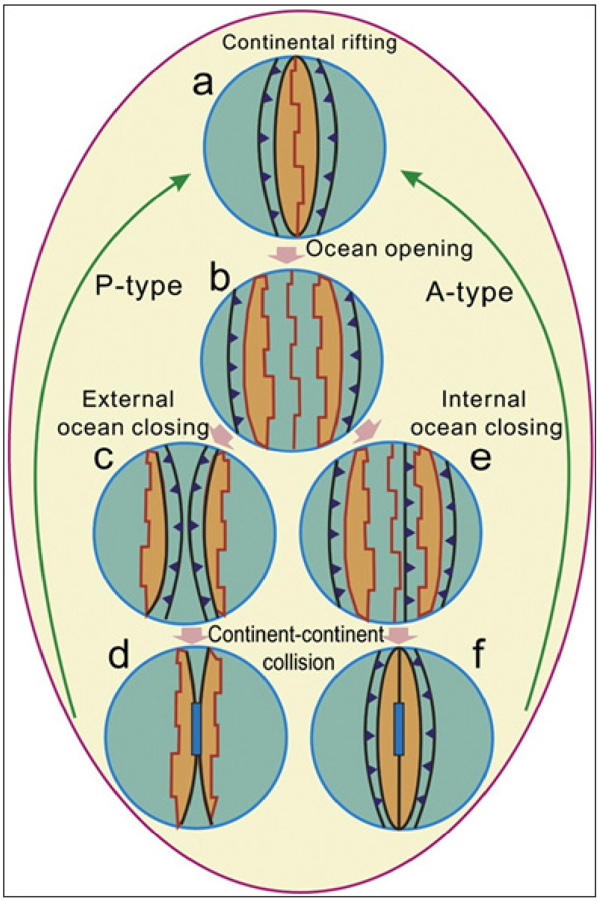

Figure 1

Supercontinent breakup

Generally speaking, plume-absent and plume-related processes can be found in supercontinent fragmentation models. According to the plume- absent models, the thermal insulation effect of supercontinents (Anderson, 1982) causes a rise in temperature beneath the massive landmass, which causes continental rifting and disintegration. According to the thermal blanket hypothesis (Fig. 2), supercontinents will fragment due to radiogenic heating (e.g., Gurnis, 1988). Compared to mantle peridotite, granites contain higher levels of K, U, Th. A significant amount of granitic crust is subducted during the formation of supercontinents through arc subduction, sediment trapped subduction, subduction erosion, according to recent studies. The mantle transition zone is where this TTG (tonalite-trondhjemite-granite) material is predicted to collect after being brought down (Senshu et al., 2009). It's likely that over time, the radiogenic components in the subducted TTG crust heat up the mantle above it, causing continental rifting and dispersion that eventually causes seas to open. Phase assemblage analysis was done by Komabayashi et al. (2009) in the MORB-anorthosite-TTG system down to core-mantle boundary (CMB) conditions. According to their findings, all of these materials are capable of subduction, even to the CMB, which causes in the formation of compositional stratification in the D" layer (Fig. 3). Coltice et al. (2007) investigated the idea that the formation of supercontinents would compel longer length scales and raise the temperature of the mantle beneath. They investigated the inherent temperature difference between continents that are close together and those that are far out. In order to remove the time-dependent features and produce a statistical steady state, the position of the continents was fixed, an equilibrium temperature field was computed by stacking the temperature fields across several billion years. Their findings indicate that the number of continents has an inverse relationship with subcontinental temperature, their internal heating convection model led them to the conclusion that the assembly of continents into supercontinents would naturally result in mantle global warming without the involvement of hot active plumes.

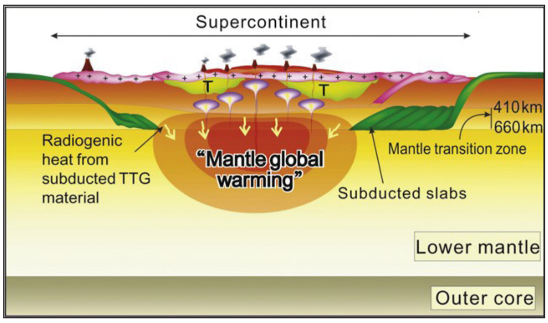

Figure 2

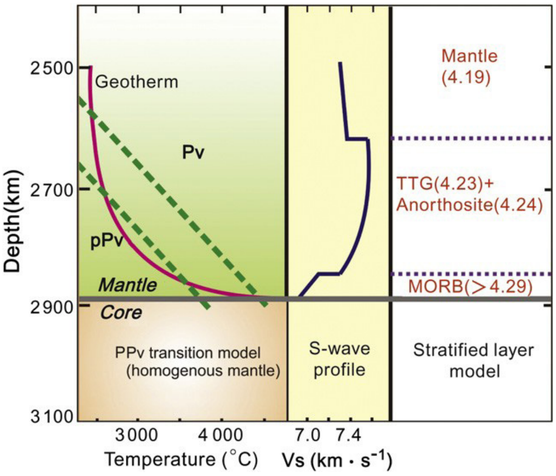

Figure 3

Figure 2 Schematic illustration of the thermal blanket hypothesis of supercontinent breakup (after Senshu et al., 2009). See text for discussion.

Heat buildup and subsequent magmatism effectively cause supercontinents to disintegrate because they greatly weaken the lithosphere and make it more vulnerable to breaking apart in response to regional tectonics. According to a conceptual model put out by Vaughan and Storey (2007), the subduction relationship to the development of supercontinents concentrates on certain regions of the 660 km mantle discontinuity, resulting in superplume events that ultimately cause the fragmentation of the continental mass above. We looked at this supercontinent-triggered superplume mechanism for continental breakdown in the context of Pangea-Gondwana's Mesozoic fragmentation. The Late Triassic-Early Jurassic superplume event, which occurred between 227 and 183 Ma ago, is equivalent in scale to those in the Late Proterozoic (about 800 Ma) and the Cretaceous (around 120e80 Ma), according to a summary of the data provided by Vaughan and Storey (2007). The subducted oceanic lithosphere of the intervening oceans either descends to the deep mantle during the amalgamation of continental fragments or becomes horizontally flattened as stagnant slabs in the mantle transition zone (Fukao et al., 1992, 2001, 2009; van der Hilst et al., 1997; Grand, 2002; Zhao, 2004, 2009). At the boundary between the core and the mantle, blobs of these immobile slabs gather and sink down into the deep mantle. Approximately 1200 km-long stationary slabs are visible floating in the mantle transition zone between 410 and 660 km, also known as the 660 km phase boundary, in Zhao's (2004) synthesised P-wave tomographic image of the Western Pacific region along a transect spanning Beijing to Tokyo.

It has been described as a "slab graveyard" by Maruyama et al. (2007; 2009). Recycled oceanic lithosphere at the core-mantle border provides potential fuel for the creation of superplumes that ascend from the core-mantle interface to the topmost mantle (Fig. 4), pierce the mantle transition zone, finally give rise to hot spots (e.g., Maruyama et al., 2007). The shape and amplitude of the velocity anomaly of two superplumes beneath southern Africa's southern Atlantic Ocean and southern Pacific are clarified using highly resolution seismic tomography models.

Supercontinent Assembly and life Evolution

Prior to the so-called Cambrian boom, at the beginning of the Cambrian, an important evolutionary episode is documented by the Ediacara fauna, which also contains vital data on the early evolution of macroscopic and sophisticated multicellular life (Xiao and Laflamme, 2009). A significant event in the evolution of life known as the Cambrian radiation saw the appearance of a huge number of animal phyla in the fossil record over a geologically little period of time. A series of severe glaciations that occurred during the Neoproterozoic culminated in the appearance of the Ediacara fauna, which served as a bridge for the ensuing Cambrian radiation, during the Late Neoproterozoic-Cambrian, when the Gondwana supercontinent was formed (Meert and Lieberman, 2008). According to Squire et al. (2006), it has been hypothesised that the poly-phase assembly of Gondwana during the East Africa, Braziliano, Kuungan, Damaran orogenies produced a significant mountain range, the weathering of which provided nutrients to a fluctuating oceanic environment. It is thought that the geochemical and tectonic changes that took place during the Ediacaran Cambrian epoch increased the complexity of the ecosystems in addition to the fundamental biological changes that encouraged the appearance and spread of contemporary life forms on Earth. It is unclear if the "Cambrian explosion" was a very quick event that took place in a short amount of time and was unheard of, or if it was a more gradual natural biological response to a shifting geological environment (Meert and Lieberman, 2008). However, the importance of the Cambrian Gondwana assembly is highlighted in most of the models, including the development of the 8000 km Transgondwanan Supermountains (Squire et al., 2006; Campell and Squire, 2010). These mountains may have been a significant source of rich nutrients, such as Fe and P, for the equatorial waters, facilitating the rapid increase in biodiversity, particularly algae and cyanobacteria, which in turn led to a significant. Because of increased sedimentation during these times, a significant portion of organic carbon and pyrite were buried, inhibiting their interaction with free oxygen and resulting in prolonged increases in atmospheric oxygen (Campbell and Squire, 2010). Through oxygenic photosynthesis, early bacteria—the ancestors of current cyanobacteria—acquired the capacity to remove electrons from water while simultaneously producing an essential byproduct: oxygen gas. One of the most significant biological advances in the history of life on Earth, this evolutionary achievement paved the way for significant modifications in the redox state of the oceans and atmosphere (Konhauser, 2009).

According to Brasier and Lindsay (2001), the Cambrian explosion that followed the fusion of Gondwana during the Ediacaran–early Cambrian period and the widespread development of foreland basins that went along with it had a significant impact on the radiation of life. Sediment accumulation rates increased between roughly 550 and 530 Ma, which shows that interior basins and cratonic edges all throughout the world experienced significant subsidence. Brasier and Lindsay (2001) hypothesised that the significant expansion of animal life across the Neoproterozoic-Cambrian gap (about 600 to 500 Ma) was accompanied by rates of subsidence and uplift based on a synthesis of sediment patterns and accumulation rates as well as carbon, strontium, neodymium isotopes. Large marginal oceans with ageing, oxygen-depleted, nutrient-rich bottom waters are produced by supercontinental assembly. The nutrient-rich bottom waters start to infiltrate the shelves as the shelf barriers start to sink. Eutrophic planktons and suspension feeders flourish as a result, while phosphatization protects tiny shelly fossils. Restricted carbonate platforms are submerged, resulting in the flourishing of pandemic early fauna. Invertebrates that swallow sediment grow in number, space formation, condensation, winnowing, phosphogenesis all occur at an accelerating rate. In the interior basins, the rapid space generation encourages the development of thick halite beds, cherts, shales that are rich in organic material. In addition to preserving Burgess shale-type faunas, fast burial improves the preservation of grazing traces (Butterfield, 1995).

In an effort to link the history of Rodinia's breakup to the beginning of the biological changes that led to the Cambrian explosion, Maruyama and Santosh (2008) offered a somewhat different hypothesis. They discovered several crucial elements needed to create a livable planet in their synthesis. Fundamentally, the right physical environment is necessary for life evolution, as several studies have shown, the creation of a broad platform by lowering the sea level results in the creation of a photic zone on the continental shelf. A fast evolving life is encouraged by the formation of the photic zone, which has a complex food chain, environment, environment with more free oxygen. This variety of life can be found in the expanded shelf and photic zone. In isolated rift basins formed by continental fragmentation, an upwelling of cold currents with enriched nutrients (especially produced from a tonalite-trondhjemite-granodioriteeTTGecontinental crust; Maruyama and Santosh, 2008) provides additional impetus. Additionally, biomineralization aids foster fundamental changes like the switch from exoskeletons to endoskeletons in addition to increasing the size of animal phyla. The frequent mutation and final evolution of metazoans that finally resulted in the Cambrian radiation are thought to have been influenced by extraterrestrial forces such protracted cosmic radiation.

South China was modelled by Maruyama and Santosh (2008) as a representative example, where many of the extreme fluctuations and oscillations in environmental factors discussed above are well-preserved in fossil records (e.g., Shu, 2008), including the numerous 'trial and error' experiments to create modern life involving a number of extinction events. Neoproterozoic Rodinia started to rift around 750 Ma, or maybe even earlier in some locations (Li et al., 1999). The supercontinent was essentially divided into three domains: South China, the eastern Rodinia, which shared Laurentia with the western Rodinia and

Australia, the western Rodinia. The late Neoproterozoic, when breakup and reconstruction created the Cambrian Gondwana, is when the western and eastern domains were likely totally divided.

The San Francisco-Congo, Baltica, Amazonia, West African cratons, as well as the Laurentia, North China, Siberia, Tarim cratons, were all separated from East Rodinia. The South China block, on the other hand, seems to have been alone after it split from Rodinia until it joined forces with Gondwana at about 540 Ma. The South China block was able to preserve one of the best preserved sedimentary records of biological evolution during a significant period in Earth history as a result of this tectonic quiescence and a continual sinking brought on by a cooling lithosphere.

The origin of vertebrates must have occurred in lakes that developed within continental rifts similar to the modern African Rift Valley and Dead Sea because hydrothermal systems in rifts with granitic basements create anomalous chemical environments enriched in nutrients that serve as the primary building blocks of the skeleton and bone of the early modern life forms (Maruyama and Santosh, 2008). The Rodinia supercontinent's rifting created a NeS-oriented seaway, along which nutrient-rich upwelling created a geochemical environment suitable for human habitation. The enormous flux of Ca, Fe2, HCO3, P, Na, K, V, other elements that helped to form their hard components is likely associated to the origin of metazoans, the ancestors of vertebrates (Maruyama and Santosh, 2008).

These components are mostly present in granitic rocks, the hydrothermal system in rifts with granitic basement produced an unusual chemical environment rich in the aforementioned nutrients.

These served as the foundation for the first modern animals' skeletons and bones. The aggregation of microbes and their development into giant multicellular creatures were made easier by the presence of enhanced Ca2. Since 750 Ma, when Rodinia began to rift, the sea level has fallen, creating a vast, shallow marine platform environment with a photic zone that provided a habitat for the diversification of life. According to Miyata and Suga (2001), cosmic radiation produced mutation at several levels, leading to genomic duplication and shuffle. However, it took a while before the shallow marine habitat and atmosphere developed sufficient oxygen levels for life to flourish, which is ultimately when the Ediacara fauna originated. This happened somewhere around 560 Ma. By the conclusion of the Cambrian period, mass extinctions and biomineralization driven by the genome had produced nearly all animal body designs. As a result, the Maruyama and Santosh (2008) model dates the geological processes that produced the "life soup" for biological evolution to the period of the Rodinia supercontinent's disintegration Figure 4.

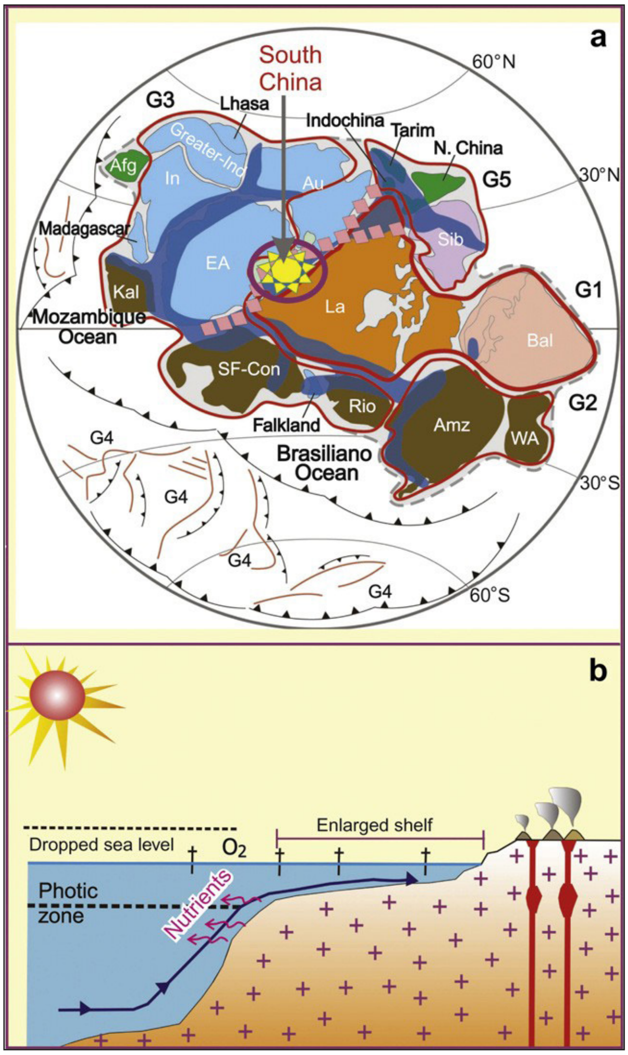

Figure 4

Figure 4 A speculative model for the evolution of modern life forms following supercontinent breakup. The breakup of the Neo- proterozoic Rodinia supercontinent (a, after Rino et al., 2008) generated enlarged shallow marine environments (b, after Maruyama and Santosh, 2008), with increased oxygen level and enrichment of nutrients. This isolated environment was conducive for the extensive development of body plans and enhancement in the size and diversity life forms which finally led to the so-called Cambrian explosion. The rift-related basins thus provided the 'life soup' for the rapid evolution of modern life. G1 to G5 in the Rodinia reconstruction shown in (a) correspond to the classification into various groups (North American, African, Russian and Asian Grenville Groups) based on Rino et al. (2008) on the basis of zircon age data.

Supercontinent Cycle and Mass Extinction

Mass Extinction Events in Earth History

According to Bradshaw and Brook (2009), the idea of extinction is a fundamental aspect of life on Earth. The

Archean Earth was a hot greenhouse with high levels of carbon dioxide and methane, indicating a long-lasting global warming event of 600 million years. A global warming event at approximately 1.8 Ga and a global freezing episode at around 2.3 Ga followed, respectively (Brocks et al., 2005; Canfield, 2005; Nisbett and Nisbett, 2008). Extreme climate changes like these are thought to have caused extinction events in the early Earth. Both Joseph (2009) and Elewa and Joseph (2009) offer contemporary, succinct summaries of the major extinction events that have occurred on Earth. The prokaryote and eukaryote habitats must have suffered significant damage due to the extreme cold, lower amounts of methane, increased oxygen concentration during the first snowball Earth event that froze the whole planet at around 2.3 Ga. By 1.6 to 1.2 Ga, complex multicellular eukaryotes began to arise and flourish (Xiao and Knoll, 1999; Butterfield, 2000). By 800 Ma, acritarchs had spread over the oceans and inland seas, along with plankton, coccoid and filamentous cyanobacteria, protozoa, fungi, amoebozoans, cercozoans, eukaryotic and marine algae (Butterfield, 2005). The oxygen pump was activated by photosynthesis, which significantly reduced the amount of CO2 in the atmosphere (Holland, 2006). The Neoproterozoic supercontinent Rodinia broke up, resulting in faster silicate weathering rates and higher oxygen levels, which had a major impact on the climate. The Earth entered the significant Sturtian global ice age as methane and CO2 levels decreased (Hoffman et al., 1998; Harland, 2007). Numerous species were extinct during this time, which lasted up to around 670 Ma (Fanning and Link, 2004). The Mar- inoan glaciation, which occurred on Earth between 640 and 580 Ma (Hoffman et al., 1998, 2004; Hyde et al., 2000), was followed by the Gaskiers, a less intense era of cold that ended around 580 Ma (Eyles and Eyles, 1989). Many early microscopic life forms probably went extinct during the Marinoan glaciation. A proliferation of life followed the end of the Marinoan/Gaskiers glaciation and the Earth's warming (Peterson and Butterfield, 2005), which led to the emergence of megascopic Ediacarans. The Ediacaran fauna, however, perished by 540 Ma, perhaps acting as an evolutionary link to the next Cambrian boom.

The body designs of modern animals are evidence of an accelerated development of life that began around 540 Ma and lasted for fewer than 10 million years (Conway Morris, 2000; Peterson and Butterfield, 2005; Meert and Lieberman, 2008). Trilobites, archaeocyathids, brachiopods, conodonts were among the four major extinctions that occurred during the Cambrian epoch between 540 and 510 Ma. Another two-stage mass extinction that is regarded as the second most tragic event for animal life in the history of our planet was also made possible by the Cambro-Ordovician history. A subsequent cycle of global cooling and glaciation is likely to have contributed to the extinction of over one hundred families of marine invertebrates and the near extinction of others (Sheehan, 2001). Many new species emerged during the Devonian period (410 to 360 Ma), including amphibians, insects, a fresh wave of reef builders. However, the Paleozoic era came to an end with another major extinction event that wiped out more than 70% of all life forms (Raup, 1992). The Permian period, which lasted from 290 to 248 Ma, also saw the end of several living forms, including some amphibians, reptiles, repto-mammals, as well as over 95% of all marine animal species (Raup, 1992). Therapsids, the earliest flying vertebrates, pterosaurs all underwent evolution throughout the Triassic epoch, which lasted from roughly 250 to 200 Ma. During this time, the world's land masses were tightly packed into the temperate and tropical portions of Earth's Pan-gea supercontinent (Rogers and Santosh, 2004). Another global extinction that killed off the majority of marine reptiles and over half of the marine flora occurred at the end of the Triassic period (Tanner et al., 2004). The Cretaceous period, which started at 135 Ma and ended abruptly and catastrophically at 65 Ma, produced only the dinosaurs, who were the only survivors. The KT (Cretaceous/Tertiary) extinction event resulted in the extinction of over 85% of all species worldwide (Raup, 1992).

Major climatic fluctuations, such as global cooling and warming events, major glaciations, changes in sea level, global anoxia, volcanic eruptions, asteroid impacts, gamma rays, are among the geological causes cited for such mass extinction events (see Elewa and Joseph, 2009 and references therein). It goes without saying that many of these characteristics are connected to the evolution of the world's seas, supercontinents, continents. With the exception of a few theoretical correlations, mass extinction events are mainly unknown for the Precambrian, but they were frequent in the Phanerozoic. Some of these occurrences have been influenced by the assembly and dispersion of continents, but it is still unknown if the distinct stages of organic evolution and extinction on the globe are directly related to Solid Earth processes.

Relationship to supercontinent breakup

Yale and Carpenter (1998) compiled data on the global distribution of giant dyke swarms (GDS) and large igneous provinces (LIPs), which indicate that both occur regularly and may be connected to the insulation of the mantle after supercontinent assembly. These catastrophes' periodicity (about 300 to 500 Ma) broadly corresponds with the cycles of supercontinents. Between 725 and 250 Ma, there is a 475 Myr gap in the LIP records, which was attributed to the somewhat dispersed nature of the continents at the time. It is proposed that this time frame corresponds to an era in Earth history where oxygen, carbon, strontium, sulphur isotope ratios reflect relatively low mantle flows. The cumulative percentage of the global occurrence of GDS, carbonatites, kimberlites is shown in Fig. 6, along with Yale and Carpenter's (1998) model for the periodic synthesis of GDS. The assembly and dispersion times of the world's major supercontinents are also placed on one another. The step-wise steep patterns were initially proposed by Yale and Carpenter (1998) in their model GDS production curve to correspond The cumulative percentage of the global occurrence of GDS, carbonatites, kimberlites is shown in Fig. 6, along with Yale and Carpenter's (1998) model for the periodic synthesis of GDS.The assembly and dispersion times of the world's major supercontinents are also placed on one another. Although Yale and Carpenter (1998) originally defined the step-wise steep patterns in their model GDS production curve to correlate LIP eruptions with supercontinent assembly, the data fit better with a scenario where the steep curves for production correlate with both supercontinent disruption and the intermittent quiescent periods associated with supercontinent assembly. The mid-Cretaceous superplume event and the highest rise in LIP volume occurred between 150 and 70 Ma, respectively (Larson, 1991).

The connection between the LIP and GDS event and the breakup of supercontinents may be the result of either rising mantle plumes fuelled by recycled subducted material or mantle insulation following the merger of supercontinental assembly. Numerous studies have examined the strong relationship between LIPs and mass extinction. When it comes to at least four consecutive mid-Phanerozoic examples, Wignall (2001) examined the correlation between the time of major extinctions and the formation age of LIPs. The end-Guadalupe extinction and the Emeishan flood basalts are four examples, as are the end-Permian extinction and the Siberian Traps, the end-Triassic extinction and the central Atlantic volcanism, the early Toarcian extinction and the Karoo Traps.

Wignall (2001), observing that the beginning of eruptions typically occurs slightly after the major period of extinctions in these examples, did not support a direct link. The correlation between marine anoxia/dysoxia and many of these instances, he added, emphasises how important an impact global climate has become. However, there is broad agreement that the LIP occurrences closely correlate with significant alterations in oceanic and atmospheric chemistry and may, therefore, result in global mass extinctions (Saunders, 2005).

Isozaki (2009) recently examined how the superplume, supercontinent breakup, mass extinction relate to one another. The Illawarra Reversal, an episode referred to as the Late Guadalupian (Middle Permian; ca. 265 Ma), is well visible in the Permian magnetostratigraphic record. The emergence of a thermal instability at the 2900 km-deep core-mantle boundary, which was associated with mantle superplume activity, is thought to have caused The Illawarra Reversal, a change in the geodynamo of the Earth's core. The last Guadalupian saw one of the largest global environmental upheavals in the Phanerozoic, as evidenced by the following events: 1) mass extinction, 2) ocean redox change, 3) strong isotope excursions (C and Sr), 4) sea level drop, 5) volcanism associated with plumes.

The Illawarra Reversal, the Kamura cooling event, other distinctive geologic events in the Late Guadalupian, according to Isozaki (2009), are all effects of the superplume activity that initially caused the breakup of Pangea. In accordance with this idea (Fig. 7), a superplume emerging from the planet's deep mantle symbolises the planet's massive internal movement of matter and energy. A large size whole-mantle convection cell was produced by the combination of an upwelling plume and a downwelling cold subducted slab. The Illawarra Reversal in the core geodynamo and a cooling event on the surface were initially brought on by the ascent of the superplume. The onset of a plume winter was caused by the continental rifting that resulted from the plume head impinging on the Pangea supercontinent's base and the establishment of LIPs.

Following are the two main phases that have been identified: (1) the loss of geomagnetism that caused a breach in the geomagnetic barrier when galactic cosmic rays sparked widespread cloud formation and stopped the Earth's "oxygen pump"; and (2) the second phase, which saw the emergence of the superplume and a volcanic eruption that resulted in "plume winter." Both possibilities are thought to have played a part in the global extinction.

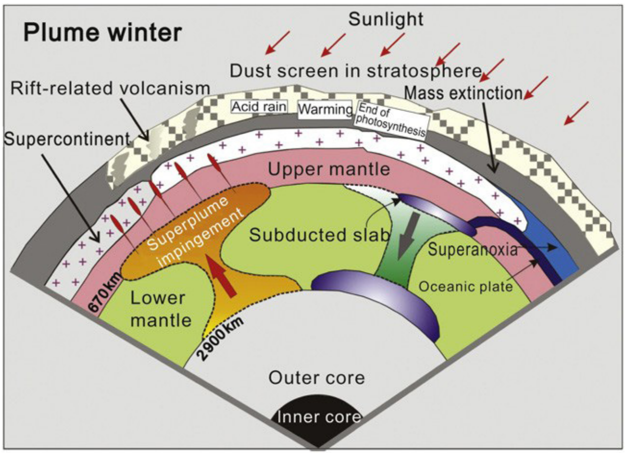

Figure 5

Figure 5, Cartoon illustrating the role of mantle dynamics and supercontinents in life history and surface environment. The figure shows the relationship between superplume, supercontinent breakup and mass extinction (after Isozaki, 2009) during the Late Guadalupian (Middle Permian; ca. 265 Ma) event, an episode termed the Illawarra Reversal. The model envisages two stages: (1) a strong retardation in the geomagnetic field led to a break in the geomagnetic barrier allowing galactic cosmic rays to infiltrate. This resulted in the formation of thick cloud layers which ultimately stopped the "oxygen pump"; the second stage is marked by the birth of a superplume and its upwelling, followed by voluminous volcanic eruption leading to plume winter.

Epilogue

Supercontinents have repeatedly merged and dispersed throughout Earth's history, beginning with Columbia's initial cohesive assembly in the Paleoproterozoic. Although there is growing evidence that the supercontinent cycles have altered Solid Earth processes and the biogeochemical cycle, many of the configurations still remain hypothetical, some of the conclusions drawn are largely based on speculative models and need more quantification. It is believed that the quick erosion of super mountains formed during continental fusion will result in a massive flux of nutrients necessary for sparking the planet's oxygen pump and the explosion of life. Large amounts of oceanic lithosphere were subducted by the supercontinent assembly, moving into the deep mantle and then building up as slab graveyards at the core-mantle boundary. It is hypothesised that their recycling will serve as the fuel for producing superplumes, which would eventually rise and split supercontinents apart. Super-plume and supercontinent disruption are connected phenomena that, according to models, will have devastating effects on the Earth's surface environment, causing the extinction of life. A difficult problem for multidisciplinary research, not only for reconstructing the past history of the planet but also for making predictions about the future of the planet, is the connection between biological innovation and geological events throughout Earth history.

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