Paper 3: Modelling the Ancient Supercontinents

"...it is theoretically possible for the continents, without shelves, to fit together at approximately 40 percent of the present Earth radius by considering that continental shelves were formed after the continental crust had fragmented." Vogel, 1983

Construction of small Earth models on an increasing radius Earth, extending from the early-Jurassic Period back to the early-Archaean, involves the progressive removal of all younger continental basin sediments and magmatic rocks and simply returning these to the ancient lands or back to the mantle where they came from. Each continental basin and igneous complex is then restored to a pre-extension or pre-rift configuration on a smaller radius Earth model. By moving back in time the adjacent margins of each sedimentary basin or igneous complex are then progressively moved closer together while still preserving the spatial integrity of adjacent, more ancient, cratonic and orogenic crusts.

The series of 24 small Earth models (Figure 1) presented here are based on the continental and seafloor crustal geology shown on the Geological Map of the World (1990). These models represent the earlier seafloor crustal models—models 13 to 23—recreated to include continental crustal geology, plus additional pre-Triassic continental crustal models extending back in time to the early-Archaean. One model has also been extended to 5 million years into the future.

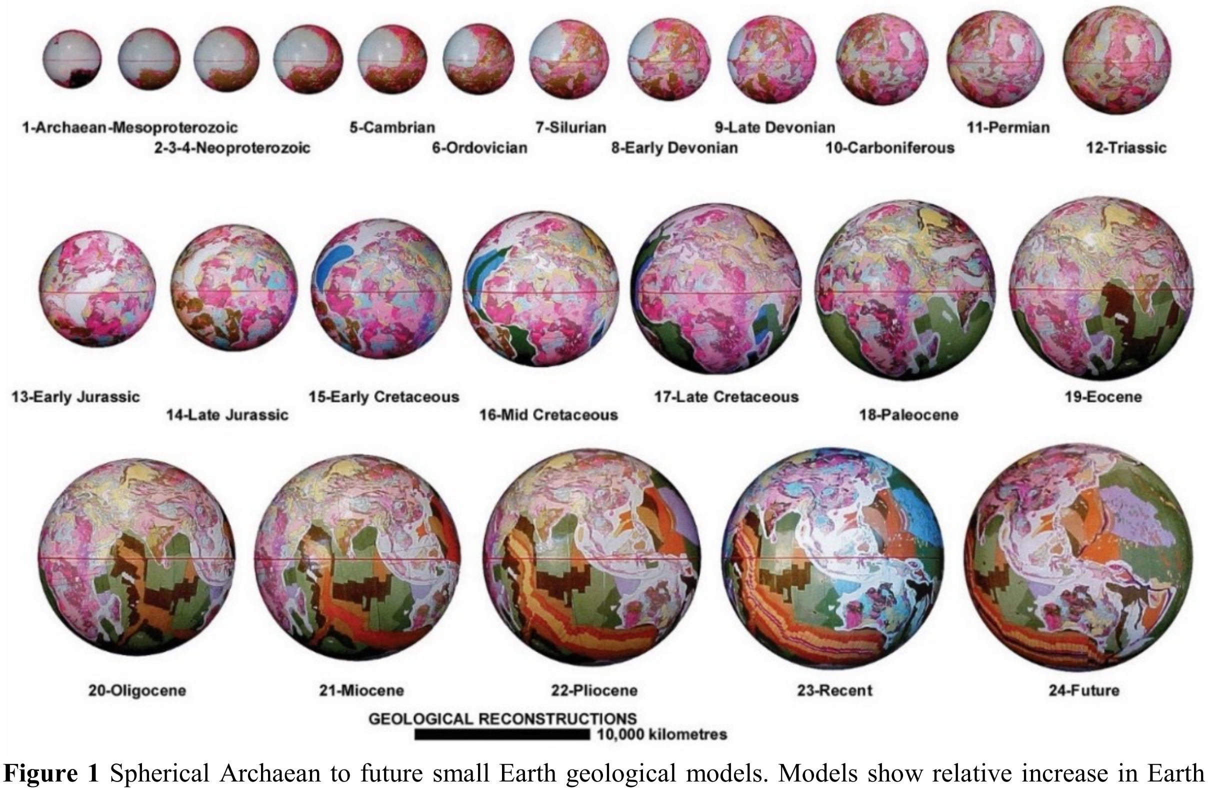

Figure 1 Spherical Archaean to future small Earth geological models. Models show relative increase in Earth radii over time showing both continental and seafloor geology. Models range in age from the early-Archaean to present-day, plus one model projected 5 million years into the future.

The step-wise construction of present-day to Archaean models presented here is continued back in time until removal of all seafloor volcanic and continental sedimentary basin sediments and magmatic rocks is complete. At that time the most ancient Archaean cratonic rocks, along with any remnant Proterozoic orogenic rocks, are then assembled together as a complete, primordial, pan-global Archaean small Earth model. Modelling studies suggest that this primordial Archaean small Earth model had a radius of approximately 1,700 kilometres, which is about 27 percent of the present Earth's radius and of a similar size to the present Earth's Moon.

Modelling the supercontinents on increasing radius small Earth models shows that the ancient supercontinents existed as a complete continental crustal shell encompassing the entire Earth for the first 94 percent of geologic history. This supercontinental phase lasted for some 3,750 million years and culminated during breakup of the Pangaean supercontinent approximately 250 million years ago. During pre-breakup times, continental crust covered the entire Earth and exposed supercontinental lands were defined by a superimposed network of continental seas. The origin and changing configuration of the supercontinents during these times involved a progressive, evolutionary crustal process during a prolonged period of crustal stretching, along with changes to both Earth surface area and surface curvature through time.

In the following sections discussion will start with the most ancient Archaean supercontinent and then move forward in time through to Rodinia, Gondwana, and finally to Pangaea. There are many lesser supercontinents described in conventional literature, however descriptions will be restricted to the better known supercontinents. The term supercontinent, as used here, will differ somewhat from conventional usage where it is used to imply an assemblage of ancient crustal fragments. The term supercontinent is used here simply to distinguish between the exposed land surfaces on a pre-breakup small Earth and the post-breakup modern continents. As such, it is iterated that on an increasing radius Earth it is the distribution of continental seas that defines the outline of ancient supercontinents, not an arbitrary assemblage of fragmented crusts.

Archaean Supercontinent

The oldest known rocks found on Earth today represent the period of time when the ancient crusts first formed and, more importantly, the period of time when conditions on Earth were stable enough for the rocks to be preserved to the present-day. Evidence from minerals preserved in the ancient metamorphic and igneous rocks suggest that global crustal temperatures during the pre- to early-Archaean where very high. This suggests that the Earth was potentially molten during the pre-Archaean Hadean Eon, prior to cooling and stabilisation of the crusts during the early-Archaean and later times.

The primordial Archaean crustal assemblage (Figure 2), as constructed during small Earth modelling studies, is shown along with location of the Archaean equator and poles. This figure represents an assemblage of the most ancient cratonic and orogenic crusts that are currently preserved on the present-day Earth. Establishing the location of the equator and poles was achieved via palaeomagnetic studies and will be introduced later. The named remnants of the present-day modern continents are also highlighted in this figure as black outlines.

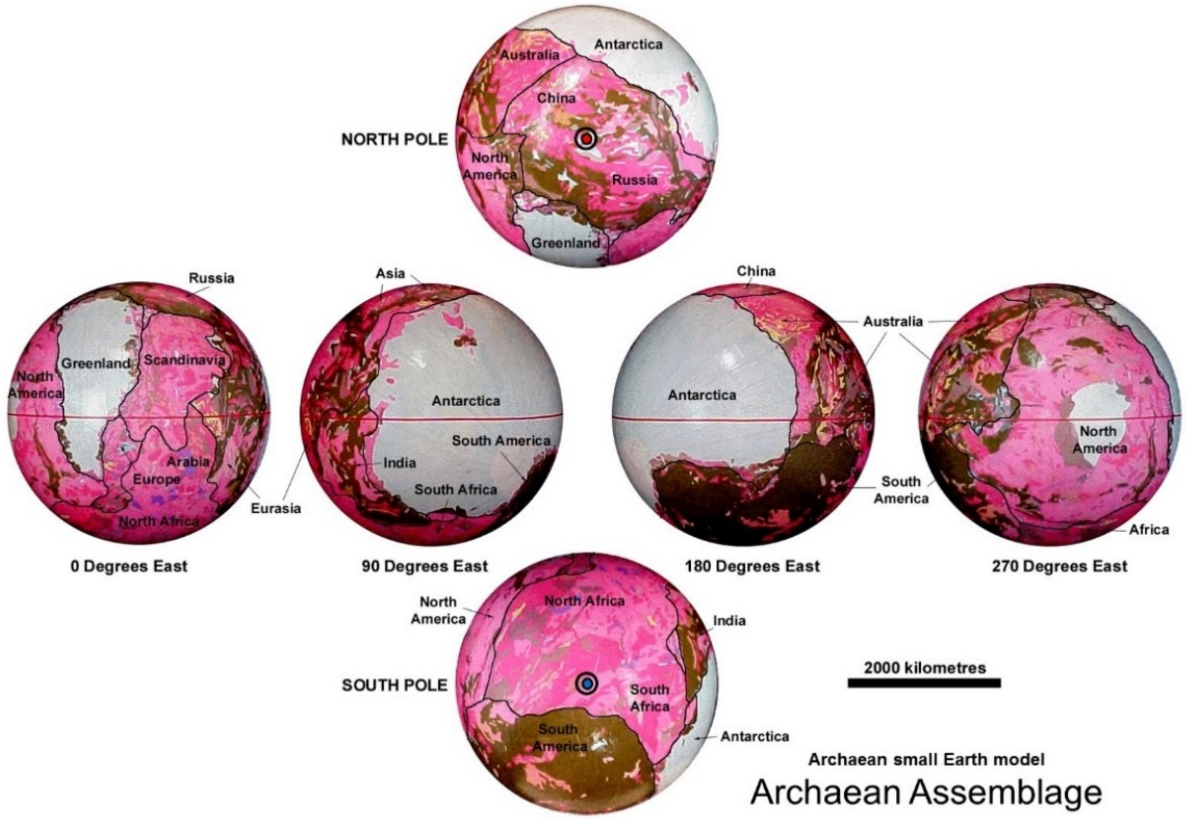

Figure 2 The primordial Archaean small Earth model showing the assemblage of ancient early-Precambrian continental crusts. The cratons are shown as pink and red, Proterozoic orogenic rocks are shown as khaki and the location of the present-day Antarctic and Greenland ice-sheets (covering Precambrian crustal rocks) are shown as off white. The ancient equator is shown as a horizontal red line and the poles are shown as red and blue dots. Ancient remnants of each of the present-day continents are outlined in black.

The size of this Archaean supercontinent is estimated to be approximately 1,700 kilometres radius, about 27 percent of the present Earth radius and about the size of the present Moon. Because of the extremely low rates of increase in radius existing during the Precambrian times—microns per year, the Archaean small Earth model in Figure 2 represents the period of time extending from the early-Archaean through to the mid-Proterozoic Era. This one model then represents about 2,400 million years, or two thirds of all known geological history.

On an increasing radius Earth, during the early-Archaean times, it is envisaged that once the primitive granite and volcanic crust had cooled and solidified, onset of increase in Earth radius was initiated as global-scale cracking and fracturing of the crust localised within a network of crustal weakness surrounding relatively stable lands. This network of crustal weakness and fracturing was subsequently intruded by renewed granite activity or primitive volcanic lava—as dykes. As time slowly progressed the influence of changing surface curvature, although minimal during that time, also assisted in maintaining a distinction between elevated land surfaces and low-lying areas coincident with the network of crustal weakness. Eroded sediments were then deposited in these low-lying areas. It is considered that this elevation contrast was instrumental in establishing a distinction between the first Archaean supercontinental lands and the first ancient seas and sedimentary basins.

The emergent Archaean land surface may have been a barren, possibly windswept rocky landscape devoid of all forms of life and exposed to erosion of rock and dust particles by winds and reduced atmospheric rain. During that time chemical weathering and erosion of the rocks may have been prevalent, in particular erosion by hot and potentially acidic waters from volcanic eruptions localised along the newly established network of crustal weakness. This weathering and erosion then gave rise to deposition of the first sediments, deposited in low-lying sedimentary basins, along with extruded volcanic lava.

In Figure 2, remnants of this network of low-lying sedimentary basins can be seen by the distribution of khaki coloured Precambrian sedimentary rocks, and the ancient cratonic crusts are shown as areas of pink and red. The early sedimentary basins would have initially been small and isolated, becoming progressively more extensive over time. This early granite-greenstone and sedimentary crust now represents the oldest preserved crustal remnants on Earth today. The prevailing reduced atmosphere and waters also enabled metals rich in sulphur, as well as elemental carbon, to accumulate within the sedimentary basins which, in turn, may have formed the basis for bacterial life forms to emerge and evolve during the latter Precambrian times.

Geological evidence suggests that during the latter part of this Archaean supercontinent phase, sedimentary basins were slowly filling to capacity over the extremely long period of time operative during the ancient times to form extensive platform sedimentary basins. The Proterozoic, in particular, is characterised by the presence of very large stable sedimentary platform basins, forming relatively shallow seas with a very low elevation contrast between the dry lands and the seas. Any further erosion of the lands and deposition of sediments was then limited to mainly chemically-precipitated siliceous chert, carbonate, and banded iron formation rocks within the shallow seas. Remnants of these chemically-precipitated rocks, along with the aerially extensive granite, volcanic, and associated sedimentary rocks making up the ancient lands are now preserved on many of the modern continents.

During this extended period of time, the ancient North and South Poles were located within what are now Northern China and West Africa respectively (Figure 2). Similarly, the ancient equator is shown to have passed through what is now North America, East Antarctica, Australia, Greenland, and Scandinavia. Over this extended period of time the primitive Archaean supercontinent also underwent subtle changes to its network of seaways and sedimentary basins. These geological changes eventually evolved imperceptibly—via the early-Proterozoic Columbia supercontinent—into the better known Rodinia supercontinent some 1,000 million years ago. It is again emphasised that on an increasing radius Earth it is the changes to sea-levels and distributions of the network of sedimentary basins that define the progression from one supercontinent to the next.

Rodinia Supercontinent

The conventional Plate Tectonic Rodinia supercontinental assemblage relies heavily on palaeomagnetic evidence to constrain a multitude of plate-fit options that are currently published in the literature. These assemblages are further supported by ancient climate, fossil, and geographic data as required. These assemblages are, however, seriously hindered by the longitudinal limitations imposed by palaeomagnetic constraints. Beyond these limitations, the presence of largely theoretical ancient oceans also requires that the continental crustal fragments making up Rodinia must be sourced from remote and equally theoretical continents, which had in turn also previously been arbitrarily fragmented and dispersed. This fragmentation and dispersal process results in a confused multitude of assemblage options for each supercontinental fragment, usually where fragmentation is not supported by local geological or geographical evidence.

Rodinia on an increasing radius Earth is represented by the late-Proterozoic small Earth model—at about 800 million years ago (Figure 3). The assemblage and distribution of the remnant modern continental outlines are shown as black outlines, along with the Proterozoic magnetic poles and equator. Because there is no published ancient coastal information available for the Precambrian times to properly define the distribution of ancient continental seas, outline of the Rodinia supercontinent and seaways on an increasing radius Earth is inferred from the distribution of Precambrian continental sedimentary basins—shown as khaki colours.

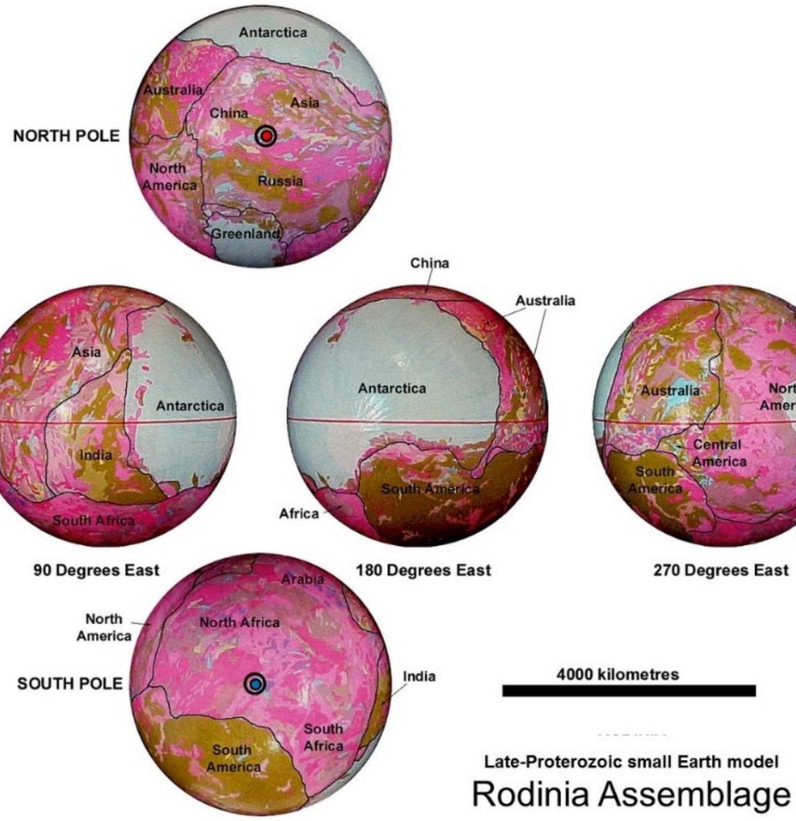

Figure 3 Late-Proterozoic Rodinia small Earth supercontinent assemblage. The model shows the distribution of Precambrian cratons (pink and red) inferred to represent exposed land, and a network of orogens and basins (khaki) inferred to represent continental seas. The black lines represent outlines of remnant present-day continents.

Comparison of the Rodinia small Earth model in Figure 3 with the Archaean model in Figure 2 shows that there is not a lot of difference between these two models. The location of the poles and equator are essentially the same and the distribution of ancient cratons is also much the same. The final phase of the Archaean supercontinental development history was the formation of very large, stable sedimentary platform basins and shallow seas with a low elevation contrast between the lands and seas. This, in essence, is the only difference between the Archaean and late-Proterozoic Rodinia supercontinents.

The distinguishing feature of the Rodinia supercontinental history is that it coincides with initiation of a second phase of steadily increasing surface area and Earth radius. As a result of this steadily increasing Earth radius, changes to surface curvature were starting to take effect which began to elevate the exposed lands and, in turn, increase the elevation contrast between the lands and seas. This elevation contrast initiated an increased rate of erosion of the exposed lands, which then influenced changes to the distribution of seas and corresponding coastal outlines of the supercontinents.

Another distinguishing feature of the Rodinian times was the changing atmospheric conditions. These conditions changed from reducing conditions throughout much of the earlier Archaean times, to the accumulation of atmospheric oxygen during the Proterozoic. This transition was marked by an increasing accumulation of banded iron formation rocks and chemically precipitated calcium and magnesium carbonate rocks during this time. The transition also coincided with development and preservation of the earliest life forms, soon to explode in diversity during the following Palaeozoic Gondwana supercontinental times.

During late-Proterozoic Rodinian times, the ancient North and South Poles continued to be located within what is now Northern China and West Africa respectively. The ancient equator continued to pass through what is now North America, East Antarctica, Australia, Greenland, and Scandinavia, as well as Europe, Asia, and India—essentially the same as during Archaean times.

On increasing radius small Earth models the Rodinia assemblage represents a supercontinent transitional to the better known Gondwana and ultimately to the Pangaea supercontinental configurations. As shown on both the Archaean and Rodinia small Earth models, the change from one supercontinent to another is progressive and evolutionary and this theme will continue to follow through to the Gondwana and Pangaea supercontinents.

Gondwana Supercontinent

The conventional Plate Tectonic Gondwana supercontinental assemblage is made up of an assemblage of the present-day South America, Africa, Arabia, Madagascar, India, Australia, and Antarctican continents, as well as crustal fragments from Florida, southern and central Europe, Turkey, Iran, Afghanistan, Tibet, and New Zealand. This conventional assemblage shows that these present-day continents were assembled into large, separate, northern and southern Gondwana supercontinents plus smaller sub-continents separated by a number of largely inferred ancient oceans. This assemblage is said to have formed during a Pan-African tectonic event. From its initial assemblage, the conventional Gondwana assemblage remained intact throughout the Palaeozoic to Early Mesozoic times. As a number of researchers have noted though, *...past movements of the Gondwana supercontinent, based on ancient magnetic, biogeographic and climatic evidence, are both equivocal and contentious,* and this contention still remains despite the addition of new data from Africa and Australia.

Gondwana on an increasing radius Earth is reconstructed on the Ordovician small Earth model—at about 460 million years ago (Figure 4). In this figure the distribution of ancient coastal outlines is shown as blue lines and the ancient continental seas as shaded blue areas (data after Scotese, 1994, and Smith et al, 1994). The various continental seas and supercontinents are also located and named.

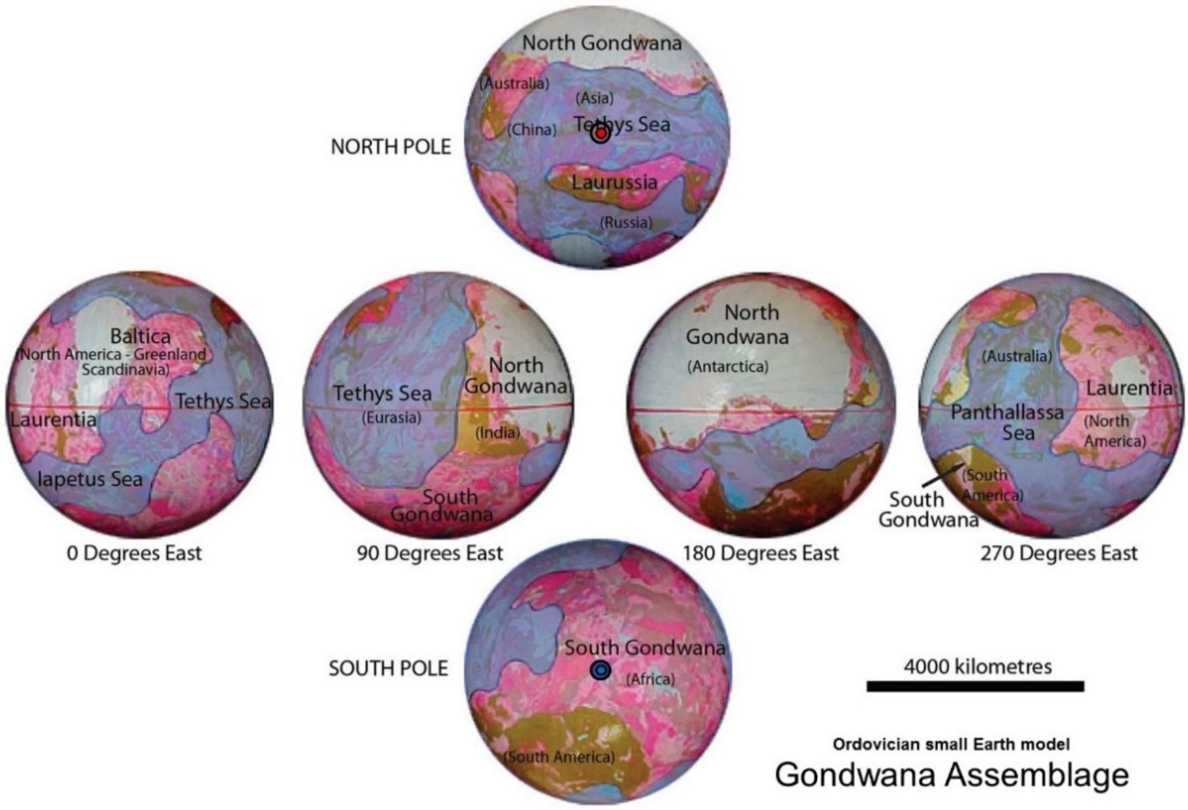

Figure 4 Ordovician Gondwana small Earth assemblage. The model shows the ancient coastline distribution (blue lines) defining North and South Gondwana in relation to Laurentia, Baltica, and Laurussia. The ancient Tethys, Iapetus, and Panthalassa Seas form part of a global network of continental seas (shaded blue areas) surrounding each of the exposed supercontinents (data after Scotese, 1994, and Smith et al, 1994).

On an increasing radius Earth, during Gondwanan times the surface of the Earth was undergoing a steady to rapid increase in radius and surface area and was also fast approaching crustal rupture and breakup. The Gondwanan crustal assemblage (Figure 4) retains the same configuration of cratons, orogens, and basins as seen on earlier Rodinia and the Archaean supercontinents. The only difference being the greater surface area of surrounding sedimentary basins and hence aerial distribution of continental seas. This crustal assemblage is retained still further in time until initiation of crustal rupture and breakup of the pan-global Pangaean continental crust during the late-Permian.

The coastal information on the Ordovician small Earth model shows that, at that time there were distinct elevated ancient land surfaces—supercontinents. These land surfaces were in turn surrounded by a network of equally distinct, relatively shallow continental seas. Gondwana on this model was subdivided into a North and South Gondwana, separated in part by an early Panthalassa Sea—the precursor to the modern Pacific Ocean. North Gondwana was made up of Australia, East and West Antarctica, and India and may have also included Tibet and Afghanistan. South Gondwana, joined at Madagascar, comprised Africa, Arabia, and South America. The ancient sub-continents Laurentia and Baltica were made up of North America, Greenland, and Scandinavia, as well as smaller Precambrian fragments now represented by Scotland and Ireland. Similarly, the ancient Laurussia sub-continent was centred on the Precambrian regions of Mongolia and northern Russia.

Each of these exposed Gondwanan land surfaces were in turn surrounded and interconnected by the ancient continental Tethys, Iapetus, and Panthalassa Seas. Remnants of these seas are now preserved and represented by many of the ancient sedimentary basins that are currently located in Eastern Australia, North and South America, Europe, Asia, and Africa.

The interval of time that the Gondwana supercontinent existed on an increasing radius Earth coincides with the later part of the second crustal development phase. This phase was characterised by a rapidly accelerating rate of increasing surface area and accompanying changes in surface curvature. These accelerating changes gave rise to a marked increase in erosion and deposition of sediments and marked changes to the distribution of continental seas and coastal outlines. The increasing changes in surface curvature also initiated localised orogenic activity within geosynclinal sedimentary basins to form long linear fold mountain belts, further disrupting established seaways. These times also coincided with the rapid development and evolution of all life forms on Earth. It is considered that the degree of crustal change during this interval of time had the capacity to markedly influence evolutionary change in all life forms.

During Gondwanan times, the small Earth South Pole was located within central West Africa in what was then South Gondwana. The North Pole was located within Northern China in what was part of the Tethys Sea. The ancient equator passed through East Antarctica, central Australia, North America, central Eurasia, and India, through what was then North Gondwana. This geographic configuration approximates conventional Plate Tectonic reconstructions in part, but differs substantially in the South Pacific region because conventional Plate Tectonics requires the presence of a wide expanse of Panthalassa Ocean.

These Gondwanan configurations are substantiated by existing physical and geological similarities between the Australian and South American continents. These similarities include the distribution of marine and terrestrial plants and animals, which link Australia and New Zealand across to Central and Southern America, and also rock and fossil types that link Australia directly to South America. The increasing radius coastal outlines also show that continental land connections existed between north Australia and North America and between north Africa-Arabia and Scandinavia. The existence of these land connections formed important migration routes or barriers for terrestrial and marine life forms. A change in configuration of the various continental seas may have also resulted in periods of relatively rapid sea-level changes in these areas, with disastrous consequences for plant and animal species existing at the time.

The late-Palaeozoic to early-Mesozoic times eventually coincided with breakup of the Gondwana supercontinent, which was accompanied by draining of the continental Tethys, Panthalassa, and Iapetus Seas as the modern oceans began to open. As a result of this draining of the seas each of the Gondwana and related supercontinents geographically merged with the smaller Laurentia, Baltica, and Laurussia sub-continents to form the more familiar Pangaea supercontinent. On an increasing radius

Earth this evolution of continents and seaways was again reflected in the progressive changes to coastal outlines and sea levels, as displayed in each of the small Earth models.

Laurentia, Baltica, Laurussia Sub-continents

Laurentia, Baltica, Laurussia and numerous smaller fragments, such as Kazakhstania and fragments making up Southeast Asia are described in conventional Plate Tectonic literature as sub-continents, or simply continental fragments. These are routinely described in the literature as fragments of pre-existing supercontinents that periodically dispersed and amalgamated between the larger supercontinents during continental breakup and subsequent reassemblage of the various continental fragments.

On the Ordovician increasing radius small Earth model (Figure 4), each of these sub-continents were geologically connected to the supercontinents. Their presence and coastal outlines depended primarily on the variation in sea levels existing at the time and the sub-continents were often separated geographically from the main supercontinents by the global network of continental seas.

As the continental crusts began to rupture during the late-Permian, the established continental seas then began to drain into newly formed marine sedimentary basins as the modern oceans opened. The previously submerged seafloor surrounding each of these sub-continents was then exposed as dry lands and the surface areas of the sub-continents progressively increased to eventually form part of the more familiar Pangaea supercontinent.

Pangaea Supercontinent

The assemblage of a large Pangaea supercontinent was promoted by Alfred Wegener in 1915. In his proposal, he presented geologic evidence to suggest that the large continental areas of the modern world were originally united late in the Palaeozoic Era prior to subsequent breakup and dispersal of the continental fragments. This has since been adopted in conventional Plate Tectonic studies, whereby Pangaea is said to have assembled from crustal fragments originating from the breakup of Gondwana. During the late-Palaeozoic Era the Pangaean supercontinent then comprised two contrasting geographical provinces: a southern Gondwana province and a northern Laurasian province. The Pangaea supercontinent was then inferred in conventional Plate Tectonic studies to have fragmented within the Tethyan region, where continental breakup began in earnest during mid-Jurassic times.

Pangaea on an increasing radius Earth is shown on the Permian small Earth model in Figure 5. This figure shows the coastal outlines as blue lines and continental seas as shaded blue areas. The various supercontinents and intervening seas existing at the time are also named. The Pangaean assemblage coincides with a Carboniferous to Permian transitional crustal development phase. During this phase increasing Earth surface area had progressed from advanced continental extension to true crustal rupture prior to continental crustal breakup and dispersal as the modern continents.

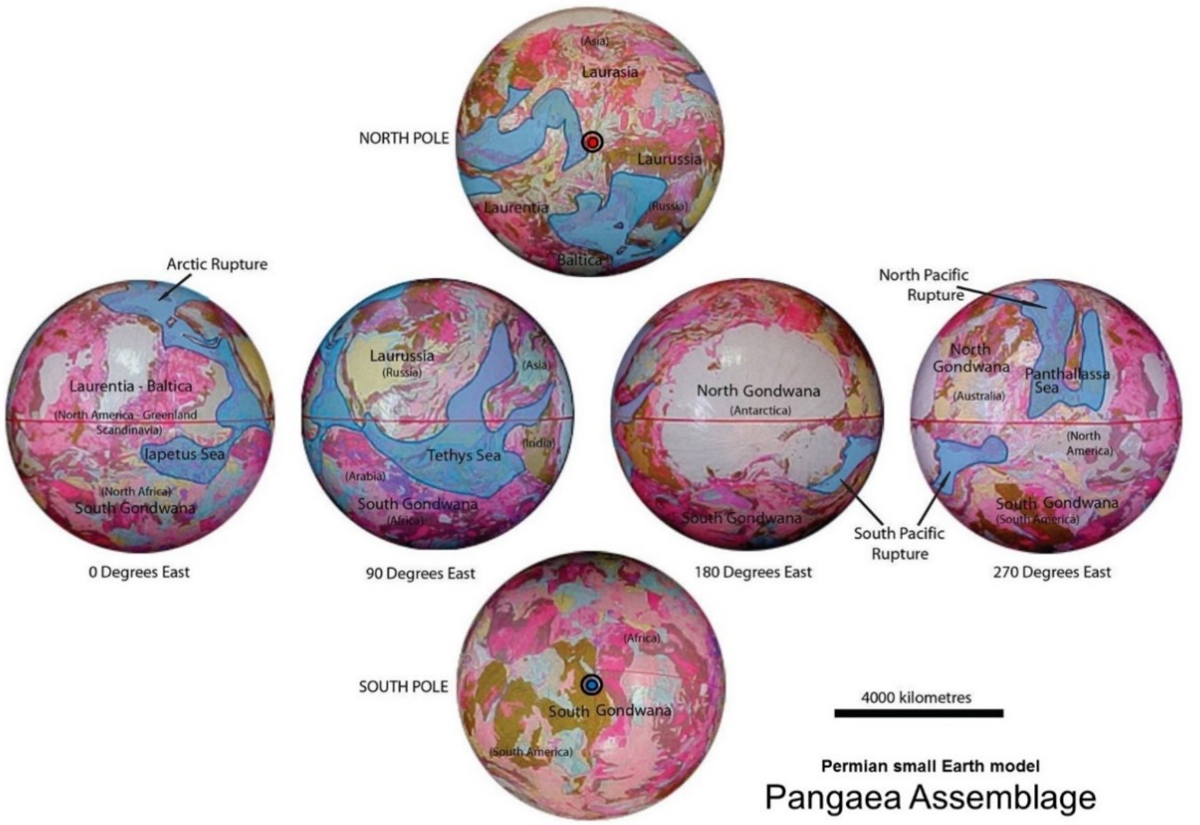

Figure 5 Permian Pangaea small Earth crustal assemblage. The model shows the ancient coastline distribution (blue lines) as well as the ancient Tethys, Iapetus, and Panthalassa Seas (blue shaded areas) forming part of a global network of continental seas (data after Scotese, 1994, and Smith et al, 1994). The figure also shows the locations of continental rupture commencing in the north and south Pacific and Arctic Ocean regions to form the modern oceans.

The presence of Pangaea on an increasing radius Earth represents a simple, progressive, although relatively rapidly changing evolution of the Gondwanan coastal outlines prior to continental breakup and formation of the modern continents and oceans. During this Pangaean time, rupture and breakup of the continental crusts had initiated draining of the continental seas which was in turn accompanied by a shift in where eroded sediments were being deposited. This shift changed from sediments being deposited within an existing network of continental sedimentary basins, to being deposited within newly opening marine basins and along the continental shelf margins of the newly formed modern continents. This influx of sediment, along with intrusion of new volcanic and magmatic rocks, is now commonly preserved within submerged marine plateaux as well as continental shelf settings surrounding most of the modern continents.

Following rupture of the supercontinental crust, Pangaea on an increasing radius Earth eventually broke-up during the late-Permian and dispersed as the modern continents during Triassic to present-day times. The subsequent migration history of the modern continents and seafloor crustal history is now preserved by the intruded volcanic seafloor lava existing throughout all of the modern oceans.

This post-Pangaea interval of time also saw large apparent shifts in the location of the North and South Poles and equator, occurring as a direct result of opening of the modern oceans and an apparent shift in the location of each of the modern continents. These shifts, as well as geographic isolation during breakup, in turn led to plant and animal evolutionary changes which increased markedly during post-Jurassic times. Changes were also accompanied by increased extinction of many of the established life forms as well as increased isolation of many species as a number of the modern continents separated to form island continents.