Paper 8: Palaeobiogeography

"Plate Tectonic reconstructions and proposed movements of continents do not correspond to the known or necessary migration routes and directions of biogeographical boundaries." Meyerhoff *et al.*, 1996

The quality and quantity of faunal and floral data available for biogeographical studies is now extensive. The brief selection of species data presented in this paper are used as examples only in order to emphasise distributions and inter-relationships on increasing radius small Earth models. Modelled data are based on the published Paleobiology Database (PaleoBioDB, 2015). The navigator used to access this data can be opened from: https://paleobiodb.org/navigator/. The reader is encouraged to visit this navigator in order to compare and contrast data plotted on increasing radius small Earth models with the same data plotted on conventional Plate Tectonic plate assemblages. The reader is also encouraged to visit my website at: www.expansiontectonics.com / Data Modelling to view an extensive array of data plotted on small Earth models. This display is interactive and shows the distribution of various species plotted over time.

Precambrian Life

Evidence suggests that life began on Earth approximately 3 to 3.5 billion years ago. By the early Proterozoic the Earth was populated exclusively by single-celled prokaryotic life forms. From these simple beginnings all advanced forms of life later evolved and spread throughout the rest of the Earth. The dominance of early prokaryotic life took the form of stromatolites and relatively simple microscopic cells.

Multi-cellular life during Precambrian times was initially composed only of eukaryotic cells and the earliest evidence for this is from around 2,100 million years ago. The distribution of known late-Proterozoic eukaryote fossil sites (Figure 1) highlights a global distribution coinciding with the network of ancient seas—shown as khaki coloured strata. This network will become more evident after mapped ancient seas are shown for the following Palaeozoic Era. In this figure, the distribution of eukaryote fossil sites is shown to favour equatorial to temperate regions, extending within shallow seas into high northern latitudes. The presence of eukaryotes in high northern latitudes suggests that either the algae were tolerant of cooler waters, or warm equatorial waters extended into the North Polar Region effectively moderating the extent or presence of a North Polar ice-sheet.

By the end of the Precambrian, life in the ancient seas had begun to diversify rapidly. Nearly all new life forms emerging during that time were soft-bodied, mainly jellyfish-like animals and worms. These, along with early-Cambrian life forms, were mainly herbivores which fed on the abundant algae that blanketed the ancient sea floors and included the cnidarians, distinguished by the presence of specialized cells used mainly for capturing prey.

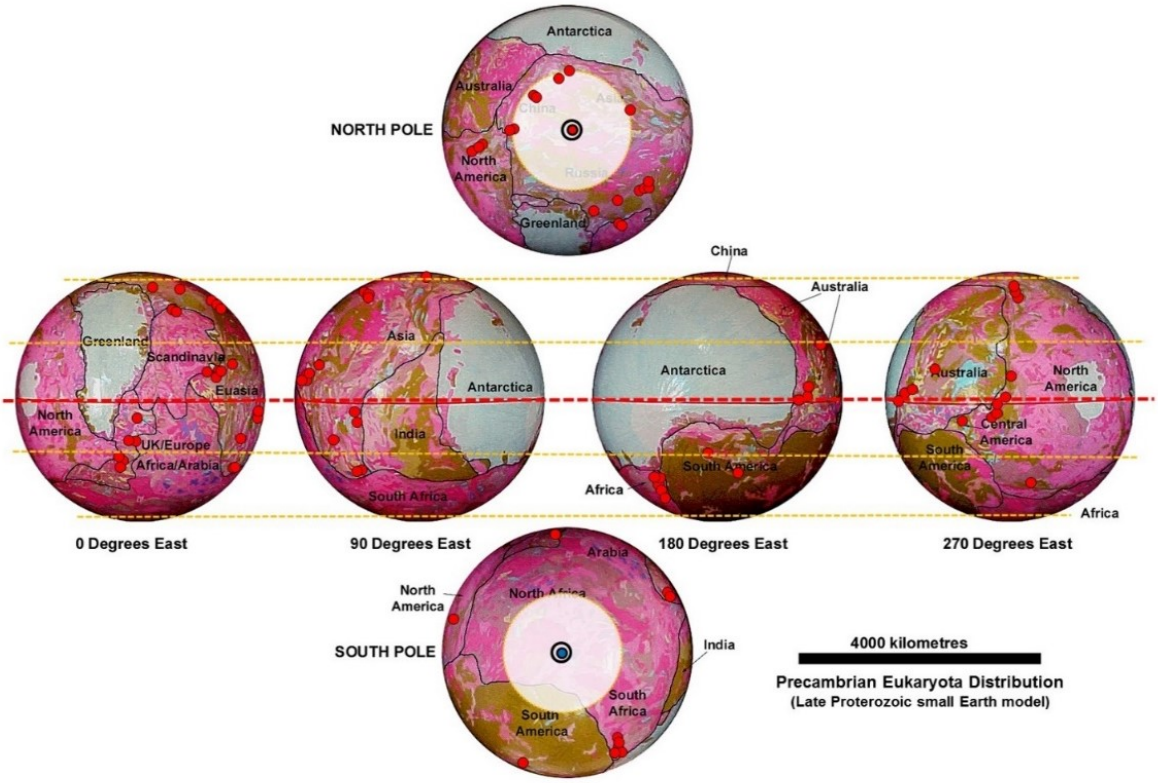

Figure 1 Distribution of Precambrian eukaryota plotted on a late-Palaeozoic small Earth model. Eukaryota data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and late-Proterozoic north and south polar ice sheets, shaded white. Black lines represent outlines of named continental cratonic crusts.

Early-Palaeozoic Life

The early-Palaeozoic is renowned for an explosion of new life forms that left behind external shells and skeletons composed of durable minerals. Terrestrial realms were still barren of all but simple spore-like forms and before the middle-Palaeozoic there were no insects, vertebrates, or plant forms.

The most conspicuous of marine animals with hard parts that evolved during the Cambrian Period were the trilobites. In Figure 2 the distribution of trilobites is shown on the Ordovician small Earth model to extend throughout all of the interconnected continental Tethys, Iapetus, and Panthalassa Seas, extending from mid southern to high northern latitudes. The presence of warm equatorial Tethys Sea waters extending into the North Polar Region restricted the presence of northern sea ice during the Ordovician glacial period, enabling the trilobites, along with many other species, to thrive in these areas.

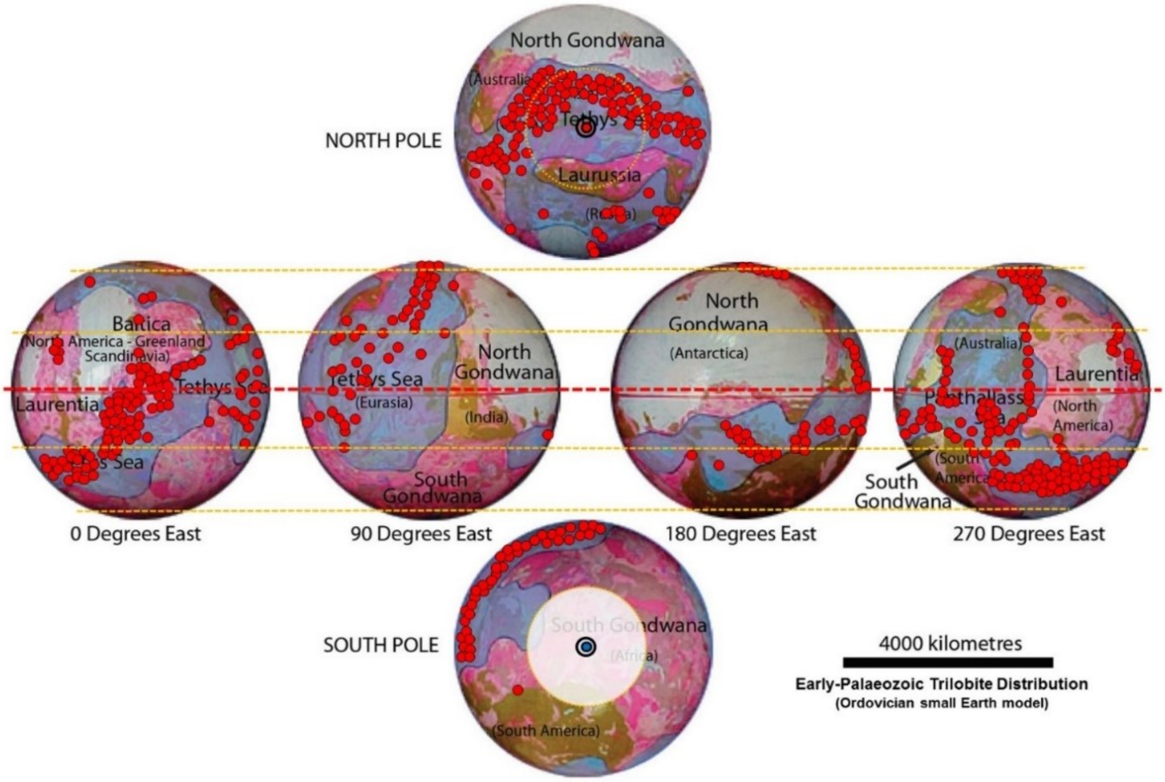

Figure 2 Distribution of early-Palaeozoic trilobite species plotted on an Ordovician small Earth model. Trilobite data are shown as red dots (after PaleoBioDB, 2015) in relation to ancient climate zones, an early-Palaeozoic South Polar ice-sheet, shaded white, and the distribution of ancient continental seas.

An important group of predators that arose during the late-Cambrian were the nautiloids which, along with molluscs, belong to the class Cephalopoda. On the Ordovician small Earth model in Figure 3 the cephalopods had an extensive distribution coinciding with distribution of the shallow continental Tethys, Iapetus, and Panthalassa Seas. Again, warm sea waters extended from the equator to the North Polar Region effectively moderating polar climates and allowing the cephalopods to thrive within the northern reaches of the Tethys Sea.

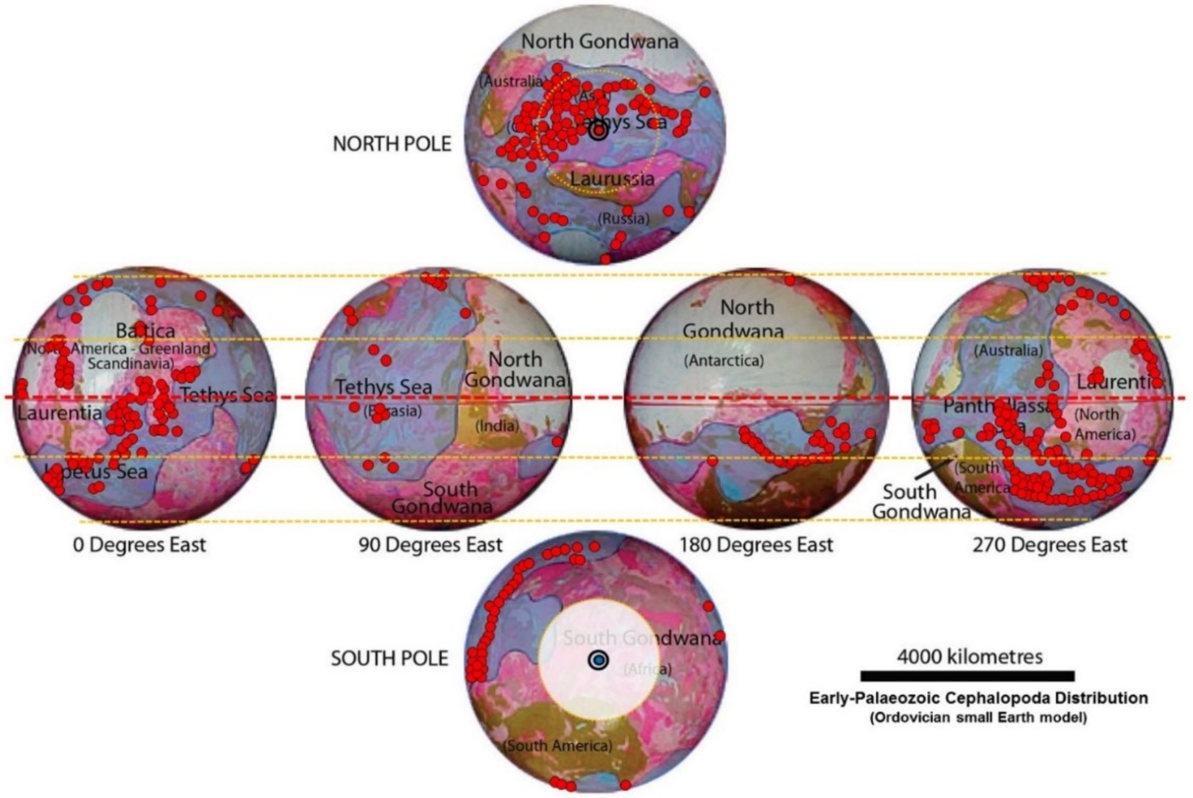

Figure 3 Distribution of early-Palaeozoic cephalopoda plotted on an Ordovician small Earth model. Cephalopod data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, an early-Palaeozoic South Polar ice-sheet, shaded white, and the distribution of ancient continental seas.

The adaptive radiation of marine animals with skeletons during this time was disrupted during the latter part of the Cambrian by several minor mass extinctions. The last of the Cambrian mass extinctions eliminated large numbers of nautiloids and trilobite genera. Three groups of animals present, but not highly diversified, during the Cambrian times emerged to become important species during the following Ordovician and included the articulate brachiopods, the graptolites, and the conodonts.

The distribution of brachiopods are shown on the Ordovician small Earth model in Figure 4 to have an extensive distribution coinciding with the distribution of trilobites and cephalopods, extending throughout the Tethys, Iapetus, and Panthalassa Seas from mid southern to high northern latitudes.

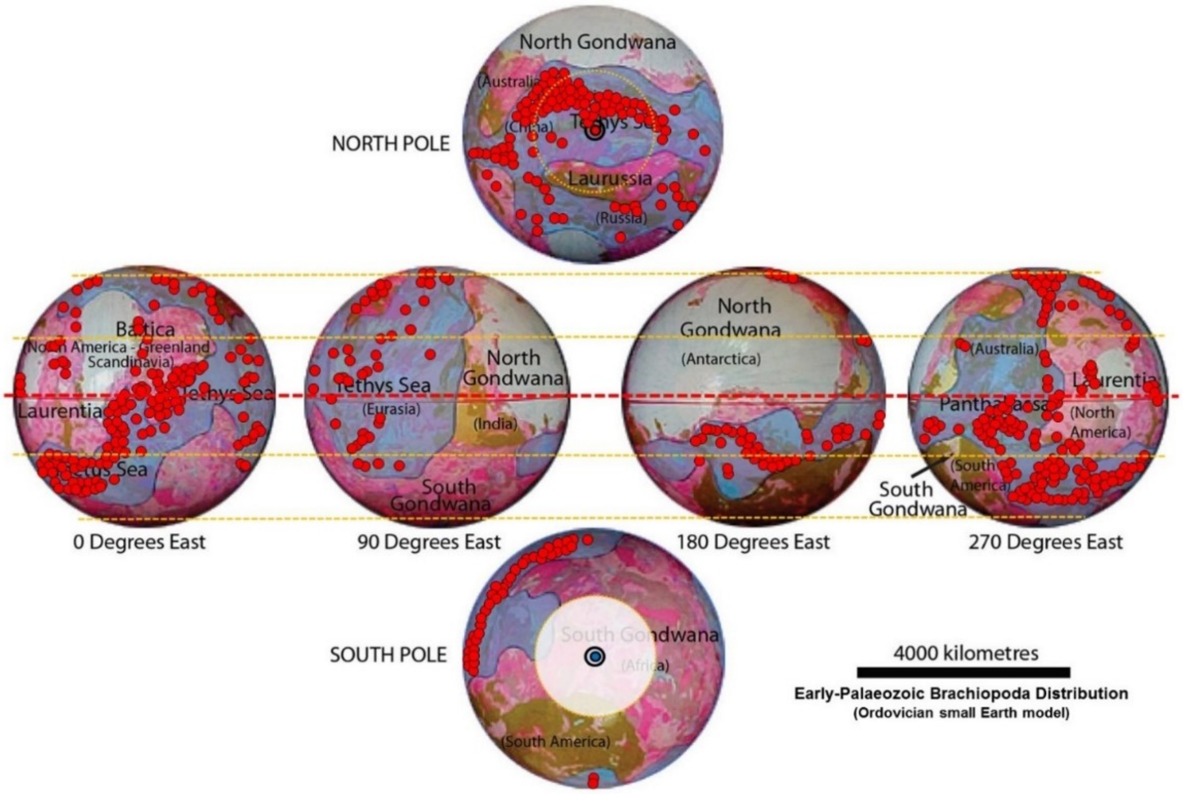

Figure 4 Distribution of early-Palaeozoic brachiopods plotted on an Ordovician small Earth model. Brachiopod data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, an early-Palaeozoic South Polar ice-sheet, shaded white, and the distribution of ancient continental seas.

Graptolites are an extinct group of animals whose fossils include benthonic species, but were more often planktonic colonial animals known chiefly from the late-Cambrian through to the early-Carboniferous Periods. Graptolite distribution is shown on the Ordovician small Earth model in Figure 5. Their distribution again coincides with the distribution of the ancient Tethys Iapetus and Panthalassa Seas, extending from mid-southern to high-northern latitudes. The preservation of graptolites within black shales suggests that the deeper parts of these ancient seas were devoid of oxygen and conditions were anoxic.

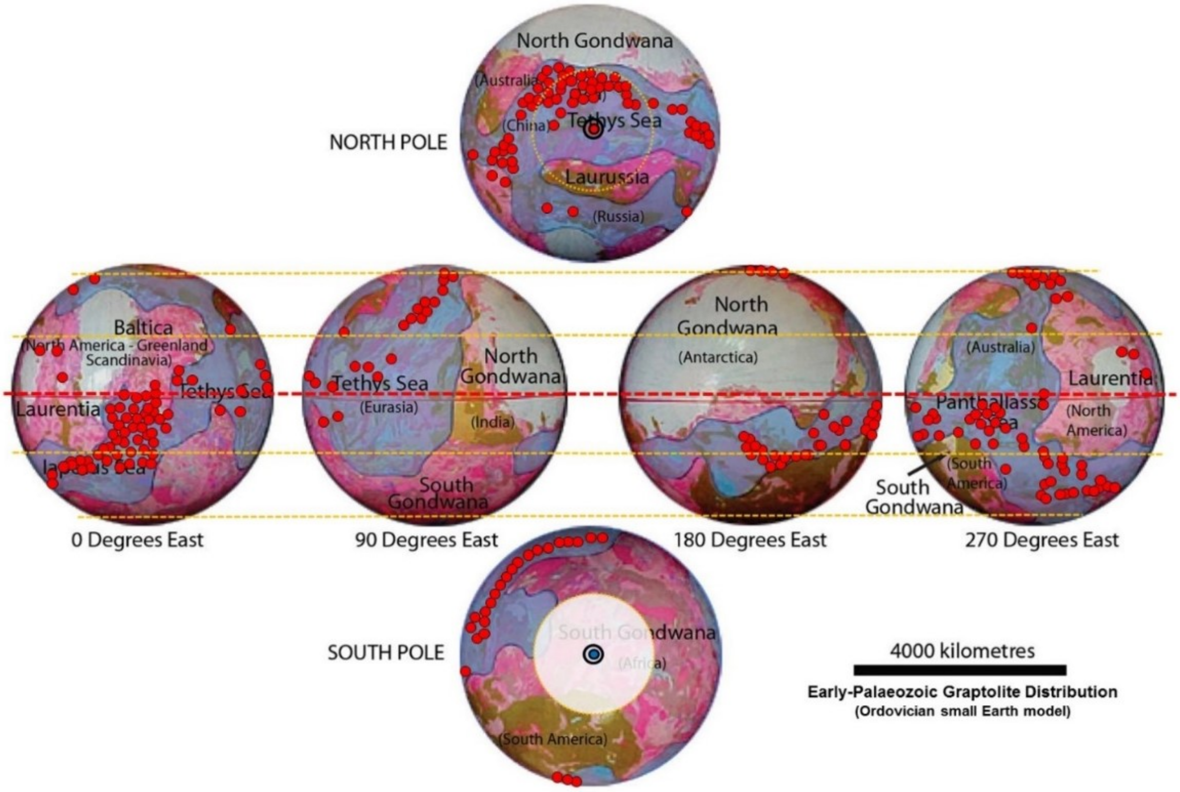

Figure 5 Distribution of early-Palaeozoic graptolites plotted on an Ordovician small Earth model. Graptolite data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, an early-Palaeozoic South Polar ice-sheet, shaded white, and distribution of ancient continental seas.

This brief early-Palaeozoic study shows that the network of relatively shallow continental seas shown on the increasing radius small Earth models provided an ideal environment for Precambrian algal mats and early reefs to proliferate throughout the ancient Earth. Warm sea waters during the early-Palaeozoic were able to extend from equatorial regions through to the North Polar Region allowing newly evolved species to readily colonise and populate throughout much of the interconnected ancient Tethys, Iapetus, and Panthalassa Seas. The warm seas enabled stable carbonate shelf environments to develop adjacent to the ancient lands, in conjunction with deeper anoxic basins further away from the coastlines. The extensive algal mats and early reefal mounds present throughout much of the Precambrian eventually gave way to predation and bioturbation by the trilobites. The trilobites were then further preyed upon by more advanced shelly marine species, such as the cephalopods and brachiopods, and the planktonic graptolites were able to readily spread throughout the deeper seas, as shown by their preserved fossil evidence in black carbonaceous shales.

Mid-Palaeozoic Life

The middle-Palaeozoic comprises the Silurian and Devonian Periods. After the end-Ordovician extinction event broad, relatively shallow Silurian and Devonian continental seas were slowly repopulated and once again teamed with life. Within the tropical zones, a diverse community of organisms built large, prominent reefs. More advanced predators emerged to include the early vertebrates in the form of jawed fishes. The Devonian is also noted for the progressive colonisation of the lands by new forms of plants and insects. Towards the end of the Devonian Period the first vertebrate animals then crawled onto the land before a wave of mass extinction again swept away large numbers of aquatic species.

The anthozoa are a group of animals that include the sea anemones and corals. The distribution of mid-Palaeozoic anthozoan corals is shown on the Devonian small Earth model in Figure 6. In this figure the distribution of the Tethys, Iapetus, and Panthalassa Seas mirrors the effects of the end-

Ordovician extinction event with disruptions to the coastal outlines and surficial extents of the seas. During this time, the circulation of warm sea currents around the ancient Laurentian supercontinent was disrupted but very little disruption to circulation occurred within the North Polar Region. Distribution of the anthozoan corals, and other species, throughout these mid-Palaeozoic seas may then represent a hold-over effect from the configuration of earlier seas.

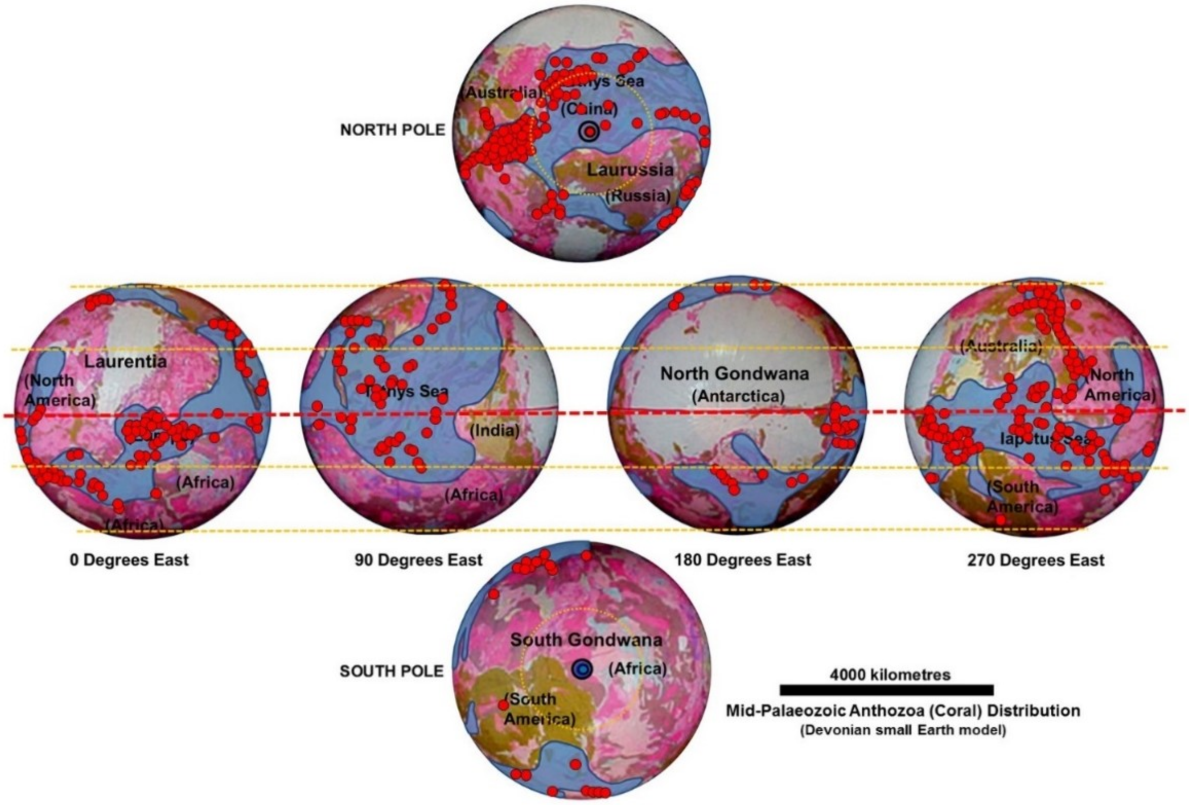

Figure 6 Distribution of mid-Palaeozoic anthozoan corals plotted on a Devonian small Earth model. Anthozoa data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, mid-Palaeozoic Polar Regions, and distribution of ancient continental seas.

The bivalves comprise a class of marine and freshwater molluscs that have laterally compressed bodies enclosed by a shell consisting of two hinged parts. The first occurrences are found in early-Cambrian strata, but it was not until the early-Ordovician that bivalve diversification exploded in the fossil record. The distribution of bivalves is shown on the Devonian small Earth model in Figure 7. This distribution suggests a preference within the ancient Iapetus and parts of the Tethys Seas surrounding Laurentia, with lesser colonisation within the more distal seas.

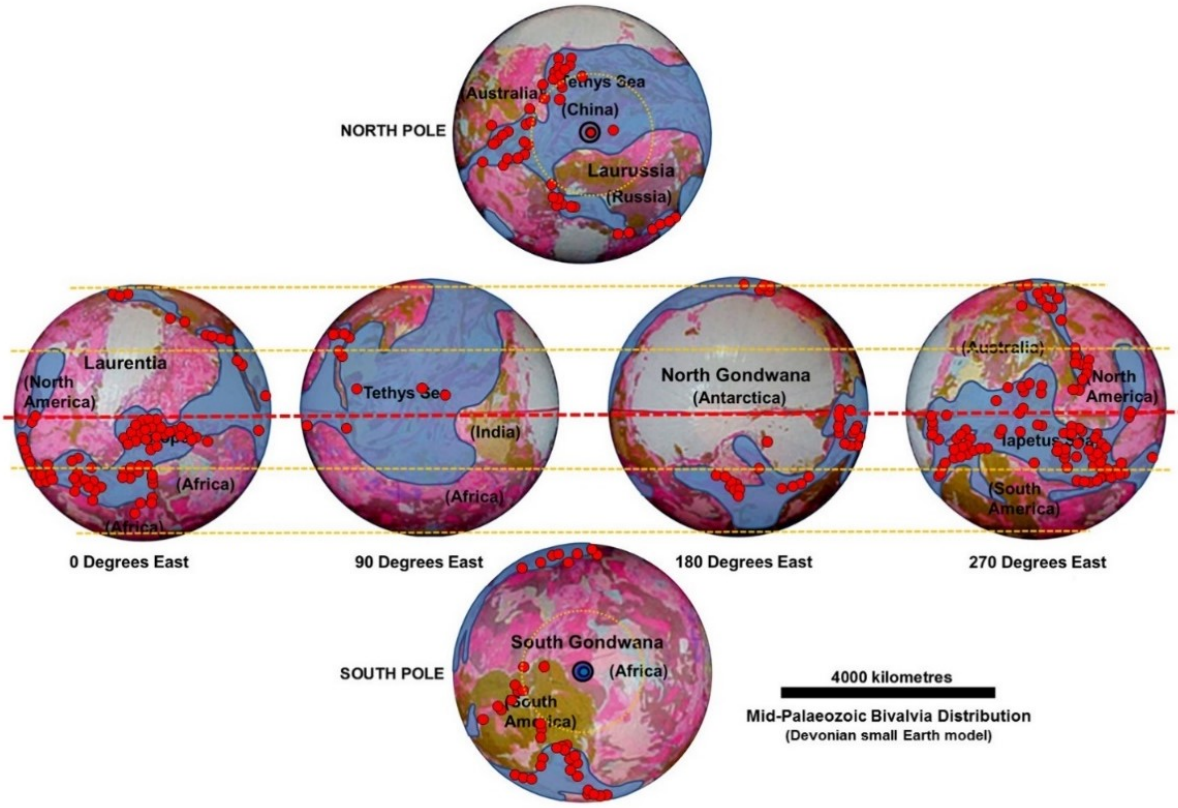

Figure 7 Distribution of mid-Palaeozoic bivalves plotted on a Devonian small Earth model. Bivalve data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, mid-Palaeozoic Polar Regions, and distribution of ancient continental seas.

The gastropods are shelly animals belonging to the phylum Mollusca. The first gastropods were exclusively marine, with the earliest representatives of the group appearing in the late-Cambrian. The distribution of gastropods is shown on the Devonian small Earth model in Figure 8. Like the bivalves, the figure again highlights a preference of distribution within the ancient Iapetus and parts of the Tethys Seas surrounding Laurentia, with lesser colonisation within more distal seas.

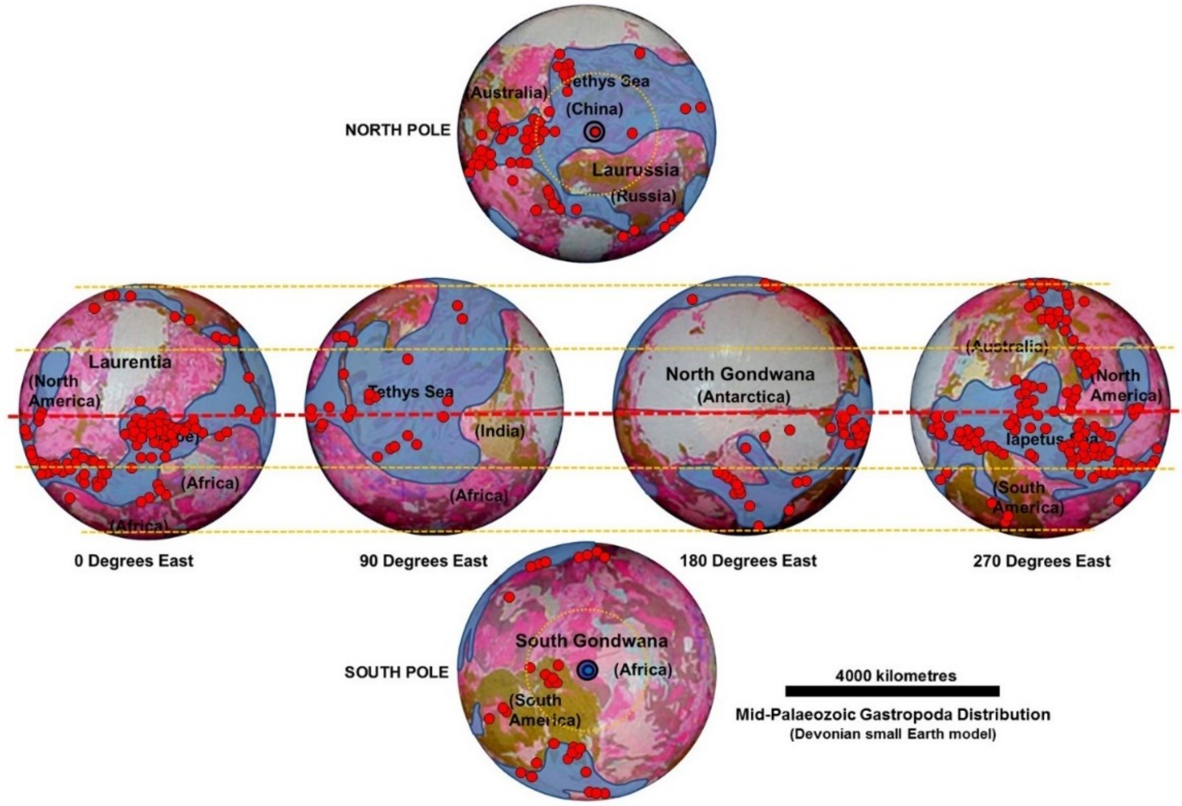

Figure 8 Distribution of mid-Palaeozoic gastropods plotted on a Devonian small Earth model. Gastropoda data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, mid-Palaeozoic Polar Regions, and distribution of ancient continental seas.

Vertebrates include the jawless fishes and the jawed vertebrates, which include the cartilaginous fish (sharks and rays) and the bony fishes. The first jawed vertebrates appeared in the late-Ordovician and became common during the Devonian Period. The distribution of mid-Palaeozoic vertebrates is shown on the Devonian small Earth model in Figure 9. The distribution of the vertebrates shown on these models suggests a preference for equatorial and temperate regions, with lesser colonisation within the North or South Polar Regions.

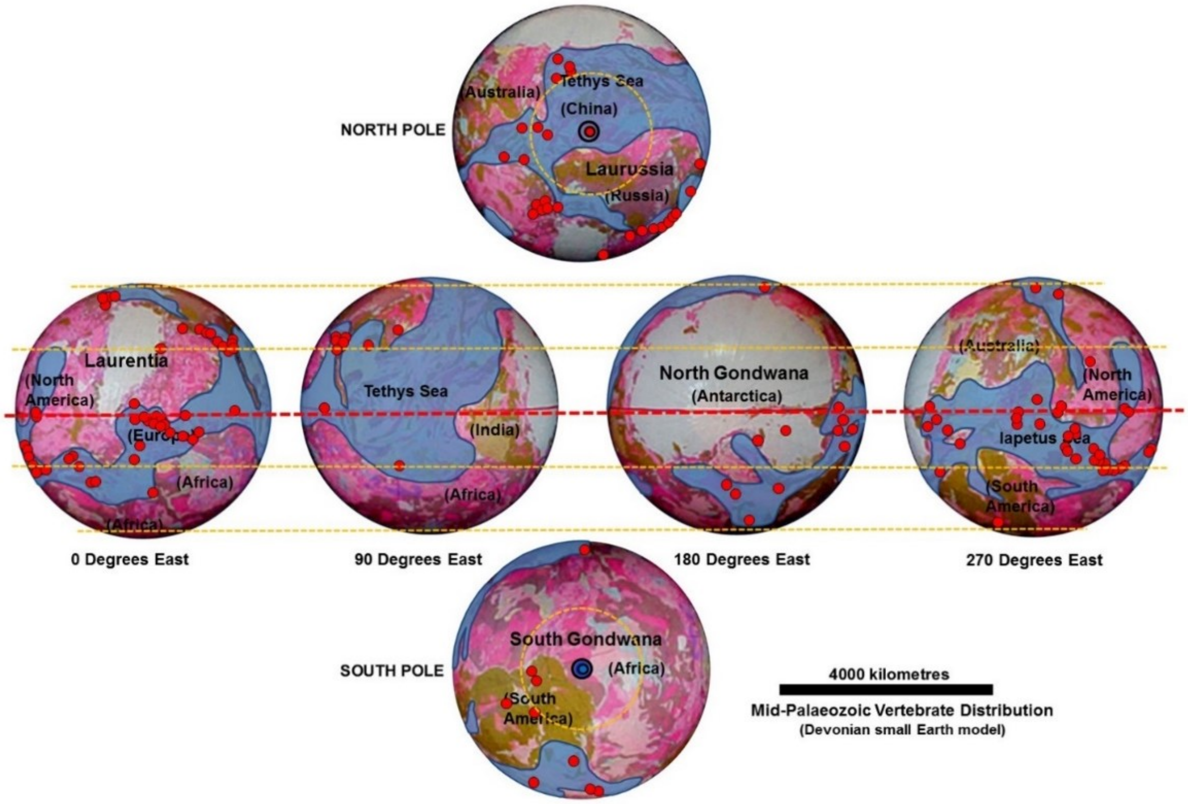

Figure 9 Distribution of mid-Palaeozoic vertebrates plotted on a Devonian small Earth model. Vertebrate data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, mid-Palaeozoic Polar Regions, and distribution of ancient continental seas.

This brief introduction to the distribution of mid-Palaeozoic life forms on an increasing radius Earth again shows that the ongoing network of relatively shallow continental seas provided an ideal environment for early reefs and marine creatures to continue to thrive and proliferate. Warm sea waters during the mid-Palaeozoic continued to extend from equatorial regions through to the North Polar Region allowing evolved species to readily colonise and populate throughout much of the ancient seas.

Late-Palaeozoic Life

The late-Palaeozoic interval of time includes the Carboniferous and Permian Periods. On an increasing radius Earth the late-Palaeozoic was a time when the ability of continental crusts to continue extending within established sedimentary basins was reaching its limit, eventually leading to onset of crustal rupture and breakup during the late-Permian. Breakup of the continental crusts during the late-Permian initiated opening and formation of the modern continents as well as rifting to form the modern, relatively deep, oceans. All of which gave rise to the major end-Permian extinction event and the demise of many plant and animal species on both the lands and in the seas. Draining of the ancient continental seas into the newly formed oceans then led to contraction of established coal swamps, plus exposure and drying of the lands along with the accumulation of evaporites.

Marine life during the late-Palaeozoic was similar to that of the late-Devonian times with new adaptive radiations occurring after the end-Devonian extinction event. The distribution of ammonites, for instance, is shown on the Permian small Earth model in Figure 10. The ammonites were predatory squid-like creatures that lived in coil-shaped shells with some growing to more than a metre across. They became extinct 65 million years ago during the end-Cretaceous extinction event.

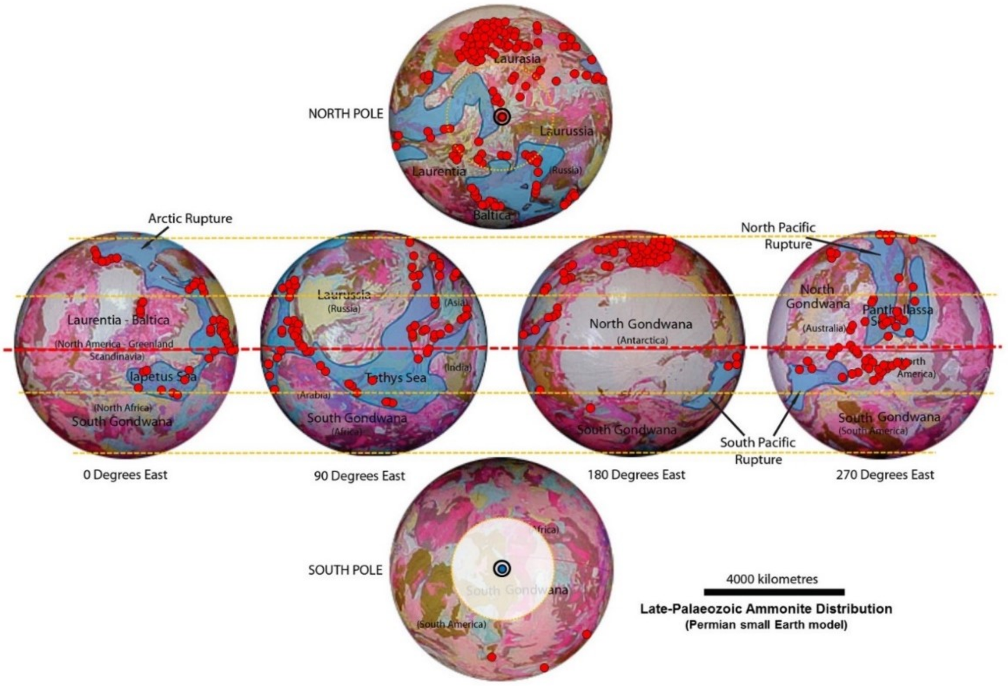

Figure 10 Distribution of late-Palaeozoic ammonites plotted on a Permian small Earth model. Ammonite data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, a late-Palaeozoic South Polar ice-sheet, shaded white, and distribution of ancient continental seas.

In Figure 10 the aerial distribution and surficial areas of the ancient seas had greatly diminished after the end-Devonian extinction event. This reflects the advanced stages of geosynclinal activity and orogenesis prevalent during the mid- to late-Palaeozoic times. The disparity of some plotted ammonite data in Figure 10 also reflects the relatively rapidly changing coastal outlines and distribution of seas during these times.

The distribution of crinoids is shown on the Permian small Earth model in Figure 11. The disparity in distribution again reflects the relatively rapidly changing coastlines and distribution of seas during these times. The distribution of crinoids also highlights the preference for coastal habitats associated with fringing reefs within the equatorial and warmer temperate regions, with lesser distribution within high northern latitudes.

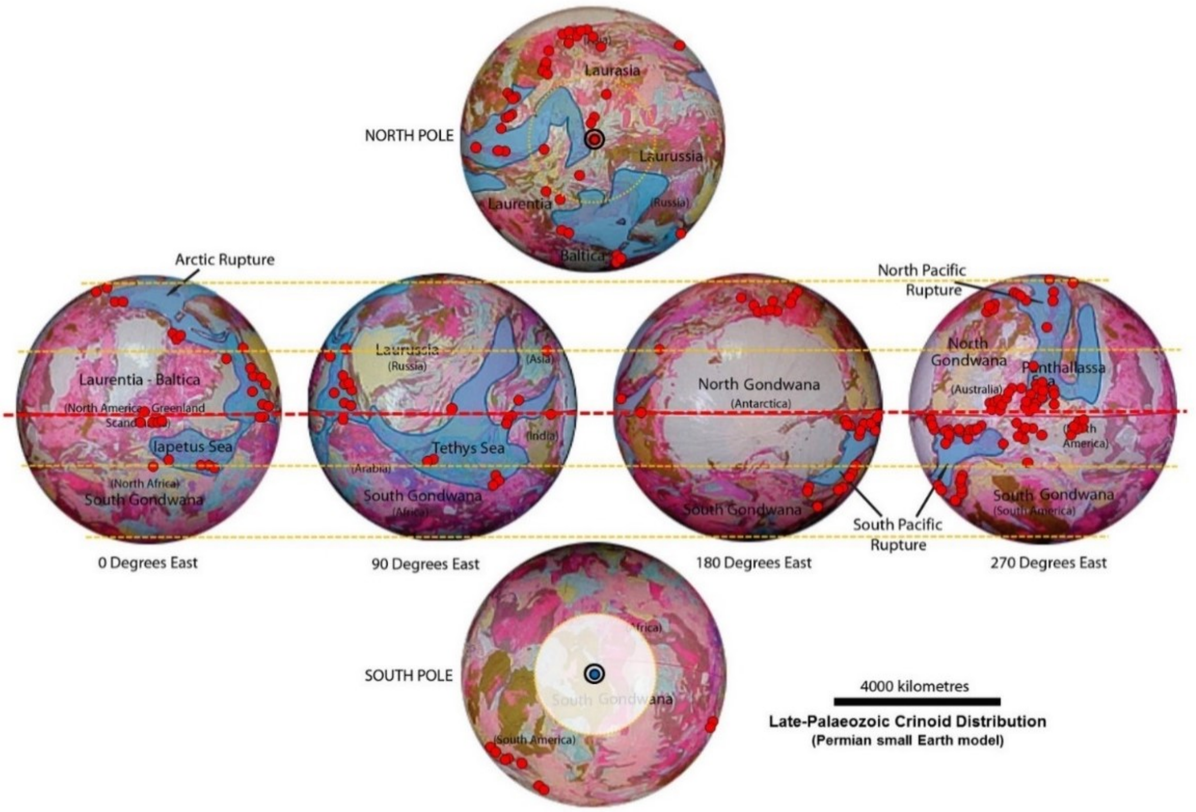

Figure 11 Distribution of late-Palaeozoic crinoids plotted on a Permian small Earth model. Crinoid data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, a late-Palaeozoic South Polar ice-sheet, shaded white, and distribution of ancient continental seas.

The late-Palaeozoic was also characterised by profound changes to life on the land, including evolution of the insects and colonisation of broad lowland swamps by spore-bearing plants. The distribution of plant fossils is shown on the Permian small Earth model in Figure 12. During the late-Palaeozoic a southern ice sheet was present over Southern Gondwana and the presence of plants in the high northern latitudes suggests that temperatures were again moderated in these regions.

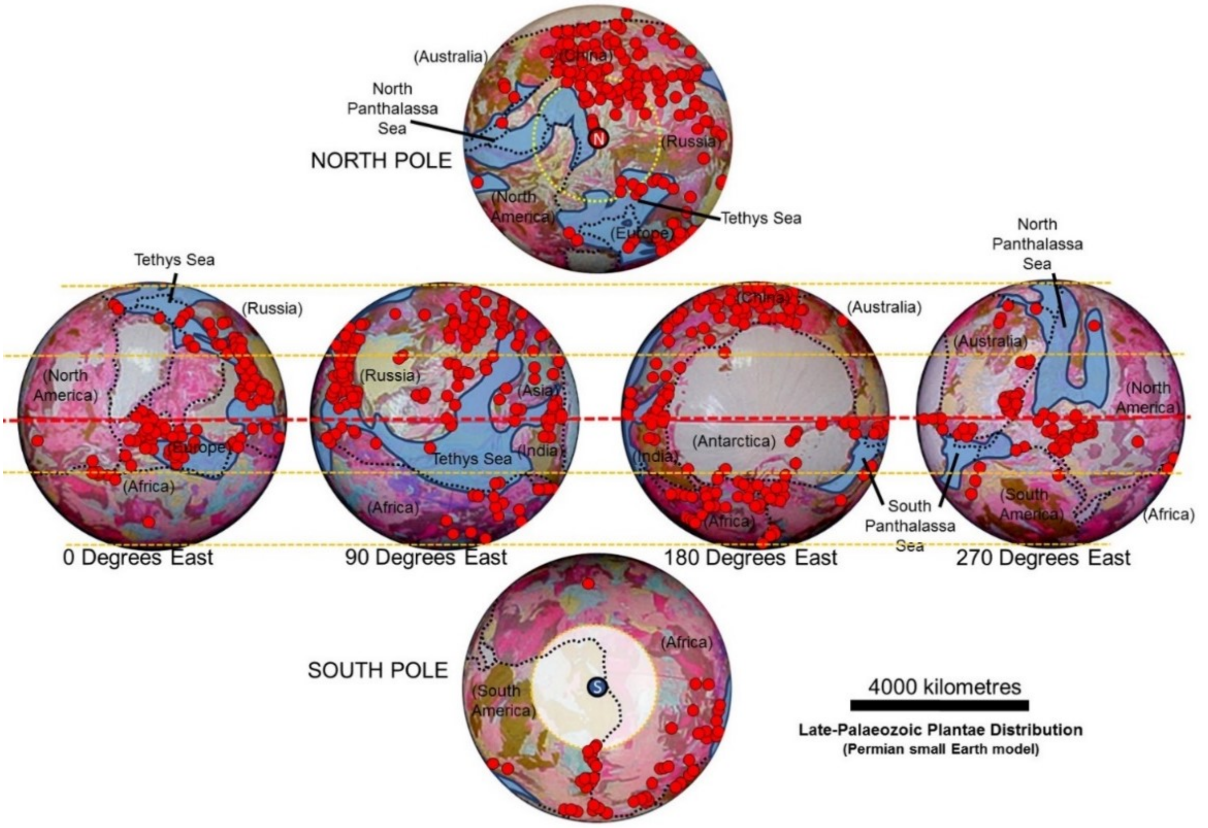

Figure 12 Distribution of late-Palaeozoic plant species plotted as red dots on a Permian small Earth model. Plant data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones, a late-Palaeozoic South Polar ice-sheet, shaded white, and distribution of ancient continental seas.

The earliest known reptiles originated around 315 million years ago during the Carboniferous Period, having evolved from advanced reptile-like amphibians that had become increasingly adapted to life on dry land. The distribution of reptiles is shown on the Permian small Earth model in Figure 13. Also highlighted on this figure are suggested migration links between the various ancient continents. These links, highlighted by green arrows, represent possible migration routes for both the reptiles and succeeding dinosaur life forms prior to breakup of the Pangaean supercontinent during the late-Permian. Some of these links remained into the early-Triassic allowing the early dinosaurs to migrate and populate many of the modern continents prior to isolation during the late-Triassic. Important provincial centres for the reptiles include western North America, western and central Europe, and South Africa.

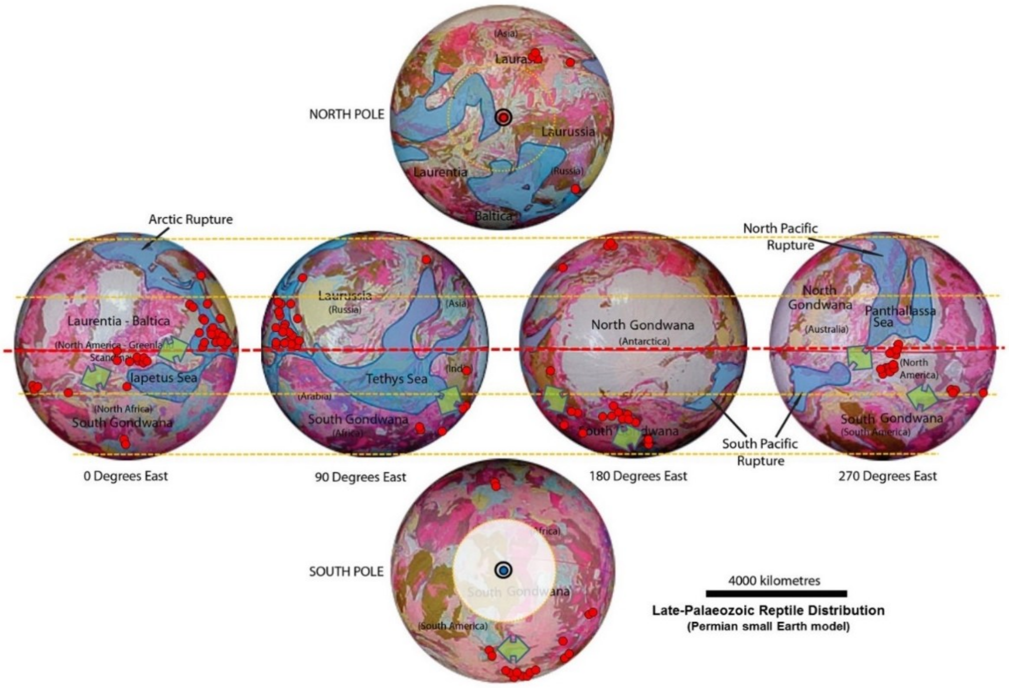

Figure 13 Distribution of late-Palaeozoic reptiles plotted on a Permian small Earth model. Reptile data are shown as red dots (after PaleoBioDB, 2015), in relation to climate zones, a late-Palaeozoic South Polar ice-sheet, shaded white, and distribution of ancient continental seas. Suggested migration routes are highlighted by green arrows.

The distribution of late-Palaeozoic life forms on an increasing radius Earth continue to highlight the importance of the ongoing network of relatively shallow continental Tethys, Iapetus, and Panthalassa Seas in providing an ideal environment for reefs and proliferation of marine creatures. During that time increasing geosynclinal activity and orogenesis severely disrupted the distribution of continental seas, resulting in isolated, often relatively deep seaways. Warm sea waters during the late-Palaeozoic were mainly confined to the equatorial and northern hemisphere regions. A southern polar ice-cap was well established, with possible seasonal icing within the northern polar region, in particular in mountainous regions.

Disruptions to the continental seas, along with elevated topography, further increased erosion of the lands with extensive coal-bearing swamps confined to low-lying regions. The late-Palaeozoic is well noted for the colonisation and proliferation of plant and insect species, along with early vertebrates such as the reptiles. This colonisation was severely disrupted during the late-Permian with the onset of breakup of Pangaea to form the modern continents and opening to form the modern oceans, coincident with the end-Permian extinction event.

Mesozoic Life

The Mesozoic Era comprises the Triassic, Jurassic, and Cretaceous Periods and is renowned as the age of the dinosaurs. On an increasing radius Earth this era coincides with breakup of the ancient Pangaean supercontinent to form the modern continents and opening of the modern oceans. This era also coincides with apparent migration of the South Pole across the opening South Atlantic Ocean, migrating from South Africa as it moved north, across to Antarctica as it moved into the South Polar Region. During that time both the north and south poles were centred over oceans and there were no polar ice caps. The era was also punctuated by the end-Triassic extinction event during merging of the North and South Pacific Oceans and the era terminated with the end-Cretaceous extinction event.

The following figures focus on the various dinosaur-related lineages to highlight their global distributions in context with opening of the modern oceans and dispersal of the modern continents during the Mesozoic Era. During the slow recovery from the end-Permian extinction event, a previously obscure group of animals called the archosaurs—a group that includes the extinct dinosaurs and whose living representatives consist of birds and crocodiles—became the most abundant and diverse terrestrial vertebrates during the Triassic.

The Triassic witnessed the appearance of several new groups of archosaurs, some of which have living descendants today. The distribution of archosaurs is shown on the early-Triassic small Earth model in Figure 14. From their provincial ancestral reptile distributions (Figure 13) the archosaurs dispersed widely during the Triassic Period, extending from south polar to high northern latitudes.

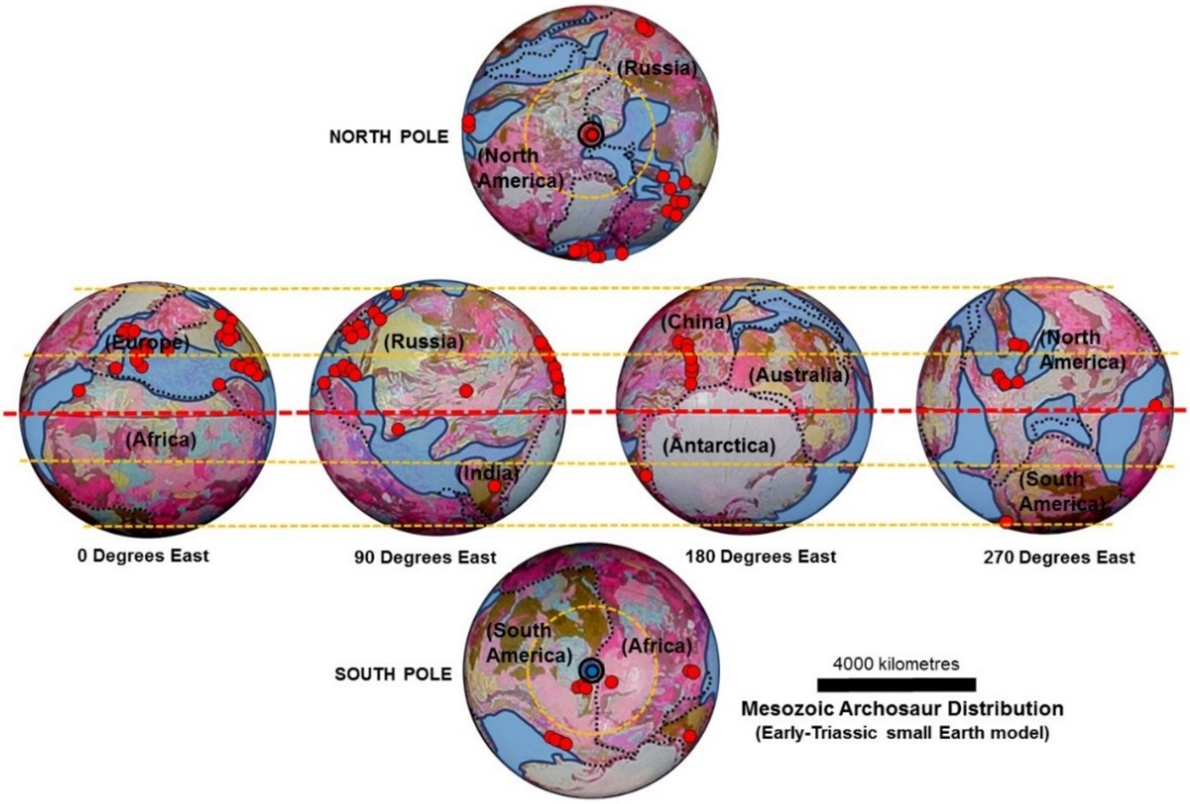

Figure 14 Distribution of Mesozoic archosaurs plotted on an early-Triassic small Earth model. Archosaur data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

The dinosaurs were a diverse group of animals that first appeared during the Triassic period. They were the dominant terrestrial vertebrates until the end of the Cretaceous. The Dinosaurs are divided into two orders, the Ornithischia and Saurischia. This division is based on the evolution of the pelvis into more bird-hip and lizard-hip like structures, details in the vertebrae, the development of armour, and the possession of a predentary bone in the front of the lower jaw used to clip off plant material.

The early distribution of the dinosaurs is shown on the late-Triassic small Earth model in Figure 15. Important provincial centres coincide with their ancestral reptile centres and include locations in Europe—located in the northern Temperate Zone, North America—located in the Equatorial Zone, and South Africa—located in the South Polar Region.

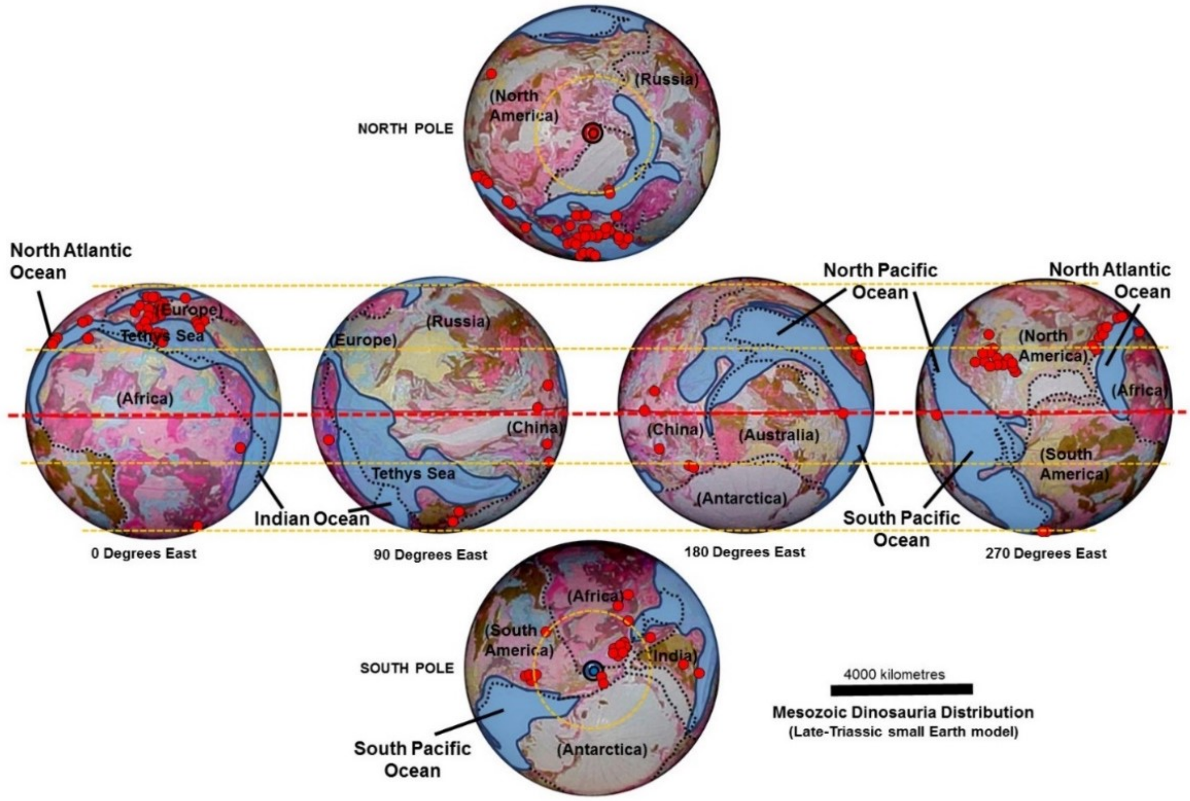

Figure 16 Distribution of Mesozoic dinosauria plotted on a late-Triassic small Earth model. Dinosauria data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

The Ornithischia are a group of medium to large, beaked, herbivorous dinosaurs. The distribution of ornithischia is shown on the late-Jurassic small Earth model in Figure 16. In this figure, as with the dinosauria in Figure 15, there is still an element of provincial distribution centred on locations in North America and Europe, plus a new centre in China. By the late-Jurassic, indications are that the South African ornithischia had either died out or had migrated to adjoining southern South America. During that time the South Pole had migrated into South Africa and breaching between Africa and South America and opening of the Atlantic and Indian Oceans had commenced. This opening effectively isolated South Africa from adjoining southern South America, India, and Antarctica. Elsewhere, other dinosaur species were becoming increasingly isolated in Australia, India, and the Asian-Russian continents.

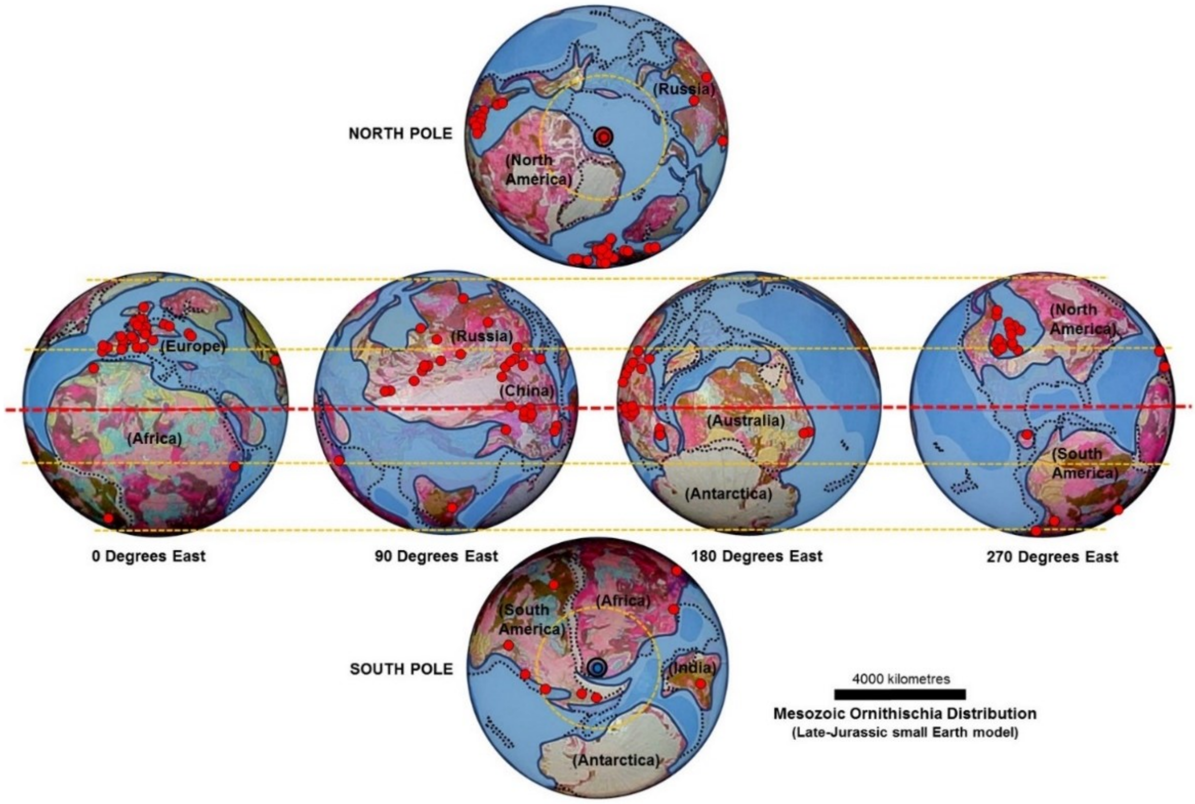

Figure 16 Distribution of Mesozoic ornithischia plotted on a late-Jurassic small Earth model. Ornithischia data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

The saurischian dinosaurs are traditionally distinguished from ornithischian dinosaurs by their three-pronged pelvic structure, with the pubis pointing forward. The distribution of saurischian dinosaurs is shown on the early-Cretaceous small Earth model in Figure 17. By the early-Cretaceous these dinosaurs were rapidly diversifying and populating most continents on Earth. From small provincial centres the saurischians were also evolving independently as continental breakup and changing sea levels formed a number of isolated island continents.

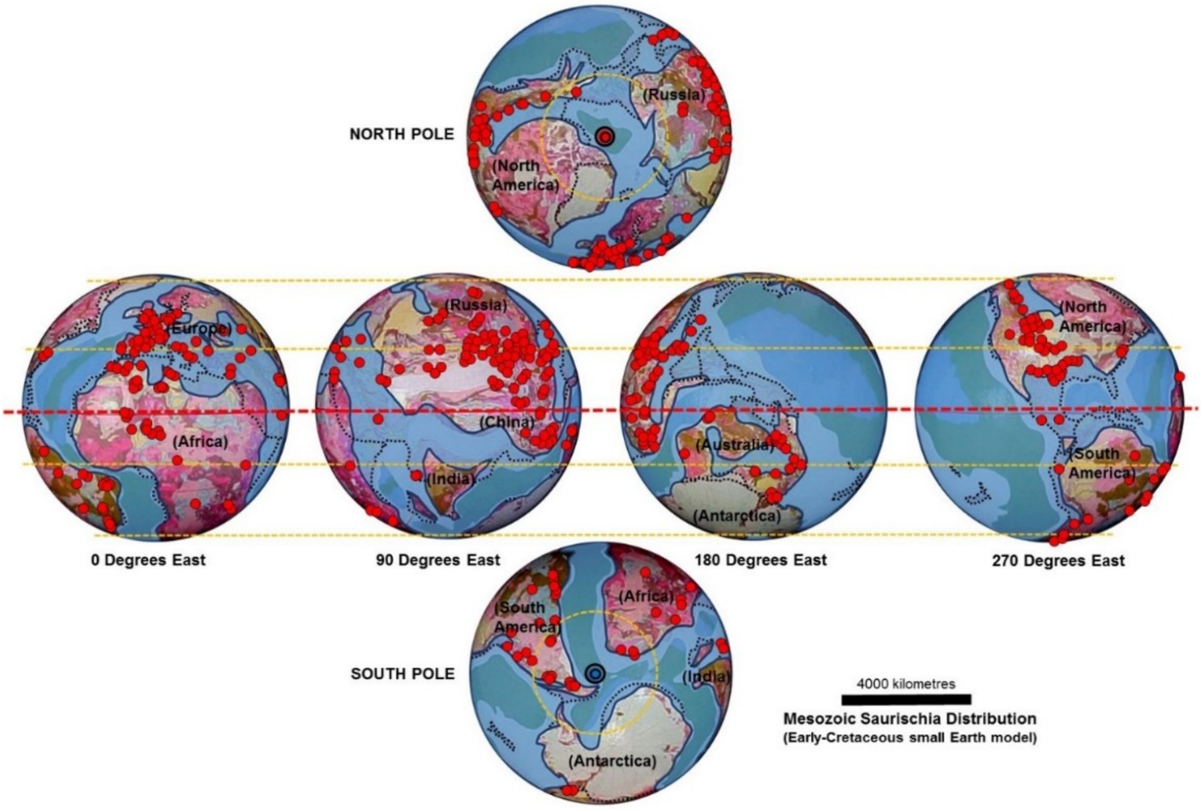

Figure 17 Distribution of Mesozoic saurischia plotted on an early-Cretaceous small Earth model. Saurischia data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

Sauropods were a group of four-legged, herbivorous animals with a relatively simple body plan that varied only slightly throughout the group. The distribution of sauropod dinosaurs is shown on the mid-Cretaceous small Earth model in Figure 18. From the mid-Cretaceous through to the late-Cretaceous their distributions remained much the same and fossil evidence shows they were more prolific during the late-Cretaceous.

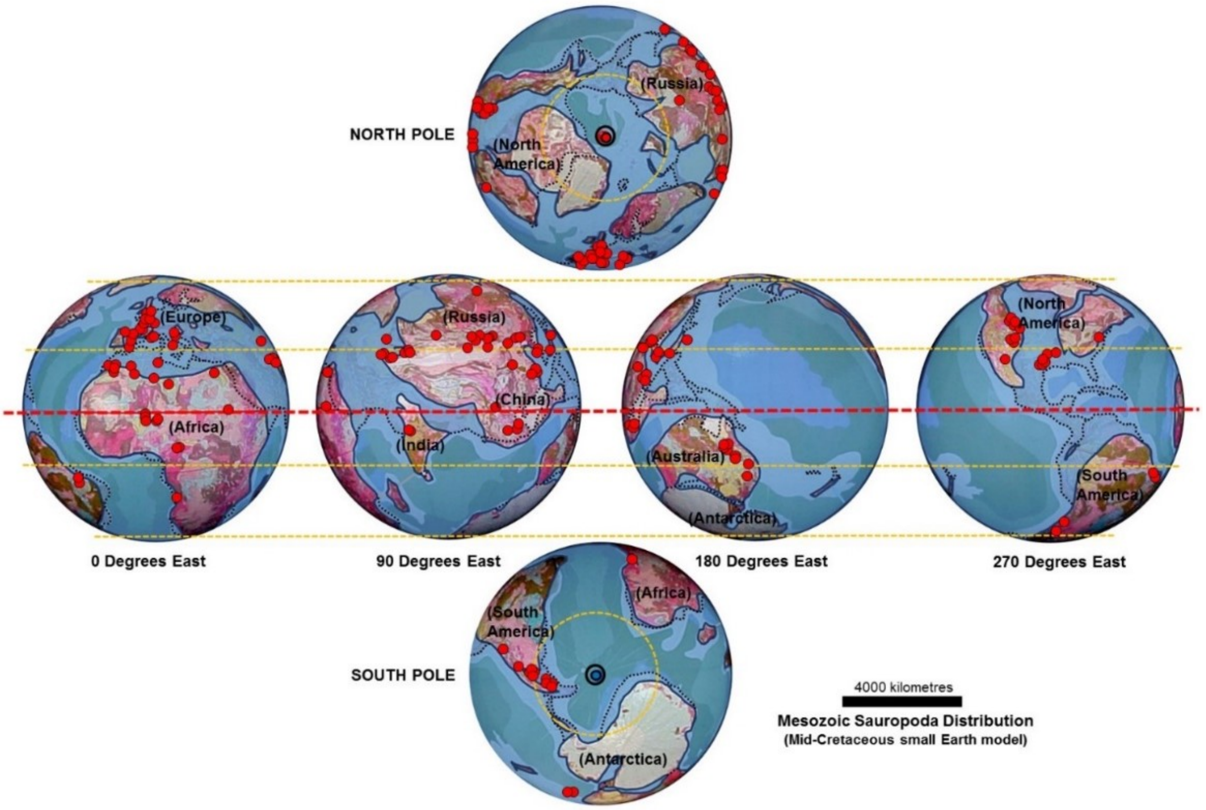

Figure 18 Distribution of Mesozoic sauropoda plotted on a mid-Cretaceous small Earth model. Sauropoda data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

The theropod dinosaurs are a diverse sub-group of the bipedal saurischian dinosaurs. The distribution of theropod dinosaurs is shown on the late-Cretaceous small Earth model in Figure 19. In this figure, by the late-Cretaceous the theropods had become widely dispersed, populating all continents and extending from the high northern to the high southern latitudes. This distribution also included theropods in remote islands such as New Zealand and Madagascar. Theropods in remote islands may represent a holdover of species from early beginnings during the late-Triassic times when New Zealand, for instance, was connected to Central America and Madagascar was connected to India and South Africa.

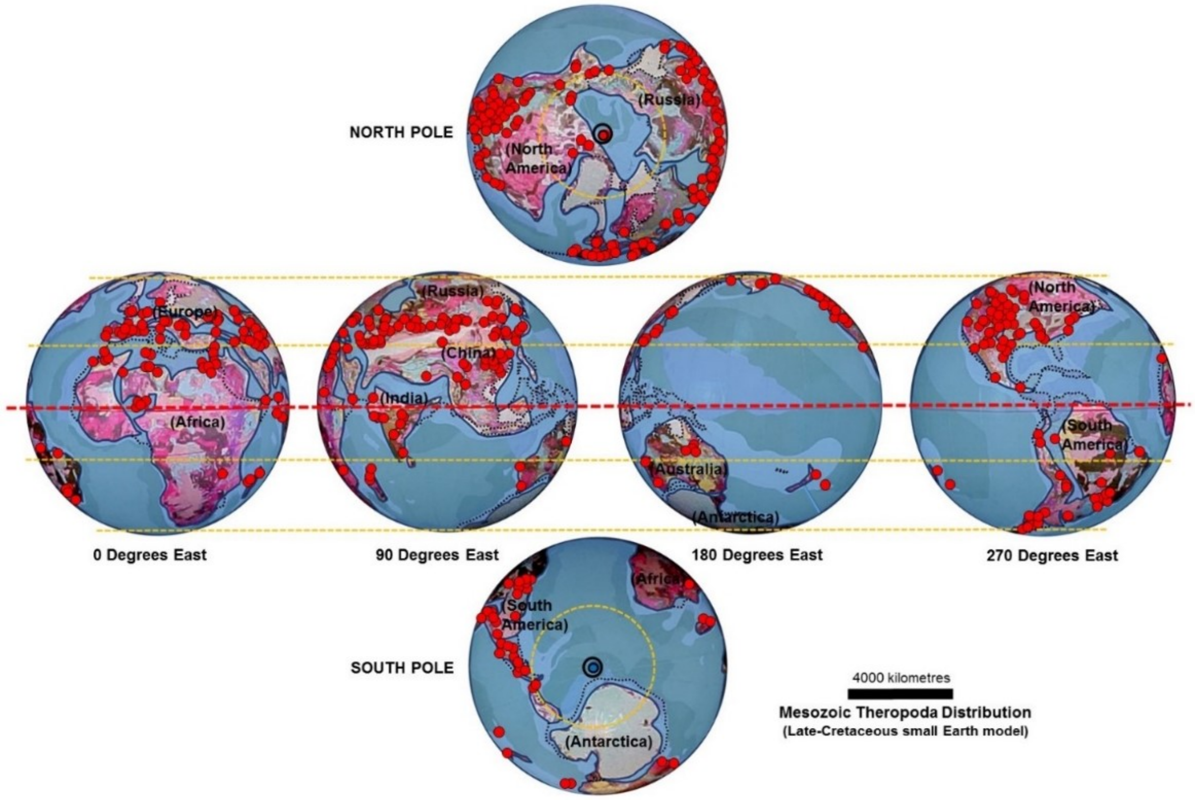

Figure 19 Distribution of Mesozoic theropoda plotted on a late-Cretaceous small Earth model. Theropoda data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of ancient continental seas and modern oceans.

On an increasing radius Earth the distribution, migration, and eventual demise of the dinosaurs can be visualised in conjunction with this very involved period of crustal breakup and new ocean development. While the prolonged period of time involved during this crustal breakup allowed the dinosaur species to migrate to more equitable locations, it also presented new physical and environmental barriers. The draining of the ancient continental seas, for instance, influenced the distribution of the modern seas and oceans and adversely affected available dinosaur habitats, migration routes, and escape avenues. Migration away from these physical barriers may have then encouraged the dinosaurs to evolve into new species. In contrast, failing to evolve, migrate, or being land-locked may have also caused their localised demise.

Cenozoic Life

The Cenozoic Era is known as the Age of Mammals. The Cenozoic is also renowned for the dominance of savanna-type environments, co-dependent flowering plants and insects, and the birds. Grasses played a very important role in this era, shaping the evolution of birds and mammals that fed on it.

The distribution of mammals is shown on the Eocene small Earth model in Figure 20. This figure shows a preferred distribution of mammals within equatorial and temperate regions, with minor occurrences within the north and south Polar Regions. This distribution may have been attributed primarily to their metabolic requirements and the presence of favourable vegetation.

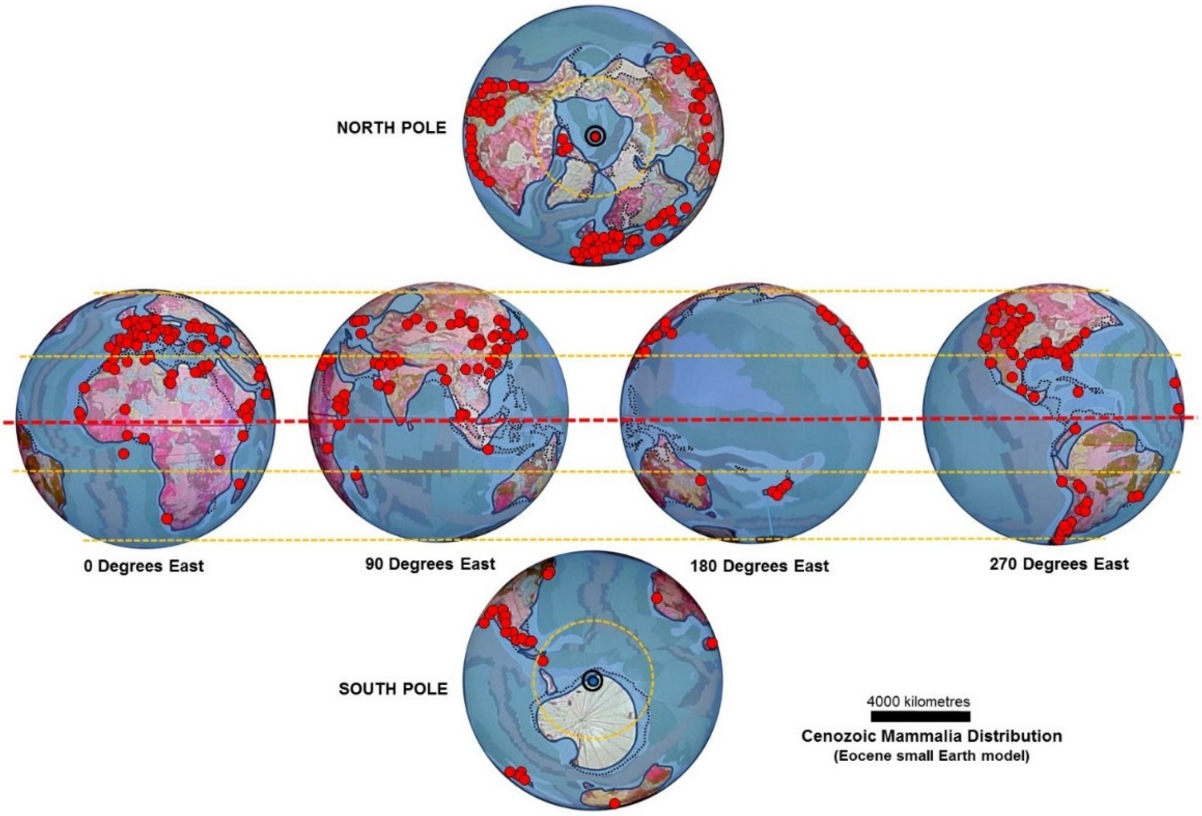

Figure 20 Distribution of Cenozoic mammalia plotted on an Eocene small Earth model. Mammalia data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of modern oceans.

On an increasing radius Earth the diversity of modern mammalian life-forms is also attributable to the relative isolation of modern continents as compared to earlier eras where land connections existed between most continents. Ancestral land connections favoured interactive migration between continents while isolation of the continents favoured adaptive radiation and diversification of the mammalian species to the present-day.

An example of adaptive radiation in isolation is the marsupials. Marsupials are thought to have reached Australia via Antarctica at least 50 to 65 million years ago suggesting a single dispersion event of just one species, most likely a relative of the opossums from South America. On an increasing radius Earth a common link between South America, Antarctica and Australia existed during the Cretaceous and Paleocene Epochs within the southern temperate region. At that time ancestors to the marsupials existed in southern South America and the first fossils in Australia existed in the Eocene. During that same time Australia separated from Antarctica and has since remained as an island continent. Antarctica also migrated into the South Polar Region and began to establish a permanent ice cap during the Oligocene. With no prior predators in Australia the marsupials then radiated in isolation into the wide variety of life forms seen today (Figure 21).

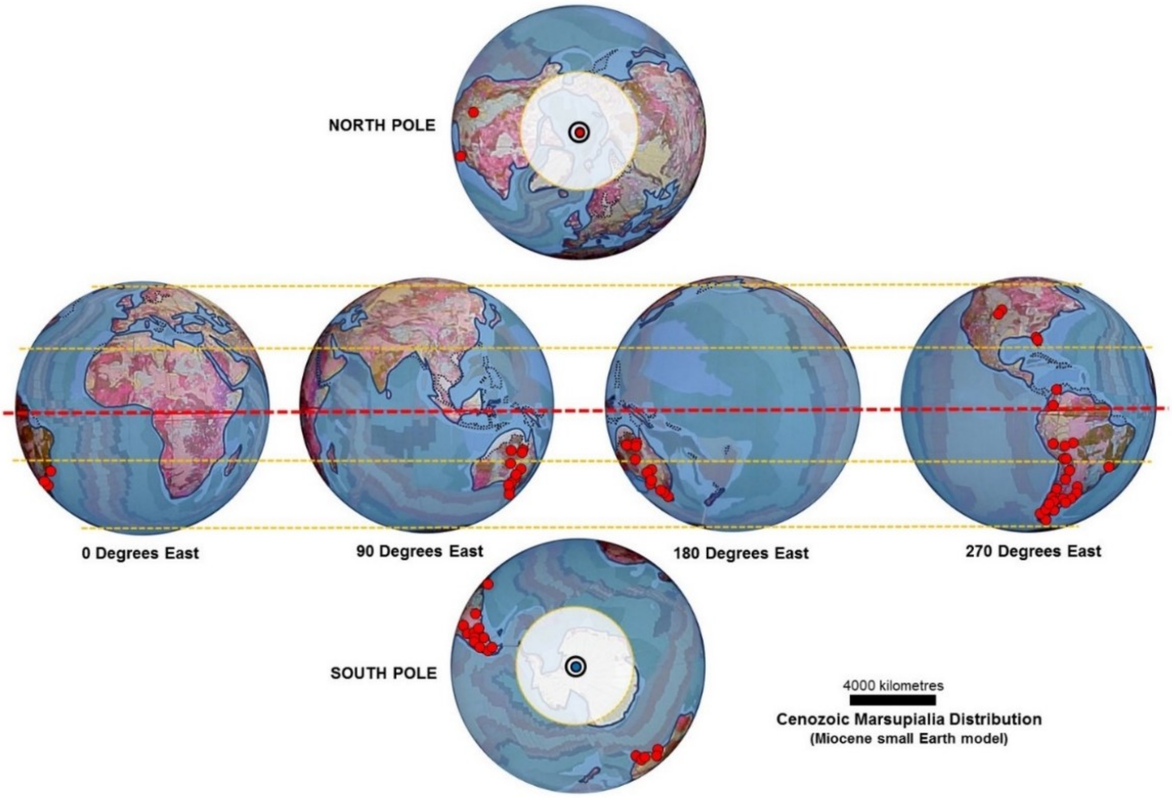

Figure 21 Distribution of Cenozoic marsupialia plotted on a Miocene small Earth model. Marsupialia data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of modern oceans, as well as North and South Polar ice caps, shaded white.

Primates arose from mammalian ancestors that lived in the trees of tropical forests and many primate characteristics are thought to represent adaptations to life in this environment. Most primate species remained at least partly arboreal. With the exception of humans, who inhabit every continent, most primates live in tropical or subtropical regions of the Americas, Africa and Asia. Based on fossil evidence, the earliest known true primates date to the Eocene—55.8 million years ago—although molecular clock studies suggest that the primate branch may be even older, originating near the Cretaceous-Paleocene boundary around 63 to 74 million years ago.

On an increasing radius Earth ancestors to the primates existed in southern South America, North America, Europe, and China during the Paleocene and Eocene Epochs. From there, colonisation rapidly extended into east and south Africa, Europe and China, with a decline in the Americas to the present-day. This distribution is consistent with land-based migration routes existing between each of these continents and excludes colonisation of the island continents, such as Australia and New Zealand, prior to modern-day colonisation (Figure 22).

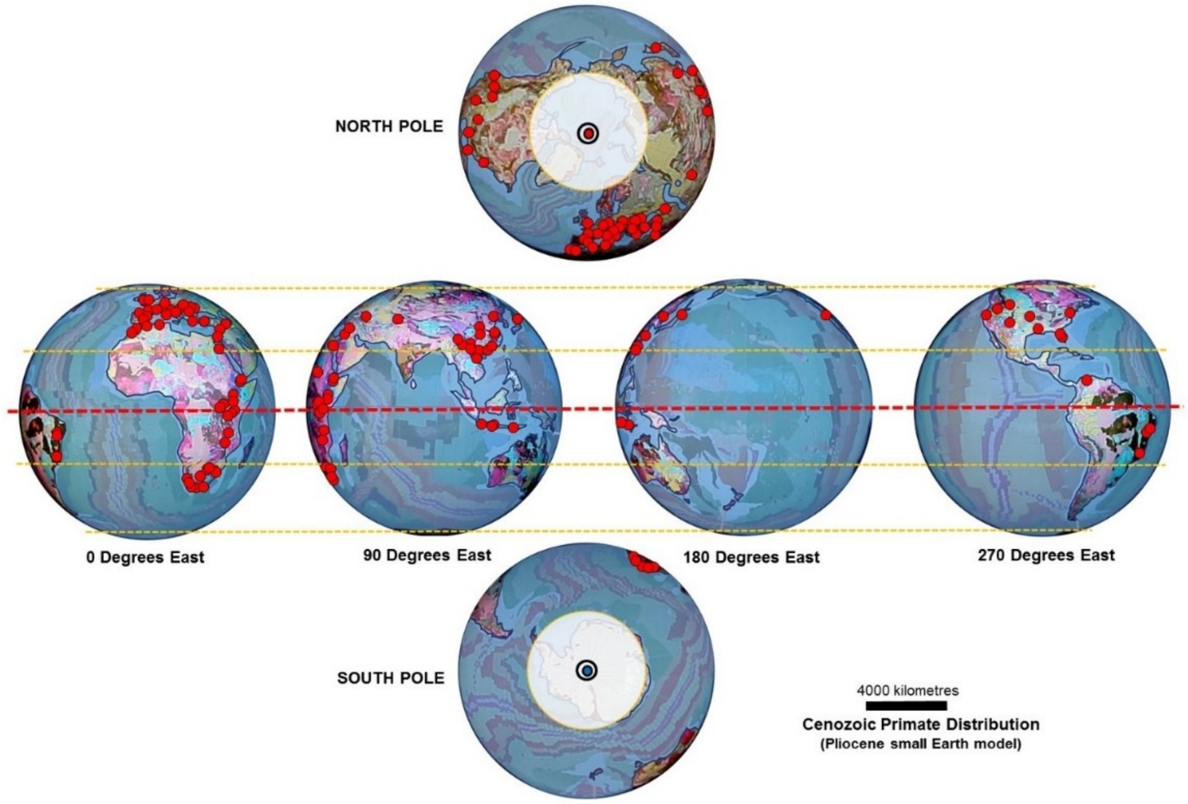

Figure 22 Distribution of Cenozoic primates plotted on a Pliocene small Earth model. Primate data are shown as red dots (after PaleoBioDB, 2015) in relation to climate zones and distribution of modern oceans, as well as North and South Polar ice caps, shaded white.