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THE PERMO-CARBONIFEROUS GLACIATION OF GONDWANA: ITS IMPACT ON WESTERN AUSTRALIA

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SOME 290 to 320 million years ago, during the Mid Carboniferous to Early Permian (Permo-Carboniferous), Western Australia was covered by a succession of thick continental ice sheets, comparable with those that cover Antarctica and Greenland today and covered large areas of Europe, North America, and Asia during the Pleistocene (2 million to 10,000 years ago). The Permo-Carboniferous glaciation occurred when Australia formed part of the Gondwana supercontinent. This huge landmass was made up of the present-day continents of Antarctica, Australia, South America, Africa, and India, clustered together around the south pole (Figure 1). Gondwana broke up during the Late Jurassic to Early Tertiary, some 150 to 60 million years ago, and the individual continents gradually drifted apart (Figure 2). Western Australia is still moving steadily towards the north-northeast at a rate of about 7 cm per year.

The Permo-Carboniferous glaciation of Gondwana was one of three major glaciations that have affected the earth, the other two being during the Late Precambrian (around 700 million years ago) and the Pleistocene. For most of the earth's history there were no major ice caps centred on the north and south poles, although a number of less extensive glaciations occurred periodically. The reasons for the development of ice ages are not fully understood, but they may be linked with changes in the sun's radiation, ocean circulation, and the positions of the earth's continents.

The great Permo-Carboniferous glaciation is evidenced in Western Australia by extensive glacial sediments and pavements. The sediments contain striated and facetted boulders, known as erratics, that were dragged along the base of the moving ice sheets for very long distances (up to several hundred kilometres). These

Figure 1: Map (south polar projection) of Gondwana, showing the maximum extent of the Permo-Carboniferous continental ice cap.

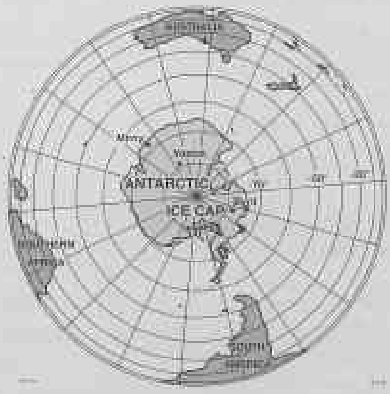

Figure 2: Map (south polar projection) showing the modern Antarctic ice sheet in relation to the present positions of Australia, South America, and southern Africa.

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Figure 3: The 'White Horse' erratic, north of Mingenew. This block of Coomberdale Chert was transported by ice from the Moora area during the Early Permian, about 290 million years ago.

erratics are as much as several metres across, a good example being the 'White Horse' erratic, north of Mingenew (Figure 3). This is a block of Coomberdale Chert, 3 m across, that was transported by ice from the Moora area, about 200 km to the south-southeast.

Glacial pavements were formed at the base of moving ice sheets, where 'dirty' ice eroded the underlying basement. Rock debris, ranging from large boulders to fine 'rock flour', was frozen into the basal ice, and this effectively planed down the underlying rocks as the ice moved steadily away from the south pole. Some of the best examples of grooved, striated, and polished glacial pavements are in the Pilbara district, east of Marble Bar (Figure 4). They are also displayed clearly at other locations around the State, notably east of Geraldton, near Lyons River, and east of Fitzroy Crossing.

The ice sheets flowed into the surrounding oceans, where 'calving' of icebergs occurred and rock debris dropped to the sea floor as the icebergs melted. Evidence of the direction of ice movement is provided by striations (scratches), grooves, and other features on the glacial pavements. The striations and grooves formed parallel to the direction of ice movement, which, in Western Australia was overwhelmingly towards the north-northwest, averaging about 340° (Figure 5).

The modern Antarctic ice cap is up to 4.8 km thick (near the Vostok base), and it seems probable that the

Figure 4: Grooved, striated, and polished glacial pavement in chert east of Marble Bar. This pavement was sculptured by 'dirty' ice at the base of the Early Permian ice sheet, which was moving towards the north-northwest.

Permo-Carboniferous ice sheets, which covered areas at least four times that of Antarctica, reached even greater thicknesses. The Early Permian ice sheet may have been more than 5 km thick over the southern part of Western Australia, perhaps thinning to 3-4 km over the Pilbara and 2 km over the Kimberley. It is expected that the whole of Western Australia, including mountainous areas in the Pilbara and Kimberley, was periodically covered by ice. There was not just one ice cap, but a succession of ice sheets that advanced and retreated regularly across Gondwana in the Permo-Carboniferous.

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Figure 5: Map of Western Australia showing the direction of Early Permian ice movement, as indicated by glacial striations and other features.

After the last major ice sheet melted in the Early Permian, about 290 million years ago, some alpine glaciers probably persisted in mountainous areas for the next 10 to 15 million years. The final continental ice sheet obliterated most of the earlier glacial pavements, putting the 'final touch' on the glacially sculptured bedrock topography. Since then Australia has never been covered by ice, although some small mountain glaciers developed in the Australian Alps and Tasmania during the Pleistocene.

The Pleistocene ice age was marked by a succession of ice sheets that advanced and retreated over Europe, North America, and Asia, with periodicities of 100,000 to 120,000 years. We are currently near the peak of an interglacial period, and it is expected that during the next few thousand years the earth will again plunge into an ice age, unless human-induced global warming is sufficient to counteract natural cooling. It must be remembered that human populations survived through the Pleistocene ice ages and associated major changes in world climates, sea levels, fauna, and flora. Aborigines have been present in Australia for at least 40,000 years, living through the peak of the last Pleistocene glacial period, only 18,000 years ago, when sea level was 130 metres lower than today. The coastline was then situated some 12 km west of Rottnest, and the climate must have been very different from that of today -- probably much more arid and with stronger prevailing winds. The key to the survival of humans in the face of drastically changing climates and environments has been their ability to adapt. During the last 6,000 years there has been relative stability in world climates and sea levels, but this situation must surely change during future centuries, partly as a result of human activities, but probably even more because of natural climatic fluctuations.

Part of the basal ice below the present Antarctic ice sheet has melted, as a consequence of geothermal heat flow radiating from the centre of the earth. This melting has resulted in thin films of water at the ice-bedrock contact in certain areas, and subglacial lakes, covering thousands of square kilometres, in others. Studies of parts of the northern hemisphere that were once covered by Pleistocene ice sheets show that subglacial meltwater drained away to the sea via networks of channels cut into the substrate or within the basal ice. Evidence of comparable Early Permian subglacial channels has been found in several areas of Western Australia. Notable topographic features that may have formed originally as subglacial channels include Windjana and Geikie Gorges in the Kimberley, and Coppins Gap, Shay Gap, and the Oakover Valley in the Pilbara. Much of the remarkable palaeoriver system that covers wide areas of inland Western Australia probably first developed as subglacial channels during the Early Permian, although they have since been modified by erosion during the Mesozoic and Cainozoic.

Limestones of the Devonian reef complexes in the Canning Basin (Kimberley district) were also subjected to extensive solution in Early Permian subglacial meltwater, with the development of subglacial lakes, potholes, dolines, tunnels, cave systems, and channels. Many of the present-day karst features in the limestones reflect exhumed Early Permian karst. The remarkable Mimbi Cave System, 90 km east of Fitzroy Crossing, and the tunnel of Tunnel Creek National Park, testify to the major effects of subglacial solution.

Large areas of Western Australia have experienced little faulting and folding since the last continental ice sheet withdrew, some 290 million years ago. Indeed, this State forms one of the most stable parts of the earth's crust. The present-day landscape, noted for its remarkable flatness, is a reflection of the glacially planed topography that remained after the last ice sheet melted during the Early Permian. The sediments that subsequently covered this ancient surface have since been stripped away by erosion over wide areas, exposing and degrading the underlying glacial topography. It seems clear that the flat landscape of Western Australia owes more to this ancient glaciation than to any other process.

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