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THE NATURAL REGIONS OF THE DESERTS OF WESTERN AUSTRALIA

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HISTORICAL INTRODUCTION

Any map of Western Australia bears well-known names of deserts in the eastern half of the State—the Great Sandy Desert, the Gibson Desert, the Great Victoria Desert. To this list may be added, for practical purposes, the Nullarbor Plain. When, however, one enquires into this situation more deeply it is found to be difficult or impossible to discover what the characteristics of these deserts are, where their boundaries lie, and in what way they are distinguished from one another and from other parts of Western Australia not popularly considered to be desert. These questions will be answered in the course of this paper after considerable discussion. As a starting point, the only satisfactory preliminary definition of the deserts seems to be that they comprise the country which is not under pastoral lease or agricultural occupation (Fig. 1.) Such country occupies the whole of the eastern half of the State south of the Kimberley, to a total of about two-fifths of the whole area, or 400 000 square miles (1 million km^2).

Until 1954 knowledge of the greater part of this area north of the Nullarbor Plain was minimal and derived from the observations of the few nineteenth century expeditions which had traversed it, but from that year progress in exploration was rapid. It is rather remarkable that even to the very dates there is a close parallel with the Antarctic Continent and its exploration, as the following quotation from Law (1967) will show:

> 'Man's knowledge of the Antarctic Continent before 1954 was fragmentary. (I choose 1954 because that was the year the Australian National Antarctic Research Expeditions established Mawson Station.) There were many stretches of coast that had never been explored and many mountains that had never been sighted. The Antarctic Plateau was almost wholly unknown, and no-one had ever experienced a winter at any point inland upon its surface. One could only conjecture as to its average altitude, the contours of its surface and the extremes of temperature which might be experienced upon it. Meteorological information was of a very elementary nature, consisting of detailed observations from a few coastal stations, and a lot of imaginative generalisations and extrapolations with little factual basis on a continental scale. Glaciological and geological knowledge was confined to a few restricted areas surrounding coastal expedition bases. Some good work had been done on the taxonomy of marine fauna, but little was known of the flying birds or the fish or the flora or the insects, and little had been done on the physiological or ecological problems of the fauna.
>
> 'A remarkable development occurred in 1956.'

With little alteration this passage could be made to apply equally to the Western Australian interior. 1954 is a significant date here also because it was the year that four-wheel-drive motor vehicles were first used to penetrate the desert by a reconnaissance party (Traves, Casey & Wells 1956). Similarly too, in 1956 a remarkable development

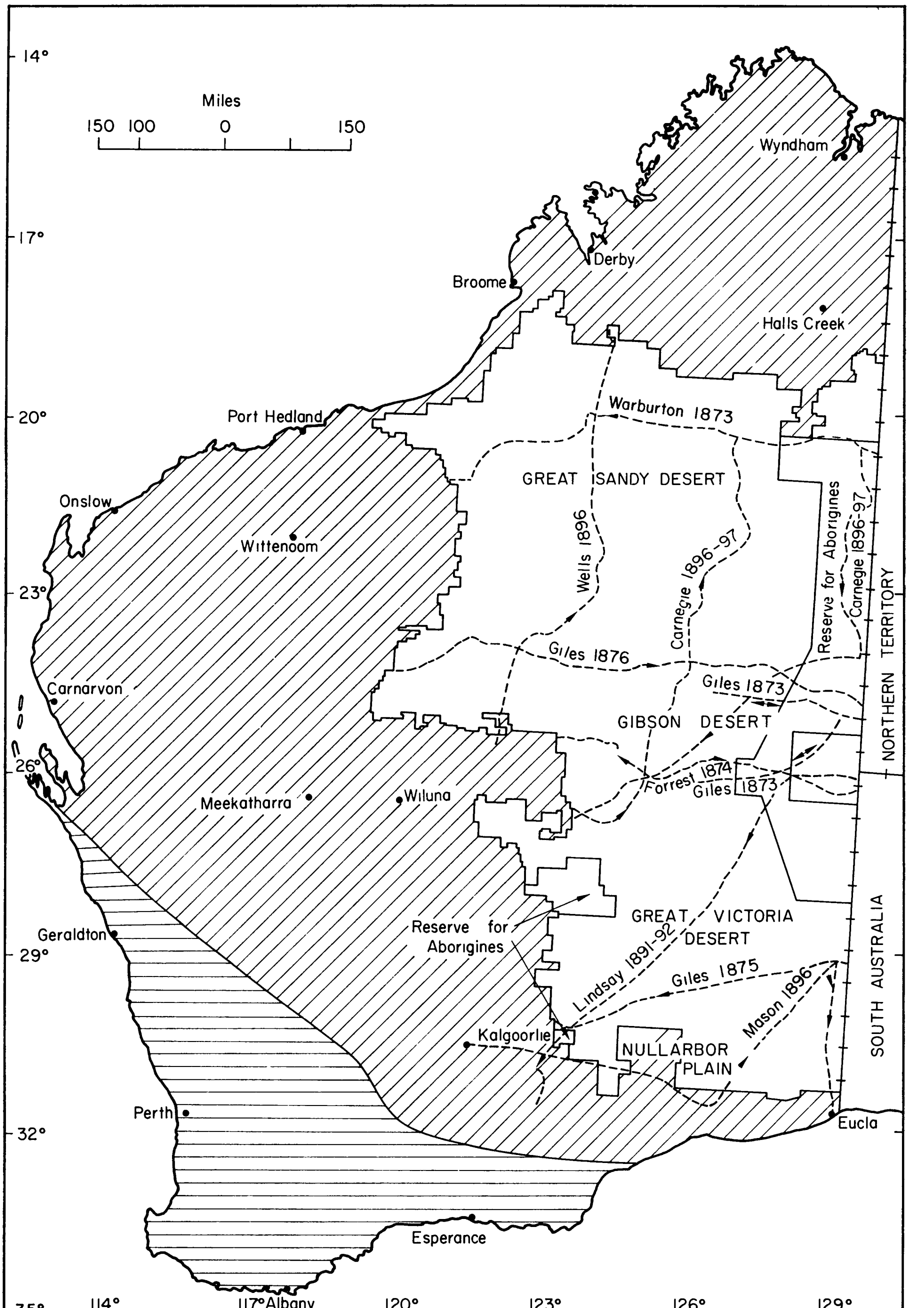


FIG. 1. Map of Western Australia showing land occupation and routes of explorers. Agricultural belt (stipple), pastoral areas (hatched) and unoccupied areas (open).

occurred with the commencement of construction of graded access roads for survey purposes by the Commonwealth Government. Hitherto it had only been possible to penetrate this region effectively with the aid of teams of camels and the earliest explorations which used horses were only marginal. E. J. Eyre crossed the continent from east to west in 1841 by following the south coast, but furnished no knowledge of the interior. The Great Sandy Desert was first discovered by Augustus Gregory in 1856 in the course of an expedition from the north coast. Lured on in those days by the myth of a great inland sea in the centre of the continent, hopes were aroused by the discovery of a river—the Sturt Creek—flowing southward. The party followed the stream for 300 miles (480 km) until to their disappointment it began to peter out, its last remnant terminating in a salt lake, 'Gregory's Salt Sea' (now Lake Gregory), beyond which lay only impenetrable sandhills. This expedition was accompanied by the botanist, Ferdinand von Mueller. A brother, Frank Gregory, came to the south-western margin of the Great Sandy Desert from the Oakover River in 1861 and endeavoured to penetrate further but was driven back, abandoning his equipment and stores, by the difficult sandy country, lack of water and lack of feed for his horses. (Account in Warburton 1875.)

Discovery of the treeless interior of the Nullarbor Plain (Eyre having only skirted its wooded coastal margin) is attributed to Miller and Dutton, two settlers from Fowler's Bay in South Australia who penetrated a short distance in 1857. E. and A. E. Delisser made the first proper exploration for the South Australian government in 1865–66 and coined the name 'Nullarbor' from the Latin *nullus arbor* (no tree) (Dunkley 1965).

From March to August 1870 John and Alexander Forrest retraced Eyre's route along the south coast from west to east, without—as Giles (1889) later acidly commented——adding anything significant to exploration as they covered no new ground. Soon after, in the early 1870s, there was a surge of exploration of the interior based mainly in South Australia and operating westwards from the overland telegraph line linking Adelaide and Darwin. The most effective of these expeditions were equipped with camels by Sir Thomas Elder of Adelaide who had pioneered the introduction of Bactrian camels from India. Their superiority over horses in the desert quickly enabled waterless regions to be conquered. Giles left the telegraph line at the Finke River in August 1872 with the intention of crossing the continent westward. This expedition, sponsored by the botanist von Mueller, used horses and was driven back in sandy desert at longitude 130°, 1° short of the Western Australian border. Early in 1873 the South Australian government mounted an expedition under W. C. Gosse, equipped with camels. Starting at the Finke River he moved westward roughly on the twenty-sixth parallel, discovering Ayers Rock on the way. He crossed the Western Australian border and penetrated as far as the Warburton Range, where he turned back and worked northward by the Rawlinson Range to rejoin the telegraph line at Central Mount Stuart in latitude 22° (Gosse 1874). In April 1873 a private expedition mounted by Sir Thomas Elder, with camels, under Colonel P. E. Warburton left Alice Springs for a continental crossing. Heading to the northward in the hope of circumventing the sand belt they eventually worked across it in about latitude 20°—actually in the most difficult sector, the heart of the Great Sandy Desert, which Warburton named. Terrible hardships ensued. One member of the party lost his reason, Warburton himself became partly blind and broken in health and the whole party all but perished, just staggering to the Oakover River in December 1873 (Warburton 1875).

In August 1873 Giles set out again, almost at the same time as Gosse and Warburton, sponsored once more by von Mueller but still equipped with horses. For this reason he was unable to effect a crossing to the west though he thoroughly explored the area of the Warburton and Rawlinson Ranges. To the west of these lay a flat and waterless region which he could not cross. Among the small ranges of the Australian centre he could find water in gorges and rockholes, and feed for the horses on creeks and small outwash plains, but with a change in geological structure further west he found only spinifex-covered sandhills and laterite plains. This latter area he named the Gibson Desert after a member of his party who was lost there.

This difficult belt was crossed in 1874 by John and Alexander Forrest working from the west and using horses. Giles also crossed in 1875, from the east and rather further south than the Forrests, with a camel-train equipped by Sir Thomas Elder of Adelaide. The area traversed, lying north of the Nullarbor Plain, Giles named the Great Victoria Desert in honour of his sovereign. When Giles was working for von Mueller he collected botanical specimens and there is a list of determinations in his book (Giles 1889). Specimens from the later expedition are said to have been lost.

In 1891 Sir Thomas Elder fitted out another expedition for an east–west crossing. This party was led by D. Lindsay and accompanied for the first time by a botanical collector, named Helms. Not himself a trained botanist, Helms made a collection of 213 species within Western Australia for von Mueller, six of them new to science (Mueller & Tate 1896). In 1896 the Hon. David Carnegie led a party north from Coolgardie to Hall's Creek and back. A small collection of botanical specimens was made and sent to Kew but record of it is unfortunately lost.

In the twentieth century reconnaissances were succeeded by moves to open up the country. In 1901 a survey party under J. Muir further explored the Nullarbor Plain with special reference to a proposal for a Trans-Australian railway. In 1906–07 A. W. Canning surveyed the famous stock route about 1000 miles long, from Wiluna to Hall's Creek, mostly through sandy desert. This route was later provided with properly dug wells each with a timbered shaft, windlass, bucket and watering trough, and iron covers to exclude animals and birds. In spite of the difficult and remote country this route was used for droving stock until comparatively recently. The Trans-Australian railway was laid down across the Nullarbor Plain in 1916–17 and necessitated the maintenance of small settlements of people at about 50 mile intervals along the track. A few sheep stations were established along the coast of the Bight and the overland track between them was converted into a formed road during World War II, for strategic reasons. This has now become the modern bituminized Eyre Highway which passes just to the south of the Nullarbor Plain proper.

In 1931 H. L. Paine surveyed a route from Laverton north of east for 360 miles to the Warburton Range and reported on the pastoral prospects of the country. In 1935 this route was used for the establishment and subsequent supply of a mission to aborigines at the Warburton Range which became the only permanent human habitation in the deserts north of the railway. A well-graded road has superseded the original surveyor's track.

As previously noted, a new era opened in 1954 when a geological reconnaissance party spent 4 months in the field in the south-western Canning Basin, successfully operating for the first time in the desert with four-wheel-drive vehicles. In 1956 the Commonwealth Government began construction of a graded road in support of a geodetic survey project from South Australia westwards to Carnegie Station in Western Australia. A settlement now known as Giles Weather Station was established at the Rawlinson Range. This first road link across the centre of the continent was completed in 1958 and the history of it, facetiously called the 'Gunbarrel Highway', is entertainingly described by the surveyor-in-charge, L. Beadell, in his book *Too Long in the Bush* (1965). In 1963 a network of more hurriedly constructed graded tracks was put in by the Commonwealth Government for topographic survey purposes and some of these have been improved by oil companies. From 1963 the West Australian Petroleum Company was exploring in the Canning and Kidson basins, test wells were drilled and an all-weather road 400 miles long was constructed from Wallal Downs on the Eighty-mile Beach inland to the Kidson Well. The Hunt Oil Company was exploring the Officer Basin in 1965–66.

The whole area has been photographed from the air since 1953, the photographs have been used in mapping, and an almost complete series of modern topographic maps on a scale of 1:250 000 has now been published, the work being shared by the Commonwealth Department of National Development, the Army and the Western Australian Department of Lands and Surveys. The network of roads and tracks has been extensively used by scientists of many disciplines and botanical exploration has been included. As previously noted, botanical specimens had been collected on early expeditions but no professional botanist had ever set foot in the deserts until in 1960 J. B. Cleland used the Gunbarrel Highway for a circuit of the Giles–Warburton–Blackstone area, coming from the South Australian side (J. B. Cleland, personal communication). A. S. George, a botanist on the staff of the West Australian Department of Agriculture, twice visited the Warburton Range Mission and surrounding country in 1961 and 1962. George also accompanied a CSIRO party from Perth to Alice Springs via Warburton and Giles and back by the Gunbarrel Highway in 1963 and he also paid two brief visits to Queen Victoria Spring (A. S. George, personal communication).

The present writer was flown in by the West Australian Petroleum Company to their geophysical exploration camp at Swindell Field in the heart of the Great Sandy Desert in April 1964 and provided with ground transport for field work in that area. The seaward margin of the Great Sandy Desert was explored in May 1965 (Beard 1967b) and the northern edges were examined south of Liveringa and Billiluna in the same month. In September–October 1966 the writer and A. S. George made a joint expedition from Laverton to the Warburton Range, round to Giles with a westward diversion up the Gunbarrel Highway, from Giles to the Sir Frederick Range and back, back to the Warburton Range via the Blackstone Range, then south to Rawlinna on the railway, halting at Neale Junction for east–west traverses. The journey was continued by a long traverse across open country on the Nullarbor Plain from Rawlinna to Reid, thence to Eucla and back by the Eyre Highway, turning off at Balladonia to visit Queen Victoria Spring. This was the first professional botanical party to cross the Great Victoria Desert. In July 1966 Arthur and Pauline Fairall (members of King's Park staff) travelled from Wiluna to Carnegie Station and eastward on the Gunbarrel Highway to Mt Everard, making collections. In July–August 1967 the writer followed this route with D. Young, later turning north along the Gary Highway for a first traverse of the north Gibson Desert. From Gary Junction the party travelled east on the Sandy Blight Junction road for a rendezvous near Mount Webb with A. S. George, travelling with an Agricultural Department party from the Warburton Range. The two parties returned westward in company to Lake Auld and then divided, the George party travelling on by the Wapet road through Swindell Field, the Beard party doubling back to come out by the east–west track from Windy Corner to Talawana. These traverses are shown in Fig. 5.

Mention must also be made of an examination of the pasture potential of the desert area south of the twenty-fourth parallel made by officers of the Western Australian Department of Lands and Surveys in 1963–64. While untrained in botany or ecology, their practical experience and knowledge in the recognition of land units has been of invaluable assistance in mapping. Use has been made of the work together with the observations of the botanists, in preparing this paper.

A series of vegetation maps of the desert area on the scales of 1:250 000 and 1:1 250 000 is currently in production by the present author and the first publication covering the Great Sandy Desert area is expected to appear during 1969. Explanatory memoirs accompanying these maps will give the fullest available data on the plant cover and the maps themselves will be the readiest reference to all the geographical names used in this paper which could not be shown in Figs. 1 and 5 due to limitation of space. The present paper is conceived as a synoptic account of the western deserts of Australia and their vegetation, in order to put all the ecological regions into perspective relative to one another.

THE ENVIRONMENT

Climate

Meteorological Stations within the desert area are inevitably few. Railway stations along the Trans-Australian line have recorded rainfall and in some cases temperature from the inception so that data are adequate for the Nullarbor Plain. Soon after the mission was established at the Warburton Range it was equipped as a recording station and there is now a continuous series of daily rainfall and temperature readings from December 1940, except for the 4 months September–December 1946. The Giles Weather Station began recording in September 1956. These are the only two stations in the heart of the desert. Information is entirely lacking for the northern section—the Great Sandy Desert—and must be built up by extrapolation from peripheral stations both in Western Australia and the Northern Territory. In this way the Bureau of Meteorology has constructed the general rainfall map which is reproduced here as Fig. 2, and it will at once be seen that the so-called desert area does not receive a significantly lower total rainfall than many other parts of the State. It is true that the Nullarbor Plain in its north-eastern part shows the lowest rainfall for Western Australia with less than 6 in. (150 mm) a year, but there is an area on the Murchison and Gascoyne averaging less than 7 in. (180 mm) and much of this pastoral country has less than 8 in. (200 mm). However, rainfall alone is no adequate criterion and we must examine *bioclimate* which is a synthesis of rainfall, its amount and seasonal distribution, with temperature. Bioclimates for Western Australia have been worked out by the present writer according to the methods of Bagnouls & Gaussen (1957) and discussed in another paper (Beard 1969). Assessment and classification of bioclimates is made by means of the *ombrothermic diagram*, a graph on which the mean monthly rainfall for the recording station is plotted in millimetres and the monthly mean temperature in degrees Centigrade, the latter on double the vertical scale, so that $r = 2t$. Diagrams for typical Western Australian stations illustrating the ten different bioclimatic types recognized are presented in Beard (1969). The most significant factor for vegetation is taken to be the length of the growing season. 'Wet' months when the average precipitation exceeds the effective minimum and thus permits growth are shown in the ombrothermic diagram wherever the rainfall curve rises above the temperature curve. 'Dry' months when vegetation must be dormant occur when the rainfall curve is below the temperature curve. The definition of a desert climate by this procedure is that all months in the year are dry, the rainfall line being always below the temperature curve (see Giles, Peak Hill, Marble Bar and Rawlinna in Fig. 3). The ombrothermic diagram employs average rainfall and temperature figures. On the average, therefore, all months in the desert are dry, which means that there is no assured annual growing season, however short. Naturally, of course, growth periods do

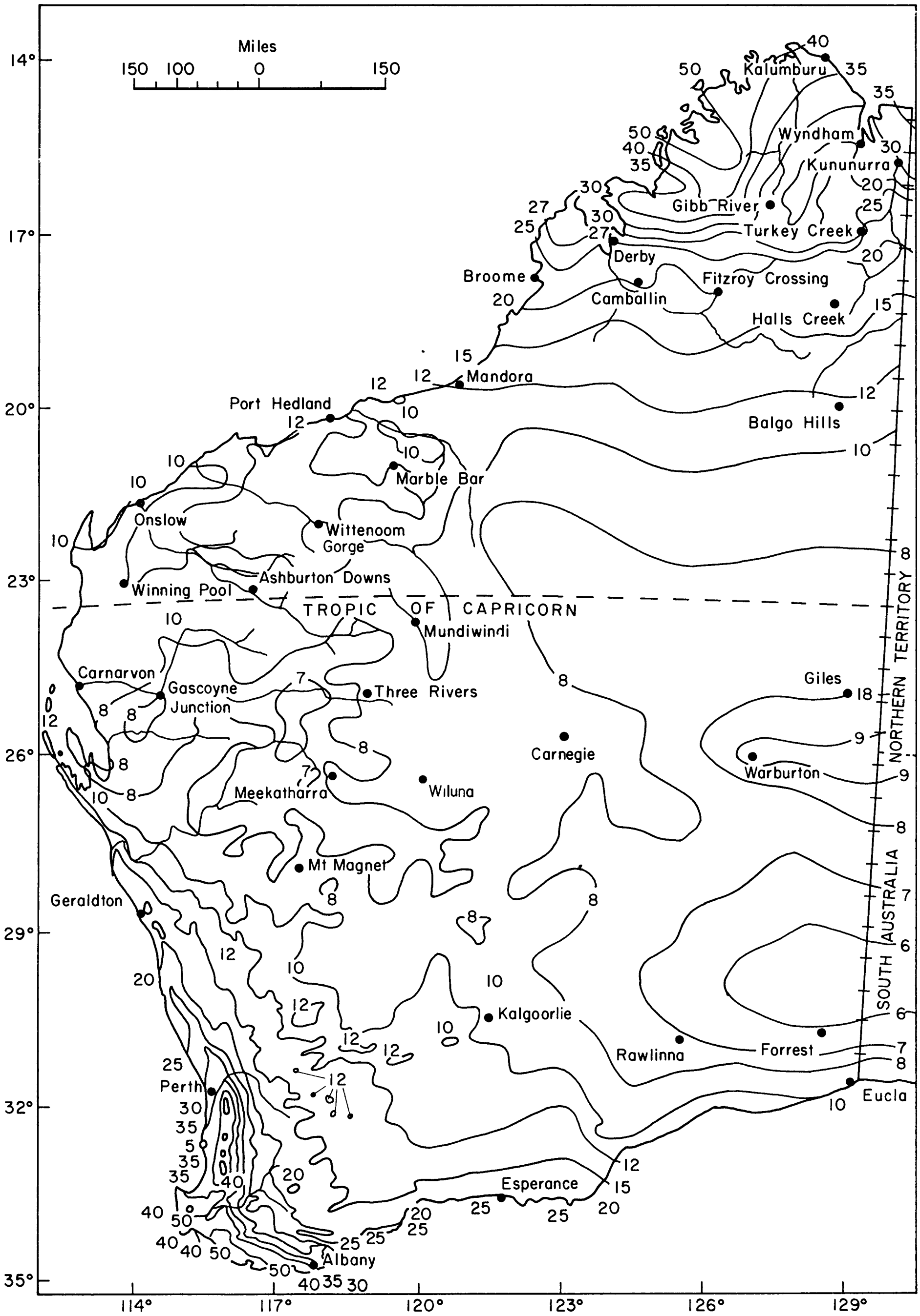


FIG. 2. Rainfall map of Western Australia. Isohyets in inches.

in fact occur, otherwise there could be no vegetation whatever which for this desert at any rate is by no means the case. The growth periods are merely erratic and undependable, following occasional falls of heavy rain.

Three different types of desert climate are distinguishable in Western Australia according to the seasonal distribution of such rains as do occur. The tropical or summer rain type classified as Type 1c is exemplified by the diagram for Marble Bar (Fig. 3). Rain is normally derived from summer thunderstorms. The 1bc intermediate type (Peak Hill) shows rainfall peaks in late summer and early winter with a dry spring and the non-seasonal type 1d (Rawlinna) has an equal chance of rain in any month of the year. Giles and the Warburton Range show an identical pattern to one another (Giles is reproduced) which resembles that of Peak Hill but shows some features of non-seasonality.

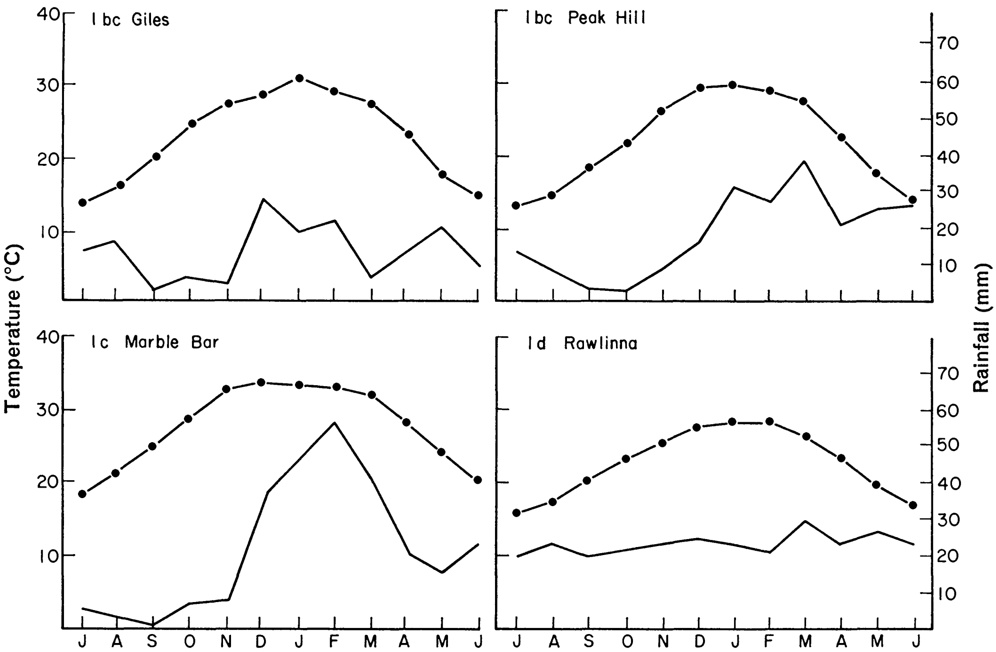


FIG. 3. Ombrothermic diagrams of four desert climates, Western Australia. ●, Temperature; ——, rainfall.

A bioclimatic map of Western Australia (Beard 1969) shows that the area of desert climates extends right across to the west coast and does not at all coincide with the uninhabited eastern half of the State. All of the latter is desert, but so is most of the pastoral country lying further west. It must be evident that some factor other than climate is responsible for the special characteristics of Western Australian 'deserts'.

The detailed characteristics of the climate of the Australian interior have by now been quite well documented in CSIRO studies. Slatyer (1962) dealt with the Alice Springs area and Arnold (1963) the Meekatharra–Wiluna area of Western Australia. Beard (1968) presented a detailed analysis of the records of the Warburton Range mission in connection with severe effects of drought observed in that locality. It is established that most falls of rain are too light to be effective. The minimum needed to initiate plant growth was calculated by Arnold to range from 0·24 in. (6 mm) in July to 1·18 in. (30 mm) in December. Once initiated, growth will continue while moisture in the soil lasts which will depend partly on the volume of initial storage and partly on any follow-up rains. The records of the Warburton Range show that for the most part soaking rains of an effective nature may be expected about three times a year on the average and account for two-thirds of the precipitation. Such events may be expected in any month except September and October which are almost invariably dry. There is much uncertainty about such rainfall, however, and a drought of 40 months is on record from January 1961 to April 1964 during which period only one effective fall of rain was experienced and there was widespread mortality of plants. Droughts of up to 1 year are quite common and are apparently tolerated by the vegetation. The Warburton Range records for 1941–60 show that the interval between effective falls of rain varied from 3 to 376 days; it four times exceeded 300 days and eight times 200 days. Like other features of the climate this liability to drought is not a special feature of the 'desert', but is shared by other parts of the arid interior being used for pastoral purposes. Further north in the tropics the minimum figure for effective rainfall is likely to be higher, but is likely to be satisfied just as frequently as the rain is concentrated more into the summer season with an increase in volume in individual falls.

Geology

Knowledge of the geology of the desert area has increased rapidly in recent years with improved access and the activities of oil exploration companies. An up-to-date general picture of the surface geology is given by the 1966 edition of the 1:2 500 000 Geological Map of Western Australia, published by the Geological Survey. It will be seen from this that most of the area of reputed desert coincides with an outcrop of sedimentary rocks laid down in a marine trough which existed intermittently from the Palaeozoic onwards. Three sedimentary basins are recognized as forming this trough and are shown in Fig. 4 which is adapted from Plate 22 of the Geological Survey Annual Report (1966). A comparison with Fig. 1 will show that the eastern limit of pastoral development coincides in a general way with the western boundary of the sedimentary basins. To the west of this line, the country is underlain by ancient rocks forming the Precambrian shield of Western Australia. Much of this area consists of Archaean granite, especially in the south, while the northern half of the shield features Proterozoic rocks of varied lithology. To the east of the general boundary line, with the exception of a further upland Precambrian area along the state border (north of the Warburton Range), the sedimentary basins contain more or less horizontally bedded strata. North of the Nullarbor Plain the sedimentary rocks are for the most part sandstones and siltstones of Permian or Cretaceous age, while the Nullarbor itself is of limestone of Eocene to Miocene age.

The Kimberley in the far north is another ancient Precambrian block bordered on the south by a sequence of Phanerozoic sediments ranging in age from Cambrian to Permian. Small isolated hills and ranges of Precambrian rocks crop out along the border between Western Australia and the Northern Territory. These rocks constitute a part of the upland area of central Australia and cross westwards into Western Australia for as much as 150 miles (240 km). With this exception the reputed desert is clearly associated closely withs the younger sedimentary rocks, and in addition to climatic factors, its plant cover is greatly influenced by the topography and soils these rocks have produced.

The past geological history shows that the area where the desert now lies was once covered by an arm of the sea 250 miles (400 km) or more wide, which separated the western shield area from the areas of the centre and north. This trough was continuous during the Cretaceous and parts were probably in existence during the Palaeozoic. A great thickness of sediments which accumulated in the trough was derived from the erosion of the adjoining Precambrian blocks. The thickness is known to exceed 14 000 ft

(4300 m) in part of the Canning Basin, but is only of the order of 2000 ft (600 m) in the Officer and Eucla Basins. Sedimentary rocks older than the Permian are confined to the northern margin of the Canning Basin flanking the Kimberley Block. Elsewhere there are extensive exposures of Permian rocks. Ice-age conditions dominated the Permian scene as most of the sedimentary rocks are of glacial origin. Marine conditions were intermittent during the Mesozoic and the general marine transgressions which prevailed

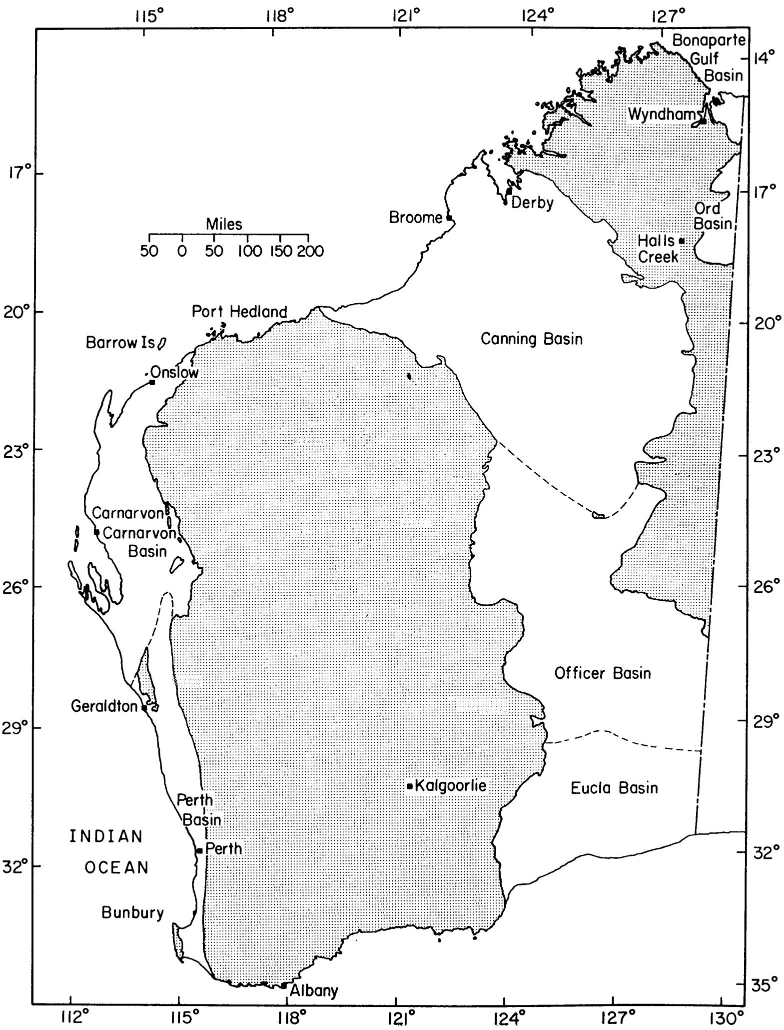


FIG. 4. Map of Western Australia showing sedimentary basins (open) and Pre-Cambrian areas (stippled).

during the Cretaceous led to the deposition of a widespread veneer of fine-grained terrigenous sediments. The trough was uplifted following the Cretaceous deposition. However, the Eucla Basin continued to be submerged during the Eocene and a thickness of up to 800 ft (240 m) of limestone was deposited. Some oscillation appears to have followed as there are thin deposits of limestones unconformably overlying the older rocks. The Eucla Basin finally emerged from the sea during the Lower Miocene and the land surface now rises to 300 ft (90 m) above present sea level at the coast, 900 ft (270 m) at its northern edge and reaches 2000 ft (600 m) at the junction of the Canning and Officer Basins. Marine sediments of Tertiary age are lacking in the Canning and Officer Basins. Some deposits known in the lower Oakover valley are attributed to a lacustrine origin.

The geological structure of the area along the eastern boundary is not well known in detail. The Warburton Range is shown in the 1966 geological map to consist of volcanics attributed to the Middle Proterozoic but in the same area there are granites and metamorphic rocks. Further east in the Blackstone and other ranges there is a considerable number of basic intrusions. The Petermann and Rawlinson Ranges, near Giles, and others lying further north are composed of massive quartzites attributed to the Middle and Upper Proterozoic. A further belt of undifferentiated Precambrian rocks extends northwards along the state boundary.

In the Eucla and Officer Basins a radical change in the conditions of deposition must have taken place between the Cretaceous and the Eocene. The Cretaceous sediments, being of terrigenous origin, indicate a high rate of erosion of adjacent land, but the limestone of the Eocene indicates clear water relatively free from terrigenous sediment. To postulate a decline in the rainfall is unsatisfactory because the flashfloods of arid areas often carry more sediment than the clear rivers of wall-watered regions. Palaeobotanical evidence suggests the Eocene as a 'wet' period and it may have been that both rainfall and temperature were more favourable than during the Cretaceous. The most significant suggestion would, however, appear to be that the rise of the angiosperms in the Cretaceous for the first time provided, by the end of that period, an effective plant cover and control of erosion on land.

Landforms

With the completion of the series of topographic maps on the 1:250 000 scale for the whole area the nature of the country is now well understood and landmarks named by early explorers have been identified and placed in their exact position. Many of the maps however lack spot heights.

The former sedimentary trough was gently uplifted leaving the rocks still lying virtually horizontal. Following emergence a drainage system developed and a very gently undulating surface was formed with wide valleys up to 200 ft (60 m) deep. Uplift was greatest in the centre, midway between the oceans, where there is now a high plain at 1400–1600 ft (430–490 m) above sea level, sloping down to the south and the north and north-west.

The Nullarbor Plain is bordered on the south by tall cliffs 200–300 ft (60–90 m) high which in part drop straight into the sea of the Bight and in part, between Twilight Cove and Eucla, pass inland and have a sandy coastal plain at their foot which lies little above present sea level and has a maximum width of 26 miles (42 km). Above the cliffs the limestone plain of the Nullarbor rises another 150 ft (50 m) in a few miles and then steadies to a very slight upward slope to the north. Along the railway altitudes are as follows: western boundary of the Nullarbor at Kitchener 650 ft (198 m), Rawlinna 600 ft (183 m), Forrest 530 ft (162 m), State boundary 510 ft (155 m). Seventy miles (112 km) north of the railway the general level has risen another 150 ft (50 m). Heights for the northern edge of the Nullarbor are not available but are probably 800–900 ft (240–270 m) above sea level. A rather more rapid rise of about 300 ft (90 m) in 50 miles (80 km) seems to occur north of this point.

The surface of the Nullarbor Plain is without major relief and there is little apparent sign of a former river system though faint traces can be seen north of the railway. The surface is pockmarked with more or less circular sinkholes or solution pockets known locally as 'dongas'. It is not clear whether this is intended to be the South African word *donga*—if so, it is misapplied as a *donga* is an erosion gully—or whether it is of local origin. Some of these sinkholes are known to lead into caverns and it is probable that even in more pluvial times drainage has been underground. Frequently the dongas are disposed in lines and particularly in the south it is common to find a microrelief of small limestone ridges and valleys arranged in parallel. The trend of these ridges changes from point to point on the plain. In the south-west it is parallel to the edge of the cliffs which terminate the plain. The soil of the ridges is shallow over limestone, a pinkish-brown silt of very floury texture to 12 in. (30 cm), then as before with lime nodules until rock is reached at 15 in. (40 cm). The soil of the depressions is a greyish-red, compact, fine silty clay to 3 ft (1 m) with few very small lime nodules and pH 8. The floury soil is typical of areas of the plain with a woodland cover. Large stretches are without trees and here the soil is a pink clay of shallow depth over limestone which frequently appears at the surface.

The coastal plain to the south, the Roe Plain, is formed of Pleistocene to recent beach detritus with a high proportion of lime, and is white in colour. In places on top of sea cliffs there are deposits of sand which appear to be older, more leached and weathered, and of a yellow colour.

North of the Nullarbor Plain the Phanerozoic rocks consist of horizontally bedded sandstones and the soil is therefore sandy and neutral to acid in reaction. Deposits of kunkar (travertine) are, however, usual along drainage lines and other evaporites appear in salt lakes. From the northern edge of the Nullarbor at latitude 29° S as far as latitude 27° there is a belt of country rising steadily to the north and seamed by ancient valleys trending generally to the south, often bordered by low lateritic breakaways, with long narrow salt lakes in their lowest sections. There are extensive areas of sand dunes especially in the eastern half, but there are also sand plains with few or no dunes, especially in the west. The dunes mostly show an east–west trend. Areas of loamy soil occur on lower-lying ground such as below breakaways or between dunes. All soil is red in colour including the sand of dunes and plains, and the loam flats. The loam is friable and contains lateritic nodules. This belt of country constitutes the Great Victoria Desert.

From latitude 26–27° up to the Canning Stockroute, in the Phanerozoic country, we find the central high plain which constitutes the Gibson Desert. To the east of it lies the mountainous area of the Warburton and other ranges which will be described later. The plateau is even and monotonous, very gently undulating between 1400 and 1600 ft (430–490 m) above sea level at its highest and dominated by occasional mesaform hills such as for example the Alfred and Marie Range with a maximum of 1775 ft (541 m). Shallow meandering valleys indicate ancient drainage systems trending southwards and northwards. Their bottom-land vegetation does not indicate accumulation of salt. At some period the surface of this plateau has been deeply weathered and a typical lateritic soil has developed with accumulation of massive ironstone conglomerate. Over much of the plateau surface, especially in the south, this soil has become truncated by removal of its sandy surface horizon. Accumulations of sand are found in valleys or on lower ground peripheral to the central plateau, and here sand dune systems with an east–west trend have come into being. In the northern part of the plateau a sand mantle is still largely preserved but consists mainly of small rounded grains of ironstone which may have originated by disintegration of laterite. Elsewhere a typical soil profile of to-day consists of decomposinglate rite, the top 6–8 in. (15–20 cm) loose and friable made up of ironstone gravel in lumps of all sizes up to $2\frac{1}{2}$ in. (6 cm) filled in with silty material, and below this indurated and massive ironstone. The surface is a *hamada* or desert pavement, strewn with ironstone pebbles up to 1 in. (2·5 cm). Wind-sorting of surface material occurs between clumps of vegetation (Phot. 1). Occurrence of a very sandy region with profuse dunes in the Lake Disappointment basin immediately to the west of the central plateau, where sand has substantially overridden Proterozoic rocks, may indicate migration of sand in that direction. The Proterozoic rocks are not generally productive of sand in quantity and the areas which they underlie in the basins of the Gascoyne, Ashburton and Fortescue Rivers are almost entirely free of sandhills. It could well be found in the Lake Disappointment basin, however, that the sand is derived *in situ* from disintegration of a thin veneer of Permian and Mesozoic sandstones.

The Canning Stockroute from Lake Disappointment at Well 23 up to Well 36 skirts the north-western edge of the laterite plains of the central plateau. The plateau has been falling gently in that direction to terminate at about 1150 ft (350 m) above sea level. From the Stockroute to within a few miles of the sea at the Eighty-mile Beach stretches the Great Sandy Desert, a rolling plain descending gradually with clearly marked valleys forming part of a former drainage system and with chains of narrow salt lakes. It seems probable that the Percival Lakes system, representing the line of an ancient river, formerly received drainage from the Lake Disappointment system at Lake Blanche and continued via Lakes Dora and Waukarlycarly in the direction of the Oakover River. According to Traves *et al.* (1956) the bed of Lake Auld is 755 ft (230 m) above sea level and Lake Dora 650 ft (198 m). Lake Waukarlycarly is said to be a little higher but with silting this may not be significant. North of this drainage system there is a belt of higher ground, the Anketell Ridge, trending west-north-west to east-south-east, which is largely sand-free and reproduces the lateritic uplands of the Gibson Desert. This ridge has provided a useful means of access by sand-free country into the heart of the desert for mineral exploration. North of it again is another drainage system now almost entirely choked with sand and leading out to the 'Mandora estuary' (Beard 1967b).

The Sturt Creek approaches the north-eastern margin of the Great Sandy Desert at Billiluna. Below its confluence with the Wolf Creek the stream terminates in a delta or overflow zone 30 miles (50 km) long, an expanse of clay pans and marshes leading finally to a salt lake, Lake Gregory. The height of this above sea level is not known exactly but appears to be between 900 and 1000 ft (270–300 m). It is not clear whether this is a true interior basin or whether the stream once continued further to reach the sea, perhaps at the Mandora estuary. The behaviour of the Sturt Creek is reminiscent of the rivers of the northern Kalahari which appear to have had a similar history.

The Great Sandy Desert is almost entirely a sandhill region and shows the most pronounced development of seif dunes of any part of the State. Elsewhere dunes normally tend to an arrangement in parallel lines, but it is here that trends are most consistent and prolonged, and individual dunes reach their greatest height and length. The general trend is west-north-west to east-south-east. The dunes are from 10 to 120 ft in height (3–37 m), averaging about 40 ft (12 m). Their spacing is very variable, mostly 1 or 2 per mile (1·6 km), at times up to 8 per mile, counting braided dunes as one. Braiding is very common, each dune having two or more crests. The dunes run in immensely long lines and march remorselessly up and down hill, ignoring the basic pattern of the topography and often engulfing small hills and breakaways. They are interrupted, however, by the salt lakes. Traves *et al.* (1956) have drawn attention to the behaviour of dunes here; on the east side of lakes the dunes come down directly to the lake margin and even encroach upon it whereas on the west side the first half-mile (1 km) from the edge may often be free of dunes and for some 2 miles (3 km) the dunes are usually small, ill-defined and of complex pattern (see 1:250 000 topographical map 'Tabletop', on which the dunes are shown). The sand has migrated westward, but not, it would appear, to any major extent.

The old peneplain surface, where free of sand, is found to be deeply weathered and appears to reflect the influence of a rainfall regime much higher than that of the present day. The writer is informed by Mr F. Muir of WAPET that the influence of weathering is frequently traceable in the underlying rock to a depth of 200 ft (60 m). The actual soil mantle varies from nothing (where rock crops out) to as much as 30 ft (10 m) in depth, being generally over 15 ft (5 m) thick. Seen in small excavations where it could be studied to 5 ft (1·5 m) in depth, the profile is quite undifferentiated and consists of a structureless mass of red sandy loam with very abundant small pea-ironstone. In local patches the ironstone is concentrated to form more or less massive conglomerate. Throughout, the small pea-ironstone forms a 'desert pavement' on the surface.

The soil in low-lying drainage lines and the vicinity of salt lakes frequently contains massive travertine buried in red sand. Soft caliche may occur on lake margins. According to Traves *et al.* (1956) the bed of the lakes consists of a thin crust of salt and gypsum underlain by at least 18 in. (0·5 m) of brine-saturated sand and mud.

The seif dunes have presumably been formed by sweeping up the former sandy surface horizon of a well-developed lateritic soil. On high-lying ground the sand has migrated from the rises leaving a bare truncated profile and has choked the valleys with sandy fill. Elsewhere the sand has been piled into dunes; sometimes there is still a sandy covering on interdune floors, sometimes one has the bare truncated profile or outcropping rock. A rough calculation based on average dunes 40 ft (12 m) high, 20 yd (20 m) wide at the summit and 100 yd (100 m) wide at the base, spaced half a mile (0·8 km) apart shows that they contain sufficient material to cover the whole country evenly to a depth of 3 ft (1 m). It is not improbable that the original sandy topsoil of the area was of this depth. It would not have contained pea-ironstone and was presumably removed by deflation down to the top of the horizon containing the nodules, at which point formation of desert pavement restrained further movement. Brown (1959) has studied the nature of the sand in the dunes of the Canning Basin. It is slightly coarser than, but generally similar to, the dune sands of other desert areas of the world. The grains have an iron oxide patina giving all the sand a pinkish colour. It is considered to have been derived mainly from within the Canning Basin itself, but some of it may have come from the now relatively sand-free Gibson Desert to the south-east. However, the behaviour of the dunes at the salt lakes must surely indicate that there has been relatively little large-scale north-westerly movement of sand, or they would have completely overridden the lakes instead of terminating at or near the eastern margin. Moreover Casey (1957) reported a correlation between grain size in the dunes and the underlying rock, with finer grains over the Anketell sandstone and coarser grains over the undifferentiated Mesozoics.

It remains to speak of the mountainous area east of the Gibson Desert. Most of this is an even plateau, lying slightly higher than the Gibson Desert, about 1600 ft (490 m) above sea level. The plateau is dotted with small abrupt mountains, hills and rocks which rise no more than 400–500 ft (120–150 m) above the plain. Mount Talbot in the Warburton Range attains 2045 ft (623 m). No heights are given on the topographical maps for the Rawlinson Range or other eminences in that area but Giles recorded a height of 3085 ft (940 m) at Mount Russell, the range falling to about 2000 ft (600 m) at the western end. The impression given is that the landscape is one of immense age and that the mountains and hills are the last reduced remnants of former impressive ranges. Being formed of pre-Cambrian rocks the mountains are not mesaform but irregular and rounded in profile. They are also extremely rocky and bear very little soil. In the Blackstone and associated ranges numerous dykes of basic rock outcrop which weather to masses of large boulders devoid of vegetation. The surface of the boulders is reddish but appears black when seen at a distance. This is the origin of the name of the Blackstone Range. East and west of Giles Weather Station stretches a very long outcrop of massive quartzite dipping to the north. East of Giles this forms an impressive escarpment facing south and arranged in an arc, which was named by Giles the Schwerin Mural Crescent. The Sir Frederick Range further north is a curious feature. Formed from the weathering of an ancient conglomerate, the hills consist of huge piles of shingle.

The plains around the mountains are evidently formed of detritus derived from them. In the vicinity of the more basic outcrops, that is mainly to the south, red loam predominates and at the Blackstone Range there are even some quite small black soil plains with Mitchell grass (*Astrebla* sp.). Predominantly, however, and especially around the quartzite ranges the plains are sandy and dunes have developed. In this sector the dunes rarely show any definite trends, their direction is confused and individual sandhills are short. One may suppose that this is due to lack of consistent winds.

The numerous salt lakes, some of them very large—Lake Mackay is 40 miles (65 km) across—show no obvious evidence of wind transport of sand. Their beds consist of evaporites such as travertine, magnesite, gypsum dunes and beds of common salt.

THE VEGETATION

The natural regions

The desert area is divisible naturally into a number of quite distinct regions each having a characteristic landscape and vegetation. The boundaries of these regions, as shown in Fig. 5, are accurately derived from vegetation mapping. Each of them can be said to be a Natural Region in the sense of Clarke (1927) as well as a Botanical District in the sense of Diels (1906) and of Gardner & Bennetts (1956), and to represent a refinement of the earlier work in both cases with the aid of more advanced geographical and botanical knowledge. Each of the regions recognized here is being named as a natural region and a botanical district, correlating as follows with the earlier authors.

New regions and botanical districts	Clarke	Gardner & Bennetts
(1) Great Sandy Desert Canning Botanical District	Canning region	Part of Carnegie district
(2) Balwina Desert Mueller Botanical District	Part of Fitzroy and Carnegie	Part of Carnegie district
(3) Little Sandy Desert Keartland Botanical District	Part Carnegie	Part of Carnegie district
(4) Gibson Desert Carnegie Botanical District	Part Carnegie	Part of Carnegie district
(5) Great Victoria Desert Helms Botanical District	Part Carnegie	Part of Carnegie district
(6) Warburton Region Giles Botanical District	Warburton	Part of Carnegie district
(7) Nullarbor Plain Eucla Botanical District	Nullarbor	Eucla

Following the use of Carnegie's name by Gardner & Bennetts the newly named

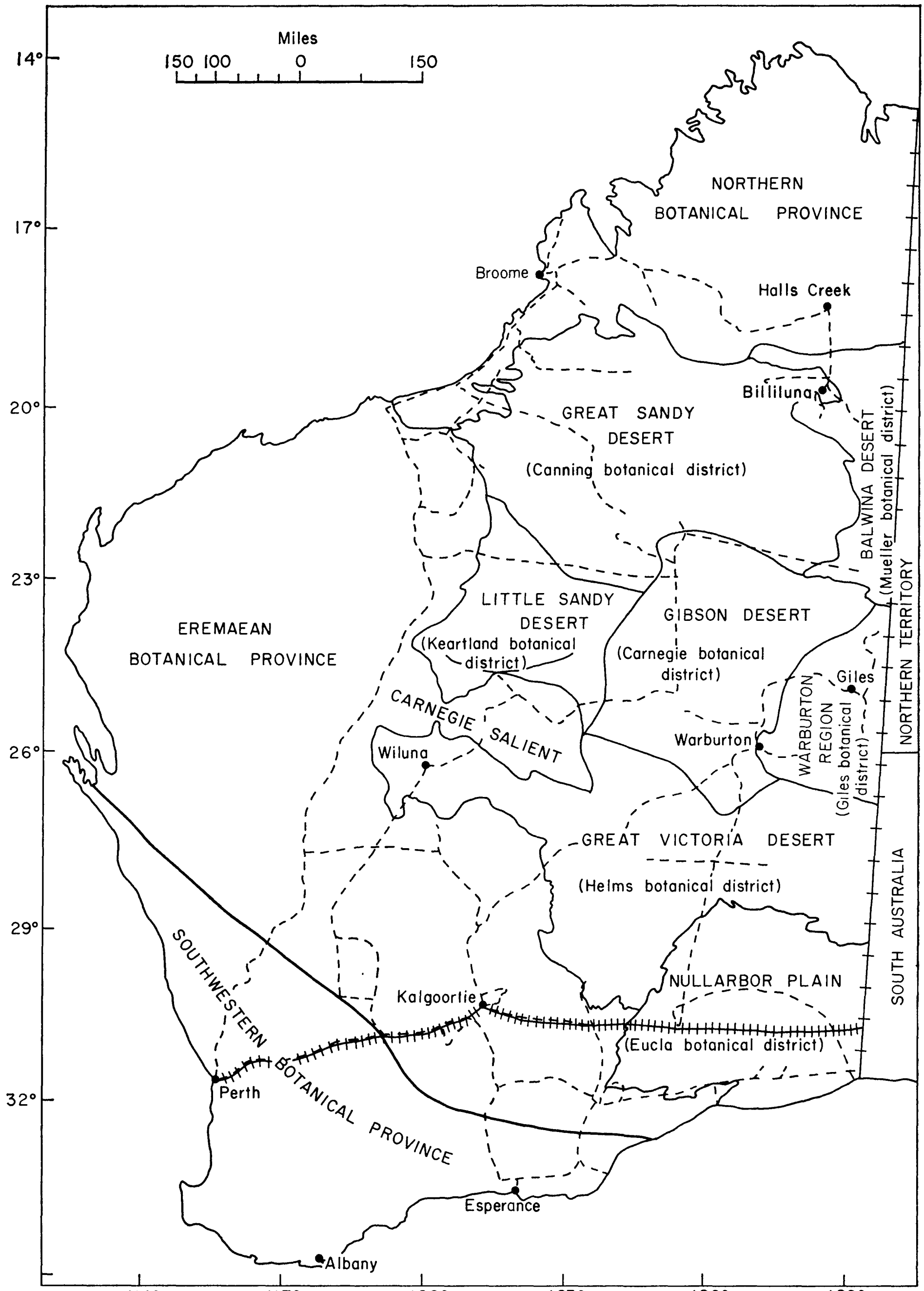


FIG. 5. The ecological regions and botanical districts in the desert area of Western Australia. - - -, Botanical survey traverses.

botanical districts have all been called after personages, as far as possible early collectors. The name of Baron Ferdinand von Mueller appears with Balwina as he was there with Gregory in 1856. The physical characteristics of the regions and their plant cover are described below. Botanical nomenclature follows that of Beard (1965).

(1) *Great Sandy Desert*

This tract occupies the greater part of the northern desert area north of the Tropic of Capricorn. It stretches from 18 to 20° S latitude, and from 120 to 128° E longitude. It is essentially a sandhill region and its boundaries have everywhere been drawn at the outer limits of sandhill country. In the north-east and east the sandhill desert is bounded by the desert sandplains of the Balwina region, in the north by the tree- and shrub-steppe formations forming the arid fringe of the Kimberley, and in the north-west by the pindan formation of Dampierland (Gardner 1942; Beard 1967a). From Christmas Creek to Callawa this boundary is also that between the Northern and Eremaean Botanical Provinces. On the south-west the boundary skirts the mountainous country of the Pilbara block, prolonged into the Throssel, Broadhurst, McKay and other ranges which form a tongue partially cutting it off from the Little Sandy Desert. On the south the boundary lies at the edge of the laterite plains of the Gibson Desert.

There are no meteorological stations within the Great Sandy Desert and inferences as to the climate can be made only from stations outside its borders. It will probably be found true to say that mean monthly maximum temperatures range from 80° F in July to 108° F in January, with 6 months (October–March) over 100°; mean monthly minima range from 40° F in July, with occasional frosts experienced, to 70° in January. Mean relative humidity would range from 30 to 45%. Rainfall is probably very erratic and decreases from 12 in. (300 mm) per annum in the north-west to 10 in. (250 mm) or less in the south-east. Rain is received predominantly from thunder showers in the summer months and sometimes from cyclonic rains bringing heavy falls. The winter months are virtually rainless.

The physiography of the region consists basically of a gently undulating plain rising from the coast to some 1500 ft (450 m) above sea level in the far interior. As has been noted it features two ancient and very extensive river basins, now inactive, divided by a low watershed which appears as the Anketell Ridge in the west and the Southesk Tablelands in the east. Both these upland areas are free of sand dunes and have a hard lateritic surface. Several parts of the region have been studied and mapped geologically. With the exception of the Paterson Range which is a solitary outcrop of the pre-Cambrian basement, all the surface rocks are more or less horizontally bedded sediments classified as follows (Casey 1957; Wells 1962):

Cretaceous	Anketell Sandstone	Fine to medium-grained micaceous sandstone, 100–200 ft (30–60 m) thick.
Undifferentiated Mesozoic		Coarse sandstone and conglomerate.
Permian	Various formations	

The more recent rocks listed above frequently crop out to form small buttes and mesas throughout the area; however, the seif dunes are the most conspicuous feature of all and sweep across the country in immense lines. They are absent only from the uplands and salt lakes. The general trend of the dunes is at right angles to the coast, and parallels the prevailing winds of the present day.

Since the dunes are a dominant feature, their vegetation is the principal feature of the plant cover. It is simple in species and structure, is extremely consistent throughout the region, and differs from the vegetation of the interdune flats. The flanks of the dunes are normally thickly vegetated with hummock grass ('spinifex'), with scattered shrubs, but the crests are often somewhat bare and subject to wind action. Feather-top spinifex (*Plectrachne schinzii*) is the universal species of hummock grass. Among shrubs, *Grevillea stenobotrya* is common, very consistent, and confined to sandhills. *G. eriostachya* and *G. juncifolia* may be found, with many species of wattles, especially *Acacia sentis*, *A. salicina* and the soft shrub *Crotalaria cunninghamii*. In depressions *Melaleuca lasiandra* may become common. South of latitude 22° small shrubs of *Thryptomene maisonneuvii* may be locally frequent between the spinifex. In addition to the above there are often trees of a species confined to sandhills. Its identity is still in doubt and it is tentatively referred to a form of *Eucalyptus dichromophloia*. Distribution is extremely irregular and it may be absent for miles, or else quite thickly distributed. It tends to grow on either side of the bare top of the dune, so much so that in many aerial photographs two rows of small dots can be distinguished along each crest. From the association of trees, shrubs and hummock grass this vegetation is termed 'tree-steppe'. The vegetation of the interdune may also be tree-steppe but is more commonly only shrub-steppe, i.e. with no trees present. The interdune is primarily influenced by the amount of sand present. On deep sand *Plectrachne schinzii* is dominant, but if this shallows or gives place to bare laterite gravel there is a change to *Triodia pungens* or, south of latitude 22°, to *T. basedowii*. The woody components are less completely dependent upon the soil constitution. Nearer to the coast, that is north-west of the Percival Lakes, presumably under the influence of a higher rainfall, scattered trees of *Eucalyptus dichromophloia*, *E. setosa* and *E. aspera* are common in sandy ground, together with numerous shrubs, notably *Hakea suberea*, *Acacia pachycarpa*, *A. impressa*, *A. tumida*, *Grevillea wickhamii* and *G. eriostachya*. On hard lateritic ground the trees drop out. In the interior sector south-east of the Percival Lakes the trees are no longer seen and only shrub-steppe covers the interdune.

A different type of tree-steppe is found in some relatively small patches close to the lower Sturt Creek, constituted by the desert oak (*Casuarina decaisneana*) over a ground cover of soft spinifex (*Triodia pungens*). The Casuarinas become quite large trees 30–40 ft (9–12 m) tall and 12 in. (30 cm) in diameter and appear to be dependent on supplies of underground water.

The lateritic, sand-free uplands carry a type of shrub-steppe with *T. pungens* dominant (or *T. basedowii* south of latitude 22°) and numerous shrubs of the species listed above, frequently growing in clumps, or disposed along drainage. The vegetation of hills and mesas is normally very sparse, consisting of a thin cover of *T. pungens* or *T. basedowii* with some small shrubs of *Eremophila* and *Cassia* spp. Mulga (*Acacia aneura*) is to be seen on the tops of mesas in some cases. The Paterson Range has not been visited but is believed to carry mainly *Triodia wiseana* with some *T. pungens* and sparse shrubs and trees.

The vegetation of salt lakes and their vicinity is distinctive. On approaching a lake there is frequently an appearance of travertine in the soil, a replacement of *Pletrachne schinzii* by *Triodia pungens*, and occurrence of the ti-trees *Melaleuca lasiandra* and *M. glomerata*, up to 6 ft (2 m) high and locally forming thickets, with *Acacia salicina* and numerous large termitaria. Lake bed communities (studied at Lake Auld) show a zonation probably corresponding to the deposition of evaporites—lime, gypsum and salt. The lowest portions where salt accumulates carry samphire communities (*Arthrocnemum*), surrounded by a saltbush zone (*Hemichroa*, *Bassia*, *Frankenia*) and this in turn by a spinifex zone (*Triodia* sp. *inedit*., Beard 3234).

(2) *Balwina Desert*

This name has been proposed for a north-easterly sector of desert country which is largely free of sandhills and extends beyond the State border into the Northern Territory. Its northern boundary extends from Christmas Creek east to the State border and is at the same time the boundary between the Northern Botanical Province and the Eremaea. Its southern and western boundary is that of the Great Sandy Desert.

Rainfall has been recorded at Sturt Creek and Billiluna Stations, and both temperature and rainfall at the Balgo Hills native mission. The temperature readings at Balgo Hills are much the same as those from stations on the western side of the Great Sandy Desert. Mean monthly temperature ranges from 66° F in July to 91° F in December. Rainfall averages 11 in. (280 mm) a year, normally received in thunderstorms during the 3 months December–February. Rainfall increases to 15 in. (380 mm) on the northern border of the desert where an assured growing season begins to be experienced.

Physiographically this region consists mainly of flat sandy plains about 850–900 ft (260–275 m) above sea level, from which rise occasional abrupt low hills and ranges, much eroded and very stony, and not attaining much more than 300 ft (90 m) above the plains. The highest point, Mt Brophy in the Gardner Range, is about 1800 ft (550 m) above sea level. The Sturt Creek and its tributary the Wolf Creek drain down into this region and are lost by evaporation. There are no other active rivers other than minor flood channels draining the hills. The whole region has been mapped geologically (Maps: Mt Bannerman, Billiluna, Cornish, Lucas, Stansmore), showing that ancient, proterozoic rocks appear in the east, perhaps representing an exhumed Permian topography, while the western side is covered with sediments, mainly sandstones and of Permian age.

Although most of the country consists of sandy plains, seif dunes are uncommon and the reason for this absence of sandhills is not clear. In many areas there is evidence that the surface sand is rather thin, overlying rock or calcareous hardpan, but this needs further investigation. It appears that the red soil is firm and of a fairly loamy nature rather than loose and incoherent, so that it may possess binding qualities. The vegetation of the sand plains is shrub-steppe. As observed at Billiluna, this has a ground cover of soft spinifex, *T. pungens*, a variable species which here adopts a stoloniferous form. Numerous shrubs, up to 10 ft (3 m) tall, mainly include the following: *Hakea suberea*, *Acacia pachycarpa*, *A. impressa*, *Grevillea pyramidalis*, *G. wickhamii*, *Gardenia keartlandii*, *Cassia* spp. Very occasional trees of *Eucalyptus aspera* and *E. dichromophloia* are seen and the mallees *E. pachyphylla* and *E. odontocarpa*. *Melaleuca lasiandra* comes in, in depressions. In the south along the desert track south of Lake Mackay the ground cover is a mixture of *Triodia pungens* and *T. basedowii*, and the principal shrubs are *Hakea divaricata*, *Eucalyptus pachyphylla*, *E. gamophylla*, *Acacia pachycarpa*, *Cassia* spp., *Grevillea wickhamii* and the tree *Eucalyptus dichromophloia*.

The vegetation of stony hills, where these occur, is very sparse, a thin cover of *Triodia pungens* with a few stunted bushes of *Grevillea wickhamii*, *Cassia* and *Eremophila* spp. or *Ptilotus*. Only on the northern border of the region do a few trees of *Eucalyptus brevifolia* appear, and some admixture of *Triodia intermedia*. These are typical elements of the tree steppe of the Hall's Creek area further north.

The course of the Sturt Creek, pouring down to terminate in this region, introduces an element of vegetation foreign to the desert. Along the Sturt Creek itself there is a flood plain mostly about 2 miles (3 km) in width, sometimes more, and there are also traces of a former course of the Sturt Creek cutting across to pick up the Lewis and Slatey

Creeks and rejoining the present course below Billiluna Station. These flood plains consist of a grey silt and are very sparsely vegetated with grasses (especially *Astrebla pectinata*) and soft spinifex (*Triodia pungens*) in between very numerous small bare claypans and occasional coolabah trees (*Eucalyptus microtheca*). South of Billiluna the flood plain spreads out into the distributary zone where the river is lost in a maze of braided channels and pans, a very desolate region with the bare clay surfaces of the pans, low sandy mounds dividing them and covered with spinifex (*Triodia pungens*), some flats with grass and forbs, small stunted trees of *Eucalyptus microtheca* mainly around pans, and shrubs of *Eremophila* and *Acacia* spp. Around some marginal claypans in sandy country there is a growth of ti-tree scrub, *Melaleuca lasiandra* and *M. glomerata*. In the adjacent sandplain there are also frequently extensive groves of desert oak (*Casuarina decaisneana*) as described under the Great Sandy Desert. The distributary zone is terminated at the south end by several extensive 'Plains' which are just bare clay flats, and by Lake Gregory which is salt. There is otherwise little sign of salt along the Sturt Creek. The lake is ringed by a belt of a well-grown wattle (*Acacia* sp. unidentified) 20 ft (6 m) tall, in close, almost closed formation with a ground layer of short annual grass. This tree resembles mulga (*A. aneura*) with grey foliage but the leaves are much longer and pendant. The lake bed is vegetated with black samphire (*Arthrocnemum*) on grey silt, becoming more and more salt towards the centre of the lake, with reduction of the samphire.

(3) *Little Sandy Desert*

This name is proposed for a sector of the desert which appears to have been nameless hitherto, and is chosen to reflect the fact that its character is much the same as that of the Great Sandy Desert from which it is partly isolated by a chain of hills and ranges. This region is still one which is very difficult of access and it largely remains an impenetrable waste of sandhills. The present writer has traversed the graded track from Windy Corner to Talawana which crosses the northern fringe, has been up to Weld Spring at the southern edge and has flown over it. Further information has been furnished by Dr D. L. Serventy and H. Ward, pastoralist, of Glen Ayle Station.

On the north the Little Sandy Desert is bounded by the Throssel, Broadhurst and Mackay Ranges, on the west and south by the limit of sandhills, and on the east also where sandhills give way to the laterite plains of the Gibson Desert. There is no human habitation within the region and climatic data are only derivable from adjoining stations. These indicate that climate remains much the same as in the Great Sandy Desert, the rainfall coming almost entirely in summer.

Physiographically this entire region is a basin with Lake Disappointment at its lowest point. The land slopes towards the lake from all sides. Structurally it has a basement of Proterozoic rocks which form hills and mountains of rounded outline emerging from a sea of sand. Some of these massifs may be 10 miles (16 km) long and five across and many attain notable heights. Mount Essendon is just under 3000 ft (910 m) high and equals the maximum heights of the Rawlinson Range on the other side of the sedimentary basin. The origin of the sand which surrounds the outcrops merits investigation. It seems unlikely that it has all been transported from the east and it may well have resulted from disintegration of a thin veneer of Permian sediments, of which mesaform remnants can be seen.

The vegetation of the sandhill country appears to be essentially the same as that of the Great Sandy Desert, with some minor changes due to more southerly latitude. The desert bloodwood, *Eucalyptus dichromophloia forma*, is conspicuous on the dunes which are thickly but not entirely flanked with *Plectrachne schinzii:* there is now a noticeable abundance of *Thryptomene maisonneuvii*, especially on the south-facing sides. Other ericoid shrubs such as *Micromyrtus flaviflora* and *Calythrix longiflora* also appear, but the universal *Grevillea stenobotrya*, *Acacia salicina* and *Crotalaria cunninghamii* remain. In depressions dunes become crowded and jumbled, travertine is exposed in the soil and shrubs such as *Melaleuca lasiandra*, *M. glomerata*, *Hakea microneura* and *Lamarchea* sp. make their appearance. Frequently in such depressions local patches of desert oak (*Casuarina decaisneana*) are seen.

Interdune flats are vegetated with *Plectrachne schinzii* in deep sand, and with *Triodia basedowii* otherwise. Notable shrubs include *Acacia pachycarpa*, *A. pruinocarpa*, *A. coriacea*, *Hakea suberea*, *Grevillea eriostachya*, and the mallees *Eucalyptus gamophylla* and *E. kingsmillii* usually in stony ground. Sand plains may occur locally, without dunes and these are typically covered with *Triodia basedowii* with scattered *Hakea suberea* and *Acacia coriacea*.

Hills and mountains have a varied vegetation. Smaller hills and mesas usually feature mulga (*A. aneura*) with soft spinifex (*Triodia pungens*) and *Eremophila* spp. On the larger massifs mulga may occur in patches on the lower slopes. Higher up *Triodia pungens* becomes dominant, with scattered small trees of *Eucalyptus aspera*, and numerous species of *Acacia*, *Eremophila* and *Cassia*, and *Grevillea wickhamii*. At the highest levels *Triodia wiseana* seems to replace *T. pungens*.

Salt lake vegetation is as recorded for the Great Sandy Desert.

(4) *Gibson Desert*

The Gibson Desert is the central and most elevated plateau section of the sedimentary basin. The name is derived historically from Giles who wished the area west of the Rawlinson Range to be known after his follower Gibson who had perished there, but it so happens that the area in question constitutes a unit ecological region. Essentially it is characterized by laterite plains, a monotonous and gently undulating topography floored with ironstone gravel and vegetated with poor spinifex and stunted mulga, relieved only rarely by low mesaform hills. The Gibson Desert stretches from 22½ to 27° S latitude and from 123 to 128° E longitude. On the north, west and south its limits have been drawn at the general boundary between the laterite plains and sandhill country. On the east the boundary is taken at the change in geological structure from Permian sediments to the Proterozoic rocks of the Warburton Region. This means that on the east side some sandhill areas are included. In the laterite plains country proper, west of the Alfred and Marie Range, sandhills occur only in the larger valleys, which are filled with deep sand. In the eastern section the lower sandy ground is more widespread and encloses large isolated patches of rising ground where the laterite surface reappears.

Within the Gibson Desert there is no permanent human habitation, there are no meteorological stations, and climatic data are thus in doubt. The rainfall is inferred to average between 8 and 9 in. (200–230 mm) per annum, with the distribution varying from predominantly summer, in the north, to somewhat non-seasonal, in the south, where only September and October are months with little chance of rain. Mean temperatures range from 85° F in January to 55° F in July, with great extremes. Summer maxima of 110° F would be not uncommon while severe frost may be experienced on winter nights. The writer recorded a minimum of 23° F on the night of 2–3 August 1967 near Windy Corner.

There is little definite information on the geology of this region. On the 1966 geological map the laterite plains are shown as developed on Cretaceous sandstones, with older Mesozoics and Permian appearing peripherally especially in the east, sandhills being treated as Quaternary. The plateau so constituted shows an ancient drainage pattern of small streams taking their rise and flowing to the north-west, west and south-west, with principal valleys traversing the eastern section from north to south. In common with the general practice of dating West Australian laterites to the Miocene the formation of the plateau surface may be held to have been completed during the Miocene although it would appear to the present writer that there are grounds for assigning laterization to the Eocene. Truncation has occurred subsequent to the Miocene and the present phase is one of slow disintegration of the lateritic crust.

South of the Tropic of Capricorn it is normal for the Eremaea to be vegetated with mulga woodland (*Acacia aneura*) except on pure sand. Except for a small area at the northern extremity therefore the Gibson Desert carries essentially a mulga formation even though mostly in an attenuated form. As the laterite plain undulates the minor valleys in which some loam has accumulated show a normal dense mulga, an almost pure stand of *A. aneura* 10–15 ft (3–5 m) tall, almost closed in places, with some admixture of *A. pruinocarpa*, *Plectronia latifolia* and smaller shrubs of *Eremophila* spp. The ground may be quite bare, or on the heavier soils carrying an open growth of *Danthonia bipartita* with ephemerals in season—*Helipterum stipitatum*, *H. floribundum*, *H. fitzgibbonii*, *Ptilotus helipteroides*. As one moves up slope the mulga opens and becomes scattered in thickets. A spinifex floor is established of *Triodia basedowii*. Numerous other shrubs add themselves to mulga and gidgee, notably *Hakea lorea*, *Acacia grasbyi*, *A. helmsii*, *Eucalyptus kingsmillii* (mallee), *Eremophila leucophylla*. Under favourable conditions, apparently when there is a successional stage of regeneration following drought or fire (Beard 1968) there will be numerous colourful subshrubs and forbs, e.g. *Dicrastyles exsuccosa*, *Burtonia polyzyga*, *Petalostyles millefolium*, *Cassia notabilis*, *Halgania solanacea; Goodenia azurea*, *Ptilotus* spp., *Dampiera* spp., *Trachymene glaucifolium*, *Helipterum stipitatum*. On the highest ground where the laterite is at its most solid and stony the shrubs thin out still further, leaving only very sparse *Hakea suberea*, *Acacia pruinocarpa* and *A. aneura*. The spinifex floor remains but the *Triodia* clumps are small with much bare gravel between them.

In the northern half of the Gibson Desert a progressive change takes place towards the north. First, eucalypts appear in the valley bottoms, *Eucalyptus microtheca* and *E. dichromophloia*, small gnarled trees, with occasional claypans. Then the valley bottoms begin to become sandy, with *Plectrachne schinzii*, and the mulga withdraws up the slope. At this stage there may be a line of eucalypts and mulga along the valley bottom. Eventually mulga is found only on the crests of the ridges, on laterite, mostly represented by its 'weeping' ecotype, with *Eremophila latrobei* as an undershrub. All the slopes and depressions have a friable soil containing a very large amount of minute pea-ironstone. The cover is *Triodia basedowii*, replaced by *Plectrachne* in draws, with shrubs of *Acacia pachycarpa*, *A. dictyophleba*, *Hakea suberea* and *Grevillea wickhamii*. We have now returned to the *Acacia pachycarpa* shrub-steppe of the Great Sandy Desert.

Major valleys and low-lying areas are filled with deep sand, normally with dune systems. Any sand plains, that is areas without dunes, have a characteristic shrub-steppe: both *Triodia* and *Plectrachne*, *Eucalpytus gamophylla* and *E. kingsmillii* (mallees), *Acacia helmsii*, *A. grasbyi*, *A. linophylla*, *Grevillea juncifolia*, *G. eriostachya*, *Eremophila leucophylla*. The vegetation of dunes themselves is transitional between that typical of the

Great Sandy and Great Victoria Deserts. Desert bloodwoods (*Eucalyptus* sp.) occur more and more sparingly towards the south, ceasing in about latitude 26°. *Plectrachne schinzii* is the dominant cover in the north but becomes replaced to an increasing extent southwards by the shrub *Thryptomene maisonneuvii*, at first mainly on the south flank of the dunes. Other components remain constant, e.g. *Grevillea stenobotrya*, *Acacia salicina*, *Crotalaria cunninghamii*, *Eremophila* spp.

Groves of desert oaks (*Casuarina decaisneana*) occur locally among dunes in the major valleys. These occur only in depressions and evidently reflect the presence of underground water.

Pure mulga formations are found on the sandstone hills and breakaways, and along the foot of these.

There are few salt lakes in this high-lying region. Bottomlands on the laterite plains show no evidence of salt, and the vegetation around claypans there—coolabah trees (*Eucalyptus microtheca*) and reeds—is not halophytic.

(5) *Great Victorian Desert*

This is a most extensive region in an east–west direction. From north to south it is only 150 miles (240 km) wide bordering the Nullarbor Plain, but it extends from longitude 122° east to the State boundary at 129° and far beyond into South Australia, while in the north-west it is prolonged in a tongue over 50 miles (80 km) wide and 250 miles (400 km) long from above Cosmo Newbery beyond Wiluna almost to Meekatharra. This extension which consists mostly of sandplains with a typically Victoria Desert flora is divided from the Little Sandy Desert by the Carnegie Salient, a sand-free basin developed on Proterozoic rocks, draining to Lake Carnegie and with a predominantly mulga cover. The salient is occupied by pastoral stations. Otherwise on the north this region is bounded by the laterite plains of the Gibson Desert and by the low mountains of the Warburton Region. On the south it is bounded by the limestone plains of the Nullarbor, on the south-west by eucalypt woodlands of the phytogeographic region known as the South-western Interzone (Burbidge 1960) and on the west by mulga country belonging to the Austin botanical district (Diels 1906; Gardner & Bennetts 1956). The Great Victoria Desert is essentially a sand belt with both sand plains and sandhill areas predominating, but falling as it does into latitudes where mulga is the normal Eremaean vegetation of soils other than deep sand, mulga will be found to come in on larger or smaller patches wherever the sand thins out, on hills and breakaways, along drainage and even frequently on flats between sandhills. Much more mulga is present than generalized small scale vegetation maps can indicate.

The Cosmo Newbery Native Mission is the only permanent human habitation within the Desert proper, but the north-western tongue includes the gold-mining town of Wiluna and several pastoral stations making use of included mulga country. Rainfall is thought to average about 8 in. (200 mm) a year with an erratic distribution. Sporadic relatively heavy falls of rain which maintain the vegetation can be expected in any month of the year except September and October. Both summer and winter rains can make themselves felt here, but the spring is normally dry.

Physiographically the region is somewhat featureless, consisting for the most part of gently undulating sandy plains broken only by low sandstone breakaways and by salt lakes. There is a general slope towards the Nullarbor Plain but this tends to be imperceptible on the ground. Geologically most of the region east of 125° longitude is shown on the 1966 map as Cretaceous, with Quaternary sand in the valleys. On the western side the Ernest Giles Range is mapped as Proterozoic, and south of this a considerable expanse of Permian. The western edge of the region and the whole of the north-western tongue are developed on granite. It would appear incorrect in this case to attribute the sandplains to a deposit of sand transported from the desert further east. Outliers of Permian have been reported and some of the sand at least has originated from the breakdown of a crust of Permian sandstones. Otherwise it is reasonable to assume that the sand is derived *in situ* from weathering of the granite, as in the case of the well-known sandplains of the South-western Province. The eastern half of the region is covered with dense dune systems but in the western half sandplains without dunes predominate. In the latter case the surface is by no means level and appears to have been irregularly sculptured by sand movement.

Within the Great Victoria Desert there is relatively little evidence of laterite. The truncated uplands, swept bare of topsoil and surfaced with iron-stone gravel, which characterize the deserts to further north, are noticeably absent. Hills and rises emerging here from the sandplain consist of fine-grained sandstones which if indurated and forming breakaways appear to have a siliceous rather than a ferruginous cementation.

The predominant vegetation is that of the sandhills and sandplains, with considerable areas of mulga and rather less of halophytic communities. The vegetation of sandhills is entirely different from that of sandplains and sandy interdune flats, a somewhat surprising feature. In the Great Sandy Desert the two differ in species but here they differ in physiognomy also. The sandplains most resemble those in the north, with either tree- or shrub-steppe, a spinifex floor (*Triodia basedowii*) and numerous shrubs and trees. The shrub-steppe is characterized by mallee (*Eucalyptus pyriformis*—replaced by *E. kingsmillii* in the north-west) with numerous associates, notably *E. rigidula*, *E. leptopoda*, *Hakea microneura*, *H. multilineata*, *Acacia salicina*, *A. helmsii*, *A. linophylla*, *Grevillea juncifolia*, *Melaleuca leiocarpa* as large shrubs: *Wehlia thryptomenoides*, a small ericoid shrub: subshrubs *Dicrastyles exsuccosa*, *Newcastelia cephalantha*, *Brachysema chambersii*, and composite ephemerals in season. Colonies of the 'blackboy' *Xanthorrhoea thorntonii* occur sporadically, never common, but throughout the whole western area of sandplains from Wiluna to Queen Victoria Spring. The tree-steppe which occurs in patches apparently where sand is deeper consists of scattered trees of the 'Marble Gum' *Eucalyptus gongylocarpa* 30–40 ft (9–12 m) tall, over a spinifex floor of *Triodia basedowii*. This species is a very handsome tree and the groves are of attractive appearance resembling the 'wandoo' or 'white gum' (*Eucalyptus wandoo*) woodlands of the South-western Province. Frequently other species are largely absent, but *E. gongylocarpa* mingles locally with elements of the shrub steppe.

On sandhills dominance is assumed by low ericoid shrubs, mainly *Thryptomene maisonneuvii*. Spinifex plants, represented by both *Triodia basedowii* and *Plectrachne schinzii*, still occur but are relatively rare. The *Thryptomene* forms a continuous cover on the flanks and footslopes of the dunes, thinning out on the crests. The same tall-shrub flora as further north occurs here and there, mainly on the crests, e.g. *Grevillea stenobotrya*, *Acacia salicina*, *Gyrostemon ramulosus*, joined by *G. pterosperma*, *G. juncifolia* and species of *Eremophila*, *Anthotroche* and *Jacksonia*. Not infrequently the dunes are invaded by occasional *Eucalyptus gongylocarpa* and *E. pyriformis* where the dunes traverse sandplain country. Another casual tree, of very erratic occurrence, is *Callitris verrucosa*.

Frequently the dunes do not traverse sandplain country. Further north it is clear that the sandy topsoil has been swept up into the dunes, often exposing the subsoil of a lateritic duricrust in the process. Where the same has occurred here in the south a friable loam soil is exposed which is a suitable substratum for mulga rather than shrub-steppe. Either there has been no laterization or the laterite has subsequently broken down. Where such mulga soil occurs in interdune flats, there is usually a sequence of vegetation types accompanying increase in sand cover as the dune is approached. Pure mulga (*Acacia aneura*) opens out and acquires a spinifex floor (*Triodia basedowii*), next merging into a shrub-steppe with the same *Triodia* and scattered *Hakea lorea*, *Grevillea juncifolia*, *G. eriostachya* and occasional *Acacia aneura* and *A. pruinocarpa*. It is common for this type of sandplain to form a corridor between the mulga and the dune. In cases of greater width of sandplain the *Eucalyptus gongylocarpa–E. pyriformis* assemblage may be present.

The mulga formation has already been dealt with under the Gibson Desert. Here, further south, *Acacia pruinocarpa* is less frequently present but in some areas small scattered eucalypts occur, typically *Eucalyptus comitaevallis*. These seem to represent some degree of calcium carbonate accumulation in the soil. The ground layer in mulga in this region is generally very sparse. Grasses are rarely seen and there is normally little but ephemerals in season, composites such as *Waitzia acuminata*, *Helipterum stipitatum* and *H. floribundum*, or *Brunonia australis*. Certain *Eremophila* and *Cassia* species are always present as a low shrub layer, but even these are not as common as in the mulga of the pastoral country outside the desert. This difference appears to be attributable to soil rather than to rainfall.

In the vicinity of salt lakes and along drainage lines there is much calcium carbonate accumulation both as kunkar and massive travertine. In mulga areas this is shown first by the appearance of eucalypts, secondly by development of an understorey of *Atriplex* and *Ptilotus obovatus*. Where there is a massive lime pan, *Acacia aneura* mixes with *Casuarina cristata* which may in some cases form a pure woodland with trees to 30 ft (10 m). Associates are *Pittosporum phillyraeoides*, *Eucalyptus* sp., *Eremophila miniata*, *Ptilotus* and *Atriplex*. In sand country there is rather an appearance of mallee on kunkar with *Triodia pungens*, the eucalypts being *Eucalyptus oleosa* and *E. concinna*. Lake beds are zoned with samphire (*Arthrocnemum*) or bare salt in their lowest parts, and saltbush on more elevated sections, a mixture of *Kochia carnosa*, *Frankenia* sp., *Zygophyllum fruticulosum*, *Atriplex* spp. Gypsum dunes are frequent: those at Lake Throssel are covered with a stunted growth of *Casuarina cristata*, *Eremophila miniata* and an *Acacia* sp.

(6) *Warburton Region*

The Warburton Region occupies an area along the State boundary in the east from the Blyth Range in latitude 27° to Lake Macdonald in latitude 24°, extending westward for a maximum distance, at the Warburton Range, of 160 miles (260 km). It really represents an extension into Western Australia of the highland area of the Centre, bringing with it a number of plant species not otherwise known in Western Australia. The boundaries of this region are geological and follow the division between pre-Cambrian and post-Cambrian rocks.

Within this region we have the Warburton Range native mission and Giles Weather Station, both permanent settlements where meteorological data have been recorded for some years. These have been summarized and discussed by Beard (1968). Over the 25 years of records kept at the Warburton Range, annual rainfall has varied from 1·37 to

27·19 in. (35–680 mm) with an average of 8·52 in. (216 mm). Giles' figures, kept for a shorter period, are very similar. Nil rainfall may be recorded in any month in the year and heavy falls of rain may also be experienced in any month except, generally speaking in spring. September and October are consistently dry months. Mean temperatures range from 85° F in January to 55° F in July. Both frost in winter and great heat in summer can be experienced.

The physiography of the region consists of a low plateau standing about 1600 ft (480 m) above sea level from which rise numerous isolated and rather abrupt small mountains and ranges. These fall into two groups, a northern acid group and a southern basic group. In the north stratified massive quartzites attributed to the middle Proterozoic form a number of relatively long continuous ranges. The Petermann Ranges in the Northern Territory are continued in the Schwerin Mural Cresent, an impressive south-facing escarpment, and in the Rawlinson Range. Numerous smaller isolated ranges occur further north. The southern area consists of proterozoic granites and metamorphics, largely basic in character, with large intrusions of basalt. The plains surrounding these mountain remnants are known in places to carry Permian sediments but are mostly overlain with more recent material derived from the weathering of the Proterozoic outcrops. In the northern sector this consists mostly of sand and in the southern sector mostly of red loam. In the north therefore sandhills and shrub steppe predominates, and in the south plains with mulga.

The quartzite ranges are exceedingly rocky with very little actual soil. The lower slopes carry mostly a thin cover of low shrubs such as *A. xylocarpa*, *Eremophila elderi*, *E. gilesii*, *Prostanthera* sp. *inedit*., among tufts of *Triodia basedowii* and *Plectrachne melvillei*. Small eucalypt trees, *Eucalyptus aspera* and *E. grandifolia* occur, mainly in drainage. The upper slopes, however, are more thickly covered with larger shrubs 5–6 ft (1·7–2 m) tall, among which *Acacia ?cyperophylla* is dominant. Others are *A. pruinocarpa*, *A. aneura*, *A. grasbyi*, *Eucalyptus oxymitra* and *Hakea rhombalis*.

Callitris columellaris becomes dominant locally in very rocky and inaccessible places. The footslopes of the main ranges usually carry a belt of mulga, often rather open and mixed with *Eucalyptus gamophylla*, *E. oxymitra*, *Hakea lorea* and *Grevillea wickhamii*, with patches of *Casuarina decaisneana*.

Sandhill country between the ranges is as described for the Gibson Desert. Groves of desert oak (*C. decaisneana*) are a common feature here, however, and are attributed to underground water resulting from run off from the rocky ranges absorbed by the surrounding sand of the plains. On major drainage lines running from the ranges large trees are often present, *Eucalyptus papuana*, *E. grandifolia* and *E. dichromophloia*.

The bed of Lake Hopkins consists of samphire and saltbush communities as described for the preceding region, with gypsum dunes. *Casaurina cristata* has been reported on these from aerial photography but was not seen by the writer. At the point examined the dunes had a fairly dense cover of large *Melaleuca lasiandra* with smaller *Acacia victoriae*, *A. salicina*, *A. tetragonophylla* and *Santalum acuminatum*.

In the southern sector the rocky hills are most frequently vegetated with mulga and spinifex on the lower slopes, that is with open *Acacia aneura* over *Triodia basedowii* and *Plectrachne melvillei*. Mulga thins out higher up and the upper slopes carry little but spinifex with rare stunted mulga and *Eucalyptus dichromophloia*. On and around Mt Aloysius where the rock weathers into large rounded boulders, *Callitris columellaris* replaces mulga, growing in rock crevices. It appears to have been eliminated by fire on any areas capable of supporting a ground vegetation. On the other hand basic dykes in the Blackstone Range weather to large masses of naked boulders but *Callitris* is not found here, the only species being a rare *Ficus platypoda*.

The basalt Warburton Range is covered with open mulga with rich lower layers of shrubs (*Eremophila* and *Cassia* spp.) subshrubs, forbs and grasses. Spinifex is absent except for *Plactrachne melvillei* in the rockiest places. The plains at the foot of the hills in this region are typically covered with mulga of this nature, some of it up to 25 ft (8 m) tall, being the best quality mulga in any part of the desert. The tree layer comprises *Acacia aneura* (in both normal and weeping forms), *A. pruinocarpa*, *A. tetragonophylla*, *Heterodendron oleifolium*, *Plectronia latifolia:* shrubs *Eremophila latrobei* and spp., *Cassia desolata*, *C. sturtii*: subshrubs *Ptilotus obovatus*: forbs *P. alopecuroideus*, *P. exaltatus*, *P. clementii*, *P. helipteroides*, *Waitzia acuminata*, *Helipterum stipitatum*, *H. floribundum*, *H. fitzgibbonii*, grasses—*Danthonia bipartita*, *Eragrostis eriopoda*, *Enneapogon caerulescens*. *Eucalyptus dichromophloia* occurs on drainage. At the foot of the Blackstone Range there are some small black-soil plains with *Astrebla* sp. (Mitchell Grass) but these are of insignificant extent.

(7) *Nullarbor Plain*

The vast limestone plain of the Nullarbor stretches along the coast of the Bight from Israelite Bay across the State boundary and far to the east into South Australia, with a maximum width inland from the sea of 250 miles (400 km). The total area of the Plain is estimated at 75 000 square miles (192 000 km^2) and it constitutes one of the largest limestone regions in the world (Jennings 1967a). The northern boundary of the Plain is at about latitude 28½° in Western Australia and the southern at 32½°, and it extends from longitude 123½° to the State boundary at 129°. The geological and vegetational boundaries of the Plain can be said to coincide except in the south-west where due to higher rainfall and the development of deeper soil the Plain becomes covered with eucalyptus woodlands which are no longer strictly Eremaean in character and belong to the South-western Interzone. It is this vegetational boundary which is taken to delimit the natural region. The Plain adjoins the Great Victoria Desert on the north, the South-western Interzone on the west and south-west, and reaches the sea in the south.

Weather data have been recorded along the Trans-Australian Railway and at coastal stations for many years so that the climate is well documented. Average annual rainfall reaches a little over 10 in. (250 mm) on the coast, decreasing inland with the minimum over the east-centre of the Plain of only 6 in. (150 mm). This part has a lower rainfall than any other part of the whole state. Distribution throughout is non-seasonal, that is, there is an equal chance of rain in any month of the year. There is a tendency to winter maxima at coastal stations. It is interesting that while the northern, tropical part of the desert receives only summer rain, there is no part even in the extreme south which receives only winter rain. The north-south transition is not from summer to winter rain but from summer rain to non-seasonality. Mean temperatures are much lower on the plain than farther north, figures being:

Rawlinna	Mean January 74° F	Mean July 52° F
Forrest	74° F	52° F
Eucla	71° F	55° F
Balladonia	73° F	52° F

At the same time considerable extremes can be experienced with summer maxima over 100° F and frost on winter nights.

The limestone of the Nullarbor Plain lies almost horizontally, with slight gradients from west to east and north to south. Excellent accounts of it appear in the publications of Jennings (1967a,b). The limestone, which has a maximum thickness of 900 ft (270 m) is divided geologically into three formations known as the Eucla Group. At the base is the Wilson Bluff Limestone of late Eocene age with a maximum thickness of 800 ft (240 m). It is a pure white bryozoal calcarenite of chalky nature with chalcedonic bands at intervals. Towards the northern margin it changes in part to a calcareous sandstone. Overlying this unconformably is a thin member of yellow bryozoal limestone attributed to Oligocene or upper Miocene age, and above this again unconformably comes the Nullarbor Limestone of lower Miocene age with a maximum thickness of 200 ft (60 m), which forms the modern surface of the Plain. This is a dense grey crystalline limestone, harder than the other formations and much more jointed. The whole group of sediments was uplifted with very little tectonic disturbance. From the general absence of later marine deposits, this is thought to have occurred in the late Miocene.

It is considered that the Plain, as it now appears, represents an ancient sea bed uplifted bodily and since subjected to very little erosion and weathering owing to a more or less continuously prevailing dry climate. The Plain is somewhat flat but by no means absolutely level. To the traveller, the horizon may appear perfectly level all around him but the foreground exhibits very gentle undulations which it is rarely if ever possible to relate to any coherent drainage systems. The minor relief of small solution basins or 'dongas' is much more conspicuous and an integral part of the landscape. These tend to be arranged or elongated into parallel lines whose trend changes from point to point on the Plain and is thought to be controlled by jointing.

As the Plain is physiographically monotonous its vegetation is also monotonous and is uniform over great distances. The range of habitats is so small that the number of distinct communities that can be recognized is also small. The vegetation can be discussed as that of the Plain proper and that of the coastal margin.

On the plain proper the plant cover of the whole area except for the dongas is succulent steppe of the 'bluebush', *Kochia sedifolia*, a small perennial leaf-succulent shrub growing to 18 in. (45 cm) high and in open formation. This formation has usually been known as shrub-steppe to Australian ecologists, but following two discussions on the nomenclature by Beard (1966, 1967a), 'shrub-steppe' as used here means a steppe or dry grassland with scattered shrubs. The Nullarbor is not a grassland except as annual grasses may appear in season; it is essentially a succulent community and it conforms to African practice to term it 'succulent steppe.' In the centre of the Plain the bluebush is treeless but towards all the outer margins it becomes progressively more and more densely wooded with small spreading trees (15 ft) (5 m) of the myall, *Acacia sowdenii*, with rarer *Pittosporum* and *Myoporum*. Around the extreme margins these stand in an almost closed formation and are mixed with *Casuarina cristata*, *Acacia aneura* and *Eucalyptus oleosa*. The bluebush layer persists right to the boundary of the plain where there is an abrupt change to eucalypt-dominated vegetation with a spinifex floor. The arboreal component on the Nullarbor appears to be in a constant state of advance and retreat with rainfall cycles. At the time of traverse in October 1966 recent drought mortality was very apparent. In travelling out to the centre of the Plain from the margin no signs at first appeared, then the most outlying mulga were seen to be dead but myall were unaffected. As the zone was entered where the myall are more widely spaced a proportion of these was observed to be dead, and this proportion increased steadily until in the last stretch before entering treeless plains every tree was dead. It is apparent that the treelessness of the central plain is maintained by drought, lower rainfall in the centre being accentuated by shallow soil which is itself a function of low rainfall. In cycles of good rains the trees no doubt advance onto the Plain, or used to in times before the arrival of the rabbit.

The bluebush layer is interspersed with annuals according to season, especially *Stipa trichophylla* which in a good year produced a dense crop like a cornfield. Associates are *Zygophyllum ?compressum*, *Lepidium oxytricha*, *Helipterum floribundum* and *Bassia* spp. Shrubs of medium size, i.e. 4–6 ft (1·3–2 m) occur rarely and include *Myoporum platycarpum*, *Acacia tetragonophylla* and *A. oswaldii*. In many areas *Kochia sedifolia* has been eliminated by rabbits which swarmed here before myxomatosis, leaving a vegetation consisting entirely of annuals.

The vegetation of dongas is variable. Some are vegetated solely with annuals, some (especially in the southern half) are *Atriplex*-dominated, while others have a dense small-tree cover. Shrubs and trees represented include *Acacia aneura*, *A. tetragonophylla*, *Myoporum platycarpum*, *Pittosporum phillyraeoides*, *Grevillea* sp. A rich growth of annuals can be seen in these pans in season including *Lavatera plebeia*, *Swainsona* sp., *Clianthus formosus*, *Helipterum floribundum*, *H. strictum*, *Calotis breviradiata*, *Podoleptis canescens*. Pans dominated by *Atriplex hymenotheca* are treeless and may contain *Bassia* spp., samphire (*Arthrocnemum*) and *Frankenia*.

The vegetation of the coastal strip consists of a belt of mallee along the crest of the Hampton Tableland with a return to myall, saltbush and bluebush on the Roe Plain. The mallee belt is only 5–10 miles (8–16 km) wide and consists of dense scrub 10–15 ft (3–5 m) tall, dominated by a short, glaucous ecotype of *Eucalyptus oleosa* and the taller form *E. oleosa* var. *obtusa*, with *Melaleuca quadrifaria* and *M. parviflora*. Shrubs include sundry *Eremophila* spp., *Enchylaena tomentosa*, *Westringia rigida*. The ground layer is mainly *Atriplex* with some 'greybush'—*Cratystylis conocephala*—*Kochia excavata* and other succulents. The woodland tends to occur on ridges interspersed with open flats having an *Atriplex* community with *Stipa*, *Bassia*, *Kochia* and *Frankenia*.

The Roe Plain is covered for the most part with open *Acacia sowdenii* with occasional mallee and ground layer of *Atriplex hymenotheca*, *Cratystylis conocephala*, *Kochia sedifolia* and *Nitraria schoberi* alternating with open salt bush plains which are, substantially, the same thing without the trees. More recent dune sands near the coast may be mobile and unvegetated, as in the 'White Sands of Eucla' or fixed with more or less dense mallee of *Eucalyptus* sp. *indet.*, *E. angulosa*, *E. leptophylla*, *Acacia* spp., *Melaleuca quadifaria*, *M. parviflora*, *Eremophila* spp.

Economic use

It has been shown in the previous sections that the ecological regions defined for present purposes as 'deserts' are with minor exceptions uninhabited and not put to economic use. It has also been shown that while the climate of these regions is arid it is not excessively so, and not more so than other parts of Western Australia further to the west which are under occupation in pastoral leases. The 'deserts' differ from the pastoral country in that they are underlain by post-Cambrian sedimentary rocks, sandstones and limestones which produce a type of plant cover that is either unpalatable to stock or otherwise insufficient to support pastoral use. The sandstone country further gives rise to extensive areas of sand dunes which although stabilized by vegetation greatly limit ability to move about the country. Except on the Nullarbor water does not appear to be a limiting factor since what evidence there is indicates that stock water could be obtained from shallow bores not less readily than in the station country to the west. The Canning Stock Route for example follows a line of shallow wells for its whole distance, and no undue difficulty appears to have been encountered in finding satisfactory permanent water. North of the Nullarbor it is essentially the plant cover which is the limiting factor.

The Great and Little Sandy Deserts which are essentially similar present a hostile combination of sandhill country and unpalatable herbage. The dunes and sandy interdune tracts have as their grass cover *Plectrachne schinzii*, the feathertop spinifex, which is reputedly unpalatable to stock, while hard interdune or sand-free country carries either *Triodia pungens* or *T. basedowii*. The latter is definitely unpalatable, but the former, 'soft spinifex' is one of the few spinifex grasses considered palatable and large areas of it in the Pilbara are in pastoral occupation. Where this species occurs therefore, which is mainly in the northern half of the Great Sandy Desert, there might be some prospect of pastoral development. The principal area concerned is on the Anketell Ridge along the access road running into the desert from the coast, spreading out into a broad area of lateritic tablelands in the Swindell Field area. It is estimated that there are about 2500 square miles (6400 km^2) of this type of country. As against the favourable indication of the spinifex cover however this section shares the disability of the whole desert in lack of supporting plant growth. Soft grasses, forbs and subshrubs between the spinifex hummocks are scarce and while they could probably be encouraged by judicious burning programmes there would be reason to fear insufficiency of reserves in drought periods. On the whole the prospects for this area are not very favourable. Limited patches of good country would be found on the Rudall River and in and around the Broadhurst, Wells and McKay Ranges, but probably too scattered and inaccessible to be worth development.

In the Billiluna area there are already pastoral stations using the rich country of the Sturt and Wolf Creek floodplains and the soft spinifex sandplains.

The Gibson Desert gives unfavourable indications throughout. The spinifex cover is entirely of 'buck' or unpalatable types, mainly *T. basedowii*. The sandhill country in the east must be considered entirely useless, having *Plectrachne* on the dunes and *Triodia basedowii* in the interdunes. The laterite plains country contains a great deal of mulga which is normally considered favourable for stocking; however in this case ground vegetation of grasses, forbs or subshrubs is almost entirely absent and there is a marked lack of 'feed.'

The Great Victoria Desert is in somewhat better case and sheep stations have been established on the fringes, utilizing patches of mulga country. As elsewhere the sandhill country is useless and the sandplains of limited value only in conjunction with something better. As in the Gibson, however, the mulga tends to lack ground vegetation, due probably to insufficiency of water-holding capacity and possibly nutrients in a soil derived from sandstone. It is only in the vicinity of salt lakes where fine silt and calcium carbonate have accumulated that palatable ground plants attain any abundance.

It is when we reach the Nullarbor Plain that the situation entirely changes. Here the plant cover is in principle eminently suited to stock but water is the limiting factor. With very few exceptions fresh water cannot be found by boring and it is only relatively recently that the construction of artificial catchponds has been developed. The stations Noondonia, Balladonia and Nanambinia were established at an early date on the south-western margin of the plain depending on numerous granite rocks as catchments, which protrude from the limestone. Other stations were established along the coast, mainly on the Roe Plain, where water was obtainable. If water could be provided throughout it would certainly appear that the Nullarbor could be developed throughout for pastoral use. Careful management would be required as losses due to drought and overgrazing by rabbits have already damaged the plant cover, killing off the bluebush over wide areas. Where this has occurred there is only herbage in good seasons and the country could not be continuously occupied.

The Giles District is again a stretch of country of different type, much of it dune fields or barren mountains, but containing around these many areas of excellent mulga with permanent water in rock holes. Small concrete dams would add quickly and enormously to the storage capacity. As the area is an aboriginal reserve and in any case has been very remote and inaccessible little interest has been taken in pastoral possibilities. It seems that an attempt was made at one time at pastoral development at the Warburton Range mission, but was abandoned.

The above deals with the grazing potential of the natural vegetation of the desert regions, which is the first form of economic use to suggest itself. Agriculture might well appear to be out of the question but in fact is worth discussing on two counts. First, there appear in principle to be some possibilities of flood irrigation at the Sturt Creek, utilizing water which is at present lost by evaporation in the distributary zone below Billiluna. Attention and resources will naturally be devoted first to the Ord and Fitzroy Rivers, and for some years to come, but there may be a case for developing the Sturt at some future time.

Secondly, there is the possibility of date plantations. It appears to the writer that the occurrence of so large a tree as the desert oak (*Casuarina decaisneana*) in groves in certain parts of the desert must indicate the availability of ground water. People living at Billiluna station have assured the writer that water is found in very shallow wells, where desert oaks occur in open sandplain west of the Sturt Creek. In the Giles district oaks occur in depressions where it seems probable that there is a water table derived by seepage from the runoff from the surrounding rocky ranges. Such conditions and the prevailing climate appear suitable for the date, and it would seem feasible agronomically to replace desert oaks with date plantations. Whether this would be economic at present in view of distance from markets is another matter. At the present time the suggestion would appear mainly to merit consideration as a badly needed potential economic activity for aborigines in their reserve in the Giles District.

Plant forms

Under the above title we may consider the *growth forms* of plants in the sense of Whittaker (1962) rather than *life forms* in the sense of Raunkiaer (1937). In most of the world's deserts special and peculiar growth forms have evolved which confer advantage in the arid enviroment. In North and Central America the family Cactaceae has produced the well-known range of forms based on stem succulence, closely replicated by the Euphorbiaceae in Africa. In Southern African deserts leaf succulence is a dominant feature and has been developed in many families, notably the Aizoaceae and Liliaceae. Leaf-succulent rosette plants in the Bromeliaceae are a feature of both arid north-west Brazil and the cold Andean *Puna*. In all cases we are accustomed to look for deciduous, thorny trees and plants with underground perennating organs, especially bulbs and corms. In Australia there is an extraordinary lack of all these forms: where some of them exist they are confined to certain areas.

Leaf succulence is a well-developed character, essentially in the Chenopodiaceae, and is the dominant feature of the Nullarbor Plain, forming succulent steppe. An understorey of more or less leaf-succulent *Atriplex* and *Cratystylis* is characteristic of the more highly alkaline of the soils of the South-western Interzone. Leaf-succulent and stem-succulent chenopods of various genera and forms are typical of salt lake beds and margins throughout the Eremaea. It would therefore be true to say that succulents in Australia are almost all halophytes. On the siliceous soils of the deserts, sclerophylly is a dominant feature as it is throughout the continent.

In the predominantly siliceous country north of the Nullarbor Plain, stem succulence is represented in only a handful of species of no prominence such as *Sarcostemma australe* (Asclepidiadaceae), a divaricate, leafless plant found occasionally in rocky places. Others are *Spartothamnella teucriiflora* (Verbenaceae) and *Calycopeplus helmsii* (Euphorbiaceae). Likewise leaf succulence is found in a variety of groups but often weakly developed and never a conspicuous feature. *Gyrostemon ramulosus* (Phytolaccaceae) has somewhat fleshy foliage which the explorers noted as a favourite feed of camels. The Aizoaceae in Australia are mostly tropical herbs and the most genuinely succulent member, *Carpobrotus*, is not found in the Eremaean Province. The Portulacaceae are a substantial group with twenty-seven species in Calandrinia of which about twelve are Eremaean and eight in Portulaca which belong to the Northern Province. *Calandrinia* is herbaceous, leaf succulent, the 'parakeelya' of pastoralists, and several species are not uncommon but it will be noted that they are not essentially desert plants. A weak leaf succulence can be seen in *Kallstroemia*, *Tribulus* and *Zygophyllum* of the Zygophyllaceae and in *Euphorbia* and *Phyllantus* of the Euphorbiaceae. Few of these are plants of any abundance.

The vegetation of sandy desert is given the following predominant character by the physiognomy of the commonest plants.

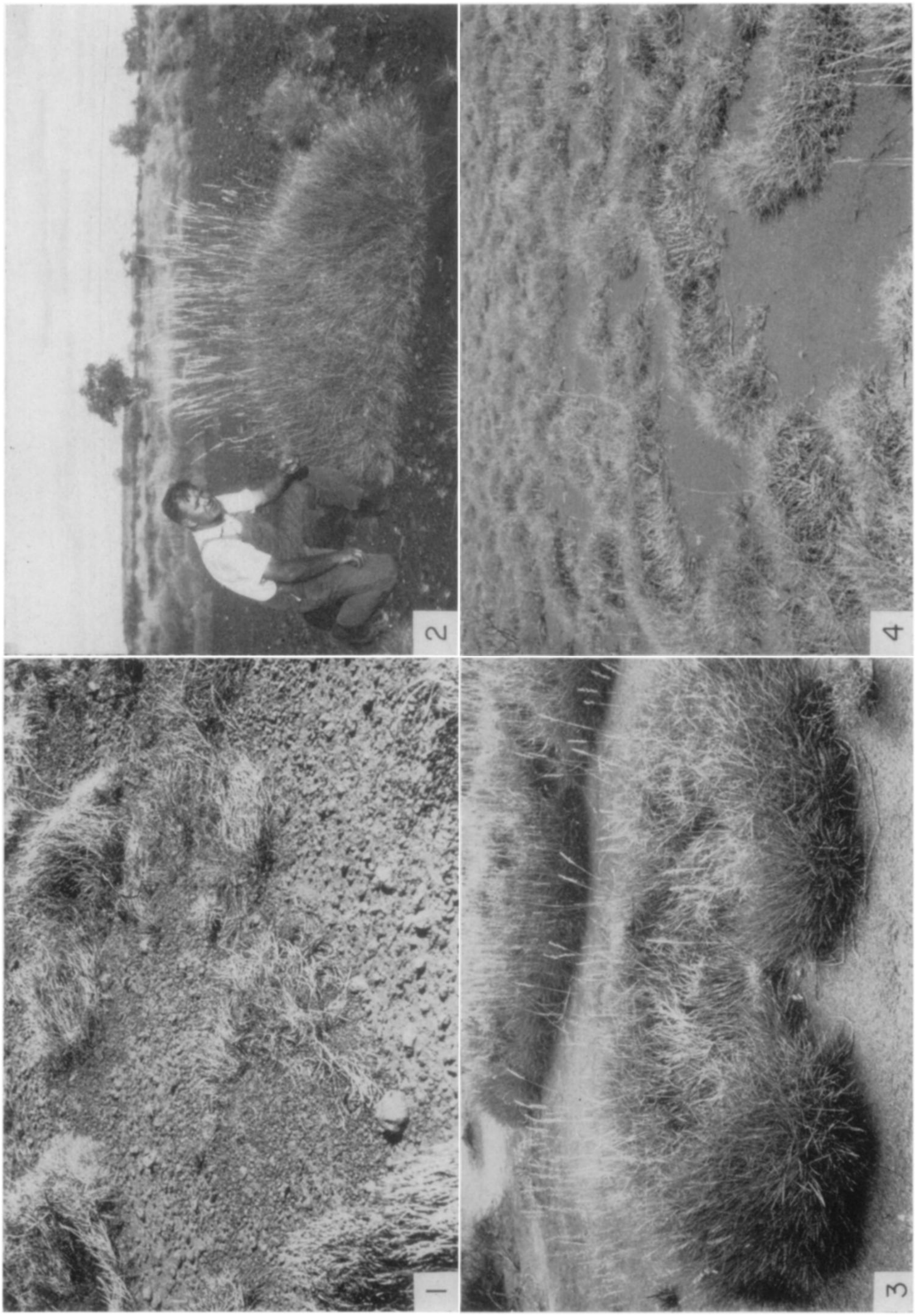
Trees. Evergreen, sclerophyll. Leaves pendant in Eucalyptus, linear, erect and glaucescent in *Acacia aneura*, vestigial in *Casuarina decaisneana*. Bark white in most species of Eucalyptus.

Shrubs. The larger shrubs are sclerophyllous, typically phyllodal Acacias, the smaller shrubs ericoid (Thryptomene).

Subshrubs. Many soft perennial subshrubs typically with densely pubescent or silver-tomentose stems and leaves, e.g. *Crotalaria cunninghamii*, numerous Verbenaceae (*Dicrastyles*, *Newcastelia*, *Pityrodia* spp.). Also suffrutices with underground rootstocks and ephemeral or more or less perennial shoots, often also densely pubescent or silver-tomentose, e.g. *Brachysema chambersii*, many *Ptilotus* spp., *Leschenaultia helmsii* and *L. striata*. Some are viscid—*Goodenia azurea* and *G. stapfiana*.

Ephemerals. Many species of Compositae, *Ptilotus* and *Goodenia* appear as brilliant-flowering annuals in season. Colours are predominantly yellow and mauve, with some pink and white. Red is absent.

Grasses. Grasses of the short bunch-grass type in the sense of Bews (1929) occur only on alluvial flats to creeks or on plains of limited extent developed on or close to basic rocks. In these cases there is a fine soil with a relatively high water-holding capacity and probably also high nutrient status. On sand, laterite and rock in the desert, grasses belong almost entirely to the genera *Triodia* and *Plectrachne* which adopt the 'spinifex' growth form (not to be confused with the genus *Spinifex*), with culms intertwined into dense hummocks and leaves reduced to long rigid spines. This growth form appears to be peculiar to Australia and to be the only unique form evolved in the Australian desert as an adaptation to aridity.



PHOT. 1. Surface of laterite plain in the Gibson Desert, with spinifex partly dead after drought.

PHOT. 2. Young vigorous plant of *Triodia pungens* showing typical spinifex growth form.

PHOT. 3. Spinifex clump beginning to die out in centre.

PHOT. 4. Old spinifex forming crescentic patterns.

(*Facing p.* 708)

The 'spinifex' growth form, being peculiar to the Australian desert, is worthy of more detailed description and illustration. From the odd shape of the clumps, spinifex country has been aptly termed 'hummock grassland' by Beadle & Costin (1952). Each plant branches repeatedly into a great number of culms which intertwine to form the hummock and bear rigid, terete pungent leaves presenting a serried phalanx to the exterior. When flowering takes place in the second half of summer, given adequate rains, upright rigid inflorescences are produced over the crown of the hummock, rising from 1½–3 ft (45–90 cm) above it (Phot. 2). The flowers quickly set seed which is shed within 2 months, although this is then the beginning of the dry season. The size of the hummock varies considerably according to the site from 1 ft (30 cm) in height and diameter on the poorest, stoniest sites up to about 3 ft (1 m) in height and 6 ft (2 m) in diameter on some deep sands. One forms a visual impression that in the former case there are more clumps per unit area than in the latter, but no numerical surveys have been made. Old hummocks, if unburnt, tend to die out in the centre or on one side, leading to ring or crescentic growth (Phot. 3). At this stage the original root has died and the outer culms have rooted themselves adventitiously in the soil (Phot. 4). Individual hummocks do not touch, and there is much bare ground between, surfaced with a desert pavement in stony areas. Quantitative analyses to give the proportion of cover in spinifex vegetation have been recently presented by Winkworth (1967) for an area in the Northern Territory.

It will therefore be seen that the Australian sandy desert is not without special vegetative characters of its own which can be supposed to be of some adaptive significance, particularly *glaucescence* of bark and leaves, *pubescence* frequently in association with glaucescence, *suffrutescence*, the presence of vernicose and viscid leaf surfaces, and the spinifex habit in grasses. Other characters such as tree and shrub growth forms and sclerophylly are not peculiar to the Eremaea but are shared with other Australian vegetation. It will also be noted that the vegetation of alkaline soils is radically different and makes a feature of leaf succulence in keeping with most others of the world's deserts.

At first sight the paucity of special adaptive forms in the Australian desert suggests that the desert may be of recent origin. Enquiry into the time scale, however, establishes that it has a history at least back to the Miocene. It becomes evident that vegetation of sandy desert has been under the dominating influence of sclerophylly and has evolved within a strait-jacket imposed by it. One is immediately reminded of Beadle's work (1954, 1966) on the relationship between sclerophylly and nutrition. On the poor deficient sands we have a sclerophyll vegetation and on the base-rich soils a succulent one. This is a distinctively Australian pattern, and it is tempting to infer that desert growth-forms support Beadle's thesis of an evolutionary history of sclerophylly imposed by deficiencies, especially in phosphate, in Australian soils. Winkworth's (1967) paper confirms the very low phosphorus content of the sandy desert soils.

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SUMMARY

Uninhabited desert occupies about two-fifths of Western Australia, being more or less the eastern half of the state south of the Kimberley Region. A historical review of the exploration of this area is given down to the botanical exploration of the past 7 years. It is shown that the climate of the desert does not differ substantially from that of other parts of the Eremaea in pastoral occupation and not considered as desert, but that the geology is distinctive and leads to important differences in the plant cover which render the area unsuitable for stock.

The desert area is divided into seven Natural Regions in the sense of Clarke (1927) which are also Botanical Districts in the sense of Diels (1906) and Gardner & Bennetts (1956). The physical conditions and vegetation of these regions are described in detail.

The paper concludes with some discussion of the potential for economic use of this area and of the growth forms of Australian desert plants.

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