Paper 7: Palaeoclimate

"Climatic features of the Mesozoic and Cenozoic have been shown to depart significantly from latitudinal predictions based on palaeomagnetism." Barron, 1983

Assumptions about the Earth's ancient climate involve the study of three complex systems: ocean circulation, atmosphere, and the past distribution of continents. Ocean circulation, in particular the development of deep ocean currents during opening of the modern oceans, is strongly influenced by the presence of land barriers. Similarly, topographic relief on the continents strongly influenced the amount of rainfall received from the atmosphere as well as the accumulation of snow and ice in mountainous regions. Correlation of coal swamps, thick bedded sandstone sequences, and glacial rocks are all considered to be excellent indicators of wet climates, while dry climates are indicated by evaporate rocks such as salt deposits, and equatorial regions by the presence of carbonate reef and carbonate-bearing sandstone strata.

The locations of each of the present-day and ancient circles of latitude and climate zones on small Earth models are plotted on Figure 1. The ancient circles of latitude, while appearing to be non-parallel in this figure, are in fact parallel and their ancient geographical locations have been adopted as being the same as the present-day latitudes. The tapered, non-parallel representation in this figure is meant only to simulate the progressive evolution of these circles and zones between each of the small Earth models. In reality, this representation may not be strictly correct. If the tilt of the ancient Earth axis varied significantly from what it presently is, then it is the width and location of the zones that would be affected.

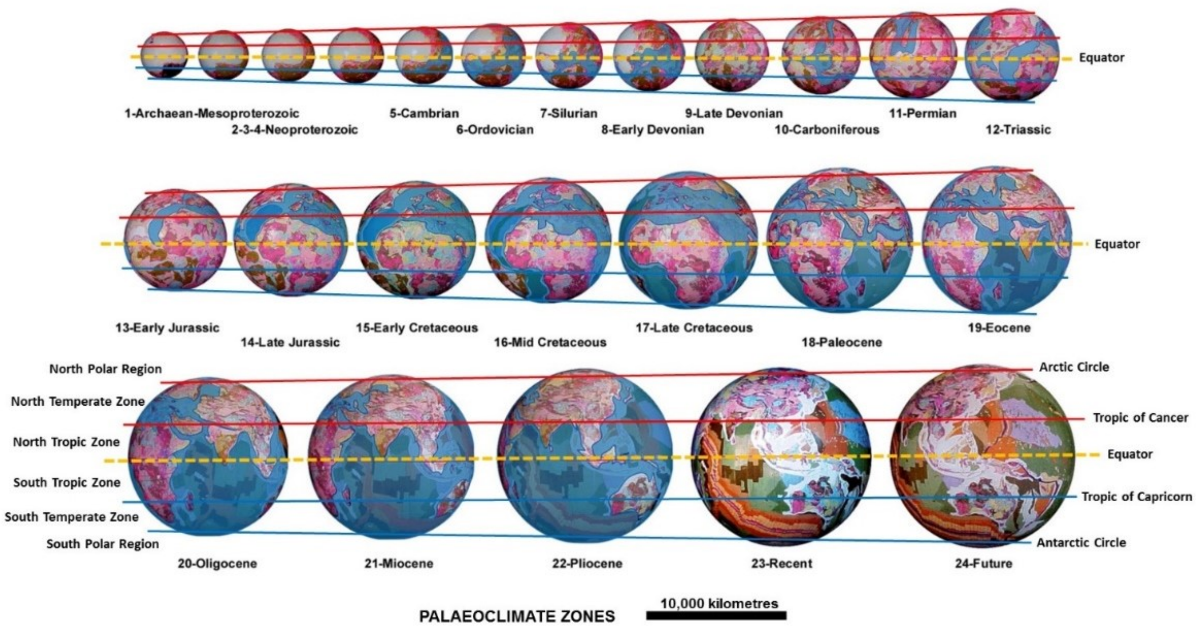

Figure 1 The location of climate and geographical zones on small Earth models, based on present-day latitudinal values.

Ancient Coral Reefs

The distribution of published occurrences of mid- to late-Palaeozoic carbonate reef deposits—around 300 to 250 million years ago—is shown on the Permian small Earth model in Figure 2 (data from Flügel, 1994), along with the location of established tropical climate zones and circles of latitude. Also shown is the distribution of ancient continental seas, previously established from the distribution of published coastal outlines on each of the small Earth models. This distribution of carbonate reefs is based on published records and does not necessarily represent the entire global distribution of reefs in lesser studied regions.

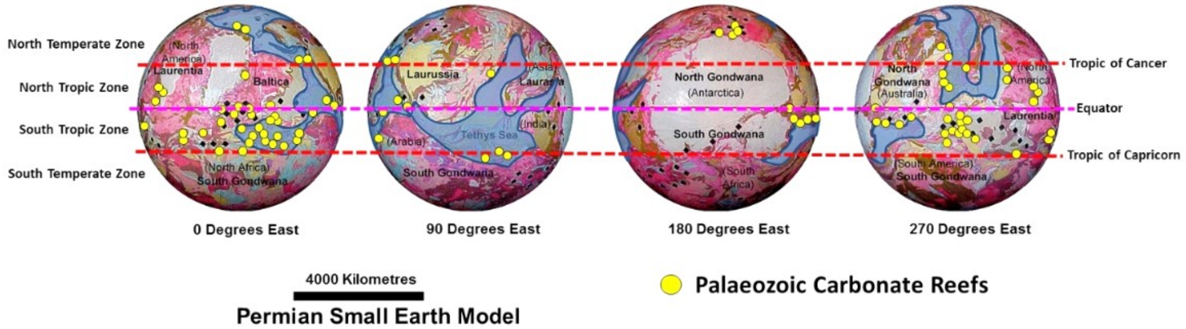

Figure 2 Distribution of Palaeozoic carbonate reefs (yellow dots) as well as ancient Permian coastlines and continental seas, plotted on a Permian small Earth model (reef data from Flügel, 1994).

In this figure there is some minor disparity between the plotted reef locations and the published ancient shorelines. This is only apparent because the reef data extend back in time a further 100 to 200 million years to times when these coastlines were different to those shown on this Permian Pangaean small Earth model. In this figure, the distribution of carbonate reefs is, in general, shown to neatly straddle the equator and shows a good correlation with the adopted equatorial Tropic zones. Outlying reefs shown within the northern Temperate Zone reflect the presence of warm tropical Tethys Sea currents extending into these regions.

The distributions of Palaeozoic through to Jurassic carbonate reefs are shown as various coloured dots plotted on an early-Jurassic increasing radius small Earth model in Figure 3. These reefs are again shown in conjunction with the anticipated climate zones. Also shown in this figure is the early opening of the modern Pacific and Atlantic Oceans, shaded in blue, as well as the locations of the early-Jurassic coastlines shown as heavy blue lines.

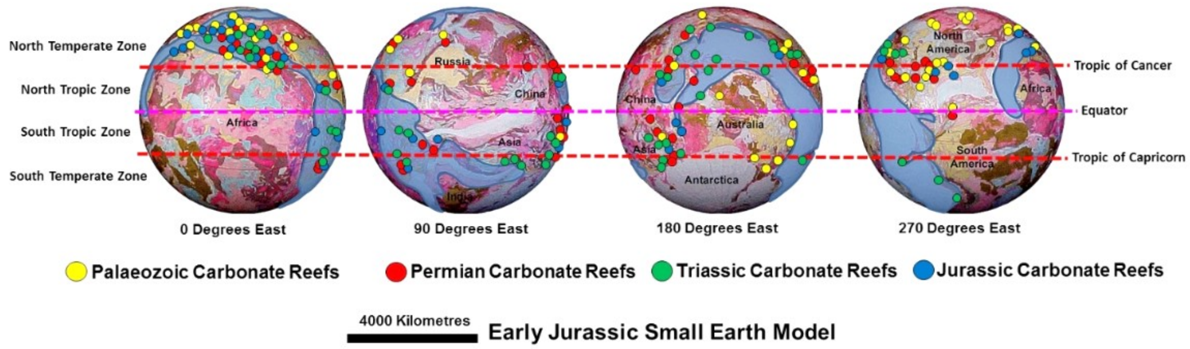

Figure 3 Distribution of Palaeozoic to Jurassic carbonate reefs as well as ancient Jurassic coastlines and opening modern oceans plotted on an early-Jurassic small Earth model (reef data from Flügel, 1994).

On an increasing radius Earth, the late-Palaeozoic to Jurassic times represent a transitional period of Earth history documenting the opening and rapid development of the early North and South Pacific, North Atlantic, and Arctic Oceans. During opening and dispersal of the modern continents, earlier formed carbonate reef communities were then subject to fragmentation, disruption, and migration away from their previously established tropical zones into new and often different climatic zones.

The various reef communities in Figure 3 highlight this period of disruption, where the continents and most of the abandoned ancient reefs are shown to have migrated well north into temperate climate zones. This is highlighted by the distribution of ancient Palaeozoic reefs, shown as yellow dots, which can be compared to their original distributions in Figure 2. The distribution of the youngest Jurassic reefs—blue dots in Figure 3—is reasonably well constrained within the Jurassic Tropic Zone, but they also extend north into the newly opening Mediterranean Sea. This may either represent a hold-over of marine species in this region or the presence of warm water currents that have extended reef development into these areas.

Ancient Polar Regions

The locations of ancient North and South Poles were previously established from small Earth modelling of available palaeomagnetic pole data. Figure 4 shows locations of the North Polar Region centred over the ancient North Pole on each of the small Earth models. Similarly, Figure 5 shows locations of the South Polar Region, centred over the ancient South Pole. Also shown on each of these figures is the published distribution of known glacial rocks and formations—shown as red dots, after Hambry and Harland, 1981, as well as the presence of known ice-sheets shaded in white. Both the glacial rocks and ice-sheets are shown to coincide with locations of the highlighted five major glacial events. The distribution of ancient continental seas and modern oceans are shown as pale blue.

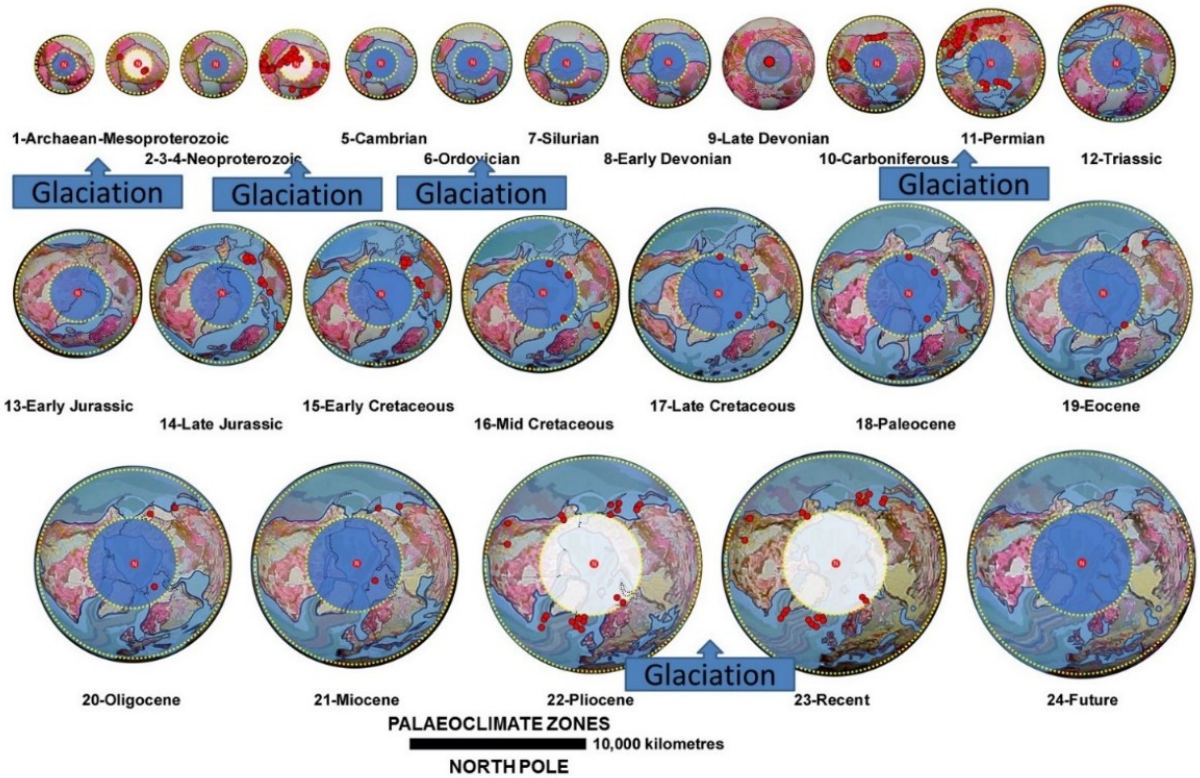

Figure 4 Locations of ancient North Polar Regions shaded blue on small Earth models. Known glacial data are shown as red dots, after Hambry and Harland, 1981, glacial events are highlighted, the presence of known ice-sheets are shaded white, and ancient seas and modern oceans are shaded pale blue.

By definition, the North and South Polar Regions remain centred over each of the ancient poles. During migration of a continent into or out of a polar region, if conditions are favourable, the leading edge of the continent may begin to establish an ice-sheet as it enters a polar region, or the leading edge of an established ice-sheet may melt as it moves out of the respective polar region. Similarly, the trailing edge of the ice-sheet may also freeze and increase in surface area as it moves further into the respective polar region. This is highlighted by the passage of Antarctica into the South Polar Region during the Cretaceous to present-day times (Figure 5) where a permanent continental ice-sheet was first established 33 million years ago.

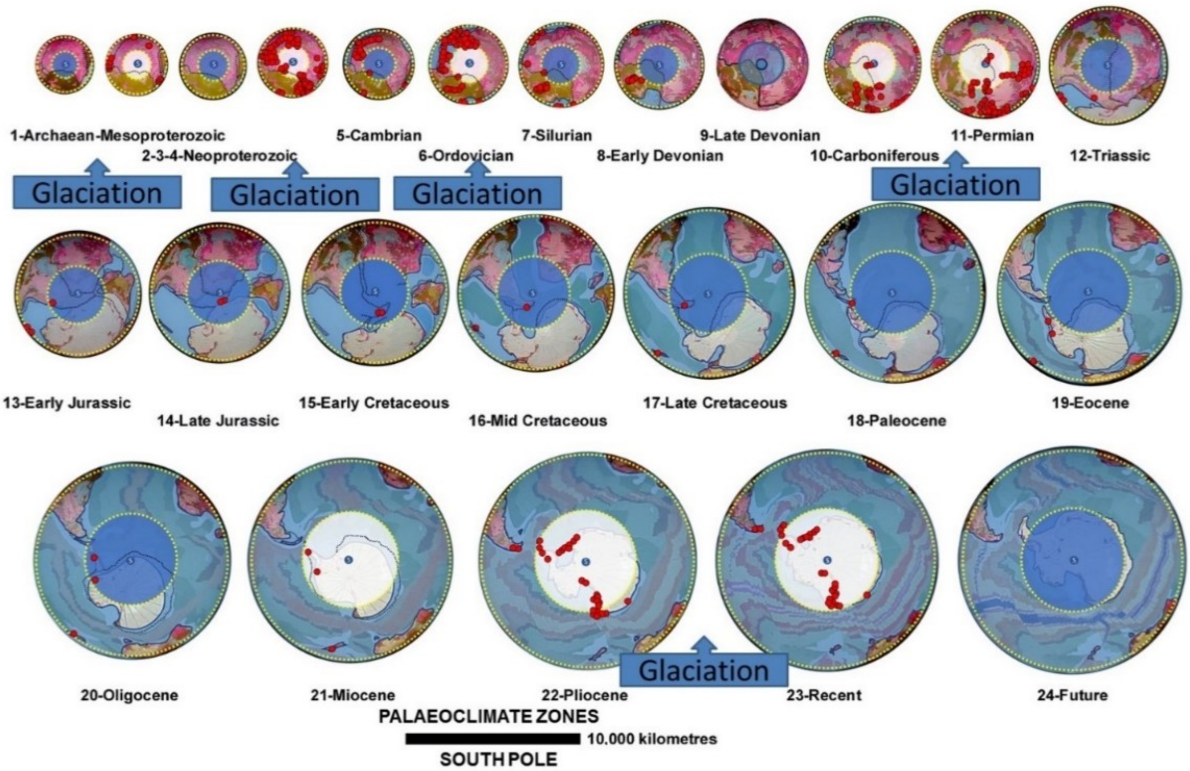

Figure 5 Locations of ancient South Polar Region shaded in blue on small Earth models. Known glacial data are shown as red dots, after Hambry and Harland, 1981, glacial events are highlighted, the presence of known ice-sheets are shaded white, and ancient seas and modern oceans are shaded pale blue.

Opening of the modern oceans beneath an established ice-sheet may also expose any existing ice to the influence of circulating ocean currents. This may then change the ice-sheet from a permanent continental sheet—such as the modern Antarctic ice cap—to a seasonal marine sheet—such as the modern Arctic ice-sheet. This may in turn affect the presence, size, and extent of ice cover within these climate zones and directly affect global climate, sea levels, and the distribution or decline of various plant and animal species. For example, migration of the South Pole and opening of the South Atlantic Ocean is highlighted in Figure 5 on the Triassic to Oligocene small Earth models. Here, no glacial rocks are present which suggests that any ice sheet present during that time may have been small to absent.

On an increasing radius Earth, the Cenozoic Era—commencing around 65 million years ago—coincided with the establishment of symmetrical seafloor spreading and on-going opening of each of the modern oceans. More importantly, the climatic changes occurring during this time coincided with the Antarctican continent migrating from an equatorial position into the south-polar region. A permanent continental ice-sheet was then established on Antarctica by about 33 million years ago. Migration of Antarctica into the South Polar Region (Figure 6) commenced during Oligocene times—around 60 million years ago. Since Oligocene times the migration of Antarctica, accompanied by opening of the surrounding Southern Ocean, continued steadily to its present location centred over the South Pole.

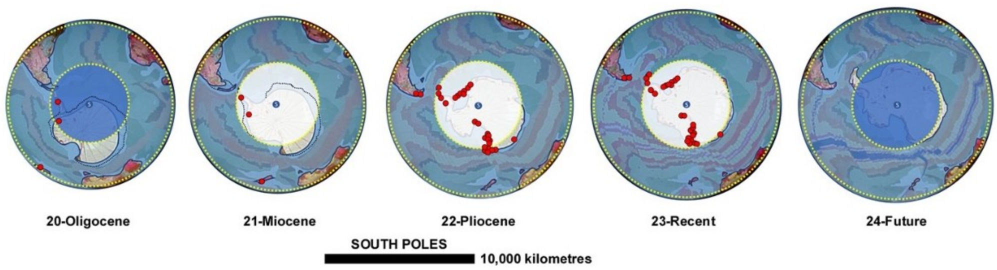

Figure 6 Cenozoic small Earth models centred over the South Polar Region showing migration of the Antarctican continent onto the South Pole. The presence of glacigenic rocks is shown as red dots, after Hambry and Harland, 1981, and the Antarctic ice sheet is shaded white. The presence of an ice sheet into the future is speculative and not shown.

Antarctica is currently continuing to migrate across the South Polar Region beneath the existing polar ice-sheet and on an increasing radius Earth Antarctica will continue to migrate across this region into the future. As a result of this migration, the Antarctic ice-sheet will be subject to melting and refreezing along the outer edges as the continent attempts to displace the ice-sheet away from the South Polar Region. This phenomenon is continuing today which may have a direct influence on the presently observed melting of the South Polar ice-sheet as well as its long term influence on climate.