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THE PHYSIOGRAPHY (GEOMORPHOLOGY) OF WESTERN AUSTRALIA

BY

J. T. JUTSON, B.Sc., LL.B.

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PREFATORY NOTE.

The Physiography of Western Australia (Bulletin 61), by Mr. J. T. Jutson, was published in 1914, and has been out of print for a number of years. As the work proved to be of general public interest, and was used extensively in the schools and at the University for educational purposes, the Government was requested to bring out a new edition, and Mr. Jutson was asked to undertake the work. The manuscript was completed several years ago, but, on account of the financial stringency caused by the depression, publication was postponed.

The work has now been thoroughly revised and brought up to the date of completion of the manuscript, and, as Mr. Jutson points out in his preface, much of it has been expanded and large portions of it wholly rewritten in the light of the knowledge gained since the issue of the first edition. It gives a comprehensive account of the physical features of our vast State, and discusses their origin. Such a work has both an economic as well as an educational value, since modern physiography (or geomorphology as it is coming to be called) touches economic geology at many points.

T. BLATCHFORD,
Government Geologist.

CORRIGENDA FOR BULLETIN 95.

p. 8—line 1: *for* "not" *read* "no."

p. 224—fig. 37, line 2: *for* "depossition" *read* "deposition."

p. 310—9 lines from bottom: *for* "that gnamma holes" *read* "that the gnamma holes."

PREFACE TO THE SECOND EDITION.

The manuscript for this edition was completed at the end of the year 1929, and, except in the brief general account of the geology of the State, no substantial alteration has been made to that manuscript. Consequently, publications since issued bearing on the subject matter of the Bulletin have not been referred to in the text. If, however, such publications had been used, they would have caused practically no alterations to be made to the work, which may therefore be regarded as substantially brought up to date.

Of papers or reports (either recent or previously overlooked by the author) which have come under his notice, the following are the most important.

Finucane and Forman on the load carried by the Swan River during the 1926 flood. (*Journ. Roy. Soc. W. Austral.*, Vol. XV., 1929, pp. 57-60.)

Fletcher and Hobson on the physiography and geology of the Upper Swan area. (*Ib.*, Vol. XVIII., 1931-32, pp. 23-37.)

F. G. Forman's list of waterholes and soaks between Thatcher's Soak and Elder Creek and in the Warburton Range area (*Ann. Prog. Rept. G.S.W.A.*, 1932, pp. 6 and 8); the same writer's notes on the coastal limestones of the Perth area (*Ib.*, 1930, pp. 10 and 12, and 1932, pp. 9 and 10); and on possible fault scarps in the Gingin district (*Ib.*, 1930, pp. 8 and 9).

W. H. Shields on sand bars on intermittent rivers. (*Journ. and Proc. Roy. Soc. W. Austral.*, Vol. X, 1923-24, pp. 1, *et seq.*)

Since the publication of the first edition of this work, much research, mainly by the staff of the Geological Survey of Western Australia, bearing on the physiography of the State has been accomplished; and, in this connection, special mention must be made of the very valuable work done by Mr. H. W. B. Talbot, who has topographically and geologically surveyed vast areas of the arid portions of the State, and who has thus made most extensive additions to our knowledge of its physical features. The references throughout the text to Mr. Talbot's various publications will show how much the author is indebted to Mr. Talbot's arduous labours.

The work of the Government Geologist, Mr. T. Blatchford, B.A., in the Kimberley district has also been of great service; and the same remarks apply to Mr. W. R. Easton's report on North Kimberley.

In view of the greatly increased knowledge of the geomorphology of the State gained by the author from the work of others and from his own researches, much expansion and, in some instances, complete re-writing of portions of the first edition, have been necessary, as shown by the size of the present volume compared with the first edition. These remarks apply more particularly to Salinaland, and to a less extent to Sandland, the North-West District and the Kimberley District. The author's own experience has been gained chiefly in Salinaland, and

since that division is one in which arid conditions (which are of great interest now to physiographers) prevail, opportunity has been taken to describe in much more detail than in the first edition the nature of the land forms in that division, and to discuss fairly fully their origin and history.

The objects of the work are fully set forth in the Introduction, so that they need not be referred to here.

It remains to acknowledge the many obligations the author is under in the preparation of the present edition.

Mr. Blatchford has facilitated the work in every way by making available numerous maps and reports; and the author and the scientific world in general are greatly indebted to Mr. Blatchford for the production of the geological map of the State attached to this work, which has been compiled under his direction by Miss Florence Armstrong, B.Sc., the Technical Assistant to the Geological Survey. Miss Armstrong, by reason of her wide knowledge of the literature (including unpublished reports) of the geology of the State, has also enabled the brief general account of the geology to be brought up to date. She has also been good enough to read the proofs and to make valuable suggestions and corrections. To Miss Armstrong also has fallen the task of preparing the index.

The author is indebted to Mr. W. E. Wood, of the Engineering Department of the Western Australian railways, Professor E. de C. Clarke, of the University of Western Australia, and Mr. F. Chapman, A.L.S., the Commonwealth Palæontologist, for valuable data.

The Commonwealth Meteorological Bureau, Melbourne, kindly supplied various maps and reports, from which the details concerning the climate have been taken. The same Department also supplied a copy of the excellent orographical map of Australia prepared by it. The orographical maps in the present work have been copied from those in McLintock's "The Swan Geography" which are based on the Commonwealth map. The Forests Department of Western Australia forwarded maps and literature relating to the vegetation of the State, and Pl. I. is copied from the important vegetation map issued by that department. The then Home and Territories Department of the Commonwealth supplied or loaned some publications.

The photographs reproduced are mainly from the fine collection of the Geological Survey. Some are from other Government departments in Western Australia, to whom thanks are due for the loan of same.

The author is indebted to the Royal Society of Victoria for permission to publish figs. 55, 105, 106, 110, 114, 115, 116, 117 and 118, to the Royal Society of New South Wales for the like permission in regard to figs. 40 and 41, and to the Royal Society of Western Australia for the like permission in regard to figs. 42 and 43.

March, 1934, J.T.J.

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THE PHYSIOGRAPHY (GEOMORPHOLOGY) OF WESTERN AUSTRALIA.

INTRODUCTION.

The thorough study of the physiography (or geomorphology) of the State is of importance from an economic point of view. In structural geology, which is so intimately associated with mining, physiography often throws light where the structural evidence is deficient. In Western Australia an exhaustive study of the present and past surface features, and of the changes of climate in comparatively recent geological time, is required in order to grapple adequately with the questions of the origin and the distribution of the auriferous and stanniferous deep leads. The forms of the valleys largely affect the engineering works of the country, and the progress of settlement is often dependent upon such forms. The distribution of the rainfall is, of course, of paramount importance, and the correlation of the forests with rainfall, contour, and soils is also very desirable. Physiography is often of vital value in problems of artesian water supply, a matter of so much concern to the well-being of this State. These examples are sufficient to show the close connection that exists between physiography and some of the economic problems of the State, and its relation to the development of the country's primary resources. No attempt is made in the present work to deal with all the aspects just mentioned. Its chief aim is to treat of the origin, growth, and distribution of the present physical features of the land, a subject which may be regarded as fundamental to the other questions mentioned.

From an educational point of view the study of physiography, by reason of its association with many different branches of science; by the ability that must be acquired to understand and read maps (which in a new country is of the greatest value from a military, mining, and, to some extent, an agricultural aspect); and by its direct association with broad human interests, has high claims.

The demands made as to the value of physiography are now generally recognised throughout the civilised world by educationists and scientists alike, and no pretension to originality in making such claims is put forward by the present writer. An endeavour has simply been made to bring before as wide a circle as possible the value and importance of the subject.

This work is, therefore, an attempt to draw a broad comprehensive sketch in physiographic terms of the main surface features of the State, and of their growth; to focus attention on the problems and points that require further elucidation; and generally to stimulate physiographic study in Western Australia.

A great disadvantage, in preparing a work of this character, is the absence of correct topographical maps with the necessary detail. In a vast young country like Western Australia, such maps cannot yet be expected to be available, although continuous progress in this direction is being made.

In criticising this work readers should remember that many of the conclusions drawn must necessarily be tentative, and as largely suggestive for future work. Dogmatism is intended to be avoided, but this intention may not always be apparent when individual problems are being worked out.

Some repetition will be found. This has, to some extent, been intentional, in order to make each part as complete as possible. It has also partly been unavoidable by reason of the variety of subjects dealt with, and the necessity of treating different phases of the same subject in different sections.

For observations bearing on West Australian physiography, the writings of F. T. Gregory, E. T. Hardman, C. G. Nicolay, H. Y. L. Brown, H. P. Woodward, A. Gibb Maitland, A. Montgomery, T. Blatchford, H. W. B. Talbot, C. S. Honman, E. deC. Clarke, and W. G. Woolnough, and the publications generally of the Geological Survey of Western Australia, have been of the greatest service. Much is also owed to the works of W. M. Davis, A. C. Lawson, Kirk Bryan, J. W. Gregory, E. C. Andrews, Charles Hedley, Griffith Taylor, and Charles Fenner.

A glossary of the physiographic and geological terms used has been added for the convenience of teachers and others who may use this work, but who may not be fully acquainted with the meaning of such terms.

Plates I to V have not been drawn expressly for this work and that fact and the expense of alteration indicate the reasons why "Eastern Division" and other administrative names and other information of little value to this work survive on some of the maps. Plate IV was originally drawn to illustrate the writer's work (in Bulletin 48 of the Geological Survey) on the physiography of the lower Swan and adjacent rivers, and it has not been brought up to date, notably in regard to the length of the Darling Scarp. The extensions, however, of the scarp are shown in fig. 30, and further details are given in fig. 38.

PART I.—BRIEF GENERAL DESCRIPTION OF THE PRINCIPAL PHYSICAL FEATURES OF WESTERN AUSTRALIA.

Western Australia has a total area of 975,920 square miles out of a whole area for Australia (including Tasmania) of 2,974,581 square miles (fig. 1).

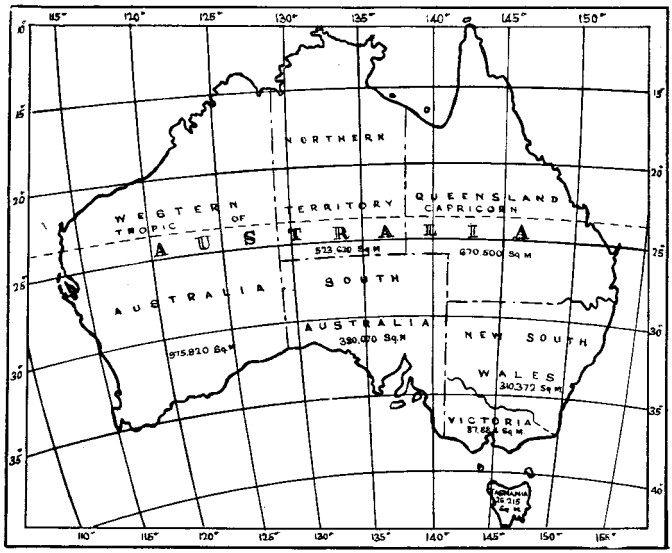


Fig. 1.—Outline Map of Australia, showing the position and area of Western Australia in relation to the other States. *Note*: Since this block was made for the first edition of this work, the Northern Territory has been divided into North Australia and Central Australia.

Notwithstanding its vast size, the State, in its broad physical features, possesses little variety. In their simplest classification they consist of a plateau and some narrow coastal plains (see fig. 2).

The plateau is a vast truncated upland, known as the Great Plateau of Western Australia. Except for the coastal plains just mentioned, which are not continuous along the coast, and which occupy a very small portion of the State, the plateau forms the whole of the country. It varies considerably in height above sea level. In places it rises very gently from the coast, and in others sharply by means of pronounced scarps. In its highest parts it attains a height of about

4,000 feet above sea-level. The greater part is probably below the 2,000 feet contour line, and its average height would probably be from 1,000 to 1,500 feet above sea-level.

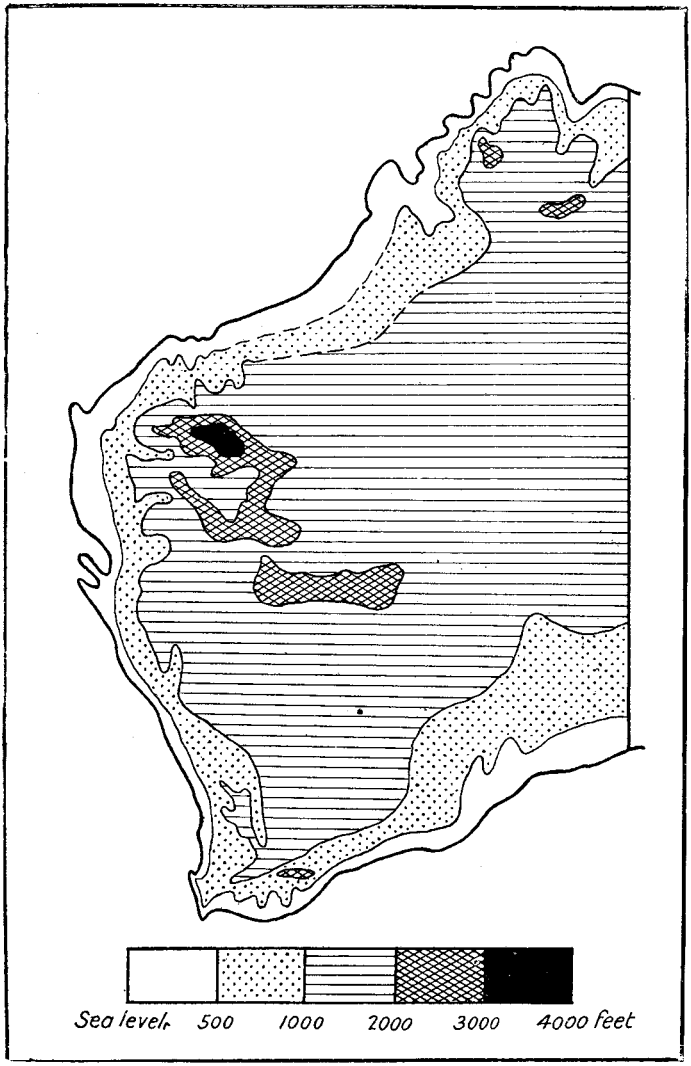


Fig. 2.—Orographical Map of Western Australia, in broad outline. (From McLintock's "The Swan Geography.")

Although there is such a great variation in height, the changes take place so gradually as a rule that they are little noticed in passing

over the country, and the plateau character of the country is not obscured. Generally speaking, except where it is bounded by scarps, as in places near the coast and along various lines in the North-West and Kimberley districts, it may be regarded as having a vast, gently undulating surface.

Above the general surface of the plateau, monadnocks or residuals of a previous cycle of erosion occur, but such have not been definitely noted to any great extent.

The Great Plateau may be divided into an area of exterior drainage (where there are definite rivers which empty into the sea), an area of interior drainage (where such water as flows passes into inland basins), and two areas of no surface drainage, but which if they had drainage would belong to the exterior drainage system. The three areas correspond to de Martonne's "exoreic," "endoreic," and "areic" divisions of the land areas of the world. The area of exterior drainage can be marked on a map by connecting the sources of the streams which flow to the sea, and if this be done, it will be seen that the width of the exterior drainage belts varies considerably. Thus in the Kimberley and North-West districts some of the rivers are hundreds of miles long, but in the South-West Division many of them are comparatively short. The areas of no surface drainage are in the north-north-west, along the Eighty-Mile Beach from near Condon to the north of Broome, and on the Nullarbor Plains in the south-eastern corner of the State. The remainder of the country forms the interior drainage area.

The interior drainage area is arid and is practically riverless. Small creeks run from the higher parts of the country, but they either disappear on extensive flats or reach the shallow basins which are termed salt or "dry" lakes, the term "dry" being used in consequence of these so-called lakes being free from water except after fairly heavy or long-continued rain. On the evaporation of the water, common salt chiefly, and other substances, such as gypsum, are deposited on the floor of the lake.

The Great Plateau in the interior is now in a cycle of arid erosion, but around the stream-bearing coasts mostly normal erosion is taking place, the stage of which varies according to the rainfall, nature of the rocks, volume of the streams, altitude of the country above sea-level and other conditions. The normal cycle has, however, not advanced far enough to obscure the fact of the existence of the Great Plateau, but in the interior the remains of the plateau are small compared with the plateau that has been developed in the present cycle, although it is not always easy to distinguish between the two plateaux.

It must be understood that when reference is made to the Great Plateau, it includes the whole plateau of Western Australia formed prior to the commencement of the present cycle. The term "old plateau" is used synonymously with "Great Plateau," but in places the

former term more particularly refers to those portions of the Great Plateau which are situated in the physiographic divisions which are subsequently referred to as "Murchisonia," "Salinaland" and "Sandland." The context will make this clear. The "new plateau" is the plateau now in course of formation in those divisions.

The Great Plateau is most probably a vast peneplain, uplifted since the formation of the peneplain to its present height. It is this old uplifted surface, although now much destroyed, planed down, and in places perhaps unrecognisable, that, as stated above, largely constitutes the "old plateau."

The narrow coastal plains are largely made up of unconsolidated gravels, sands and clays.

A Part is devoted to the main geological features of the State, but it may be mentioned here that over a very wide area in its southern half, the rocks consist chiefly of a great complex of igneous (both acid and basic), metamorphic and sedimentary rocks, all of which are regarded as Pre-Cambrian, although not necessarily of the same age. The foliation planes of the metamorphic rocks and the stratification planes of the sedimentaries are usually vertical or close to the vertical, and as no other rocks generally rest upon them, except, in places, some recent superficial deposits, their upturned edges prove that the surface of the country is a truncated upland. In the north, north-west and central north of the State similar rocks occur, but only in small areas, the greater portion of those parts of the country being occupied by rocks which are predominantly sedimentary (although there are many interbedded lava flows), and which over wide areas either lie practically horizontal or are but little folded or tilted. These rocks are of Pre-Cambrian and Palaeozoic age.

In the south-eastern corner of the State there is a large area of Miocene rocks, consisting chiefly of horizontal or nearly horizontal limestones. There are smaller areas of other rocks, but for more detail, reference should be made to the geological Part, to the geological sketch map published herewith (Pl. II) and to the descriptions of the chief physiographic divisions.

Mountains, in the sense of folded and not much denuded chains, do not exist in the State. There are many high points and ridges rising above the general level of the plateau, but such mountains are, in most instances, merely the residuals of erosion or fault blocks. The Stirling Range in the South-West, which apparently is a great horst, is probably the most striking object in the country.

The coast line of Western Australia varies from a smooth regular outline to a much indented and broken one with numerous islands and archipelagoes. Types of the former are the south-eastern coast along the Great Australian Bight, the western coast, and the north-north-

western coast along the Eighty-Mile Beach. Types of the latter are the southern coast between Capes Paisley and Leeuwin, the north-western coast between N.W. Cape and Condon; and the northern coast, which is the most varied of all.

The smooth type is due to block faulting, or to the building of sand dunes and sand bars along the coast. The more irregular type of coast is due (especially on the northern coast) to the drowning of valleys in various stages of erosion.

Along the coast in various places are lagoons, mangrove swamps and sand bars.

The main physical features of the State may now be summarized.

The simplest division of the country is into—

(A) The Coastal Plains.

(B) The Great Plateau.

It may be further divided as follows:—

Primary Divisions.	Drainage Divisions.	Physiographic Divisions.	Administrative Divisions.
The Great Plateau and the Coastal Plains	(1) Area of external (exoreic) drainage	North Kimberley ...	Kimberley
		Fitzroyland or West Kimberley	Kimberley
		Ordland or East Kimberley	Kimberley
		Pilbaraland	North-West
		Murchisonia	North-West
		South-West Division or Swanland	South-West
	(2) Area of Internal (endoreic) drainage	Salt Lake Division or Salinaland	Central
		Sand Ridge Division or Sandland	Eastern
	(3) Area of no surface (areic) drainage	Euclonia	Eucla
		Sandland (coastal area)	Eastern

The characteristics of the physiographic divisions are described in Part VI.

PART II.—CLIMATE.

CONTENTS.

Rainfall. Temperature. Winds.

This part makes not pretence to describe adequately the climate of Western Australia. Such information as is here given is brought together for reference when discussing the origin of the land-forms of the State, and to show as far as possible the extent of the dependence of those forms upon climate, especially rainfall. With this object in view, rainfall, temperature, and the winds are briefly dealt with.

RAINFALL.

This is, of course, the most important of the climatic agencies which influence the shape of the land.

The map reproduced (fig. 3) is taken from the average Annual Rainfall Map of Australia, prepared by the Commonwealth Meteorologist and revised to 1924. The isohyets (or lines which pass through districts having equal rainfall) are shown on the map. Those with continuous lines have complete, and those with broken lines have incomplete data. Another map reproduced (fig. 4), which is taken from that also prepared and published by the Commonwealth Meteorologist, shows the duration of the wet seasons, and the limits of coastal storms. By means of these two maps the mean annual rainfall for the State can be seen at a glance, as well as in what portions of the year the rainfall in different areas is the heaviest. Thus the driest area of the State, represented by a rainfall of under 10 inches, stretches from the western coast between Shark Bay and Carnarvon through the Gascoyne and Murchison districts, and thence eastward through Sandstone, Lawlers, and Laverton through south-central Western Australia as far as the South Australian and Central Australian borders.

Eastwards from the western coast the belt widens until the southern 10-inch isohyet almost touches the coast at about longitude 123° E. It then runs east-north-east close and parallel to the coast, subsequently swinging easterly until it meets the sea at about longitude 128° E. This dry belt extends for more than half the length of the eastern boundary of Western Australia.

In the south-western corner of the State the 15, 20, 25, 30 and (to some extent) the 40-inch isohyets run in a south-easterly direction, and more or less parallel to one another. North of the 10-inch belt the isohyets, although still roughly parallel to one another, are approximately east and west in direction.

There is thus a great inland area, which reaches the sea at the north end of the western coast and at the extreme south-eastern portion of the State, with an average annual rainfall of under 10 inches. The rainfall increases steadily to the north and to the south-west respectively, until in the north the greater portion of North Kimberley has

a rainfall of over 30 inches, and in the south-west, around the Cape Leeuwin district, over 40 inches are recorded. In one small area in the same last-mentioned district over 50 inches fall.

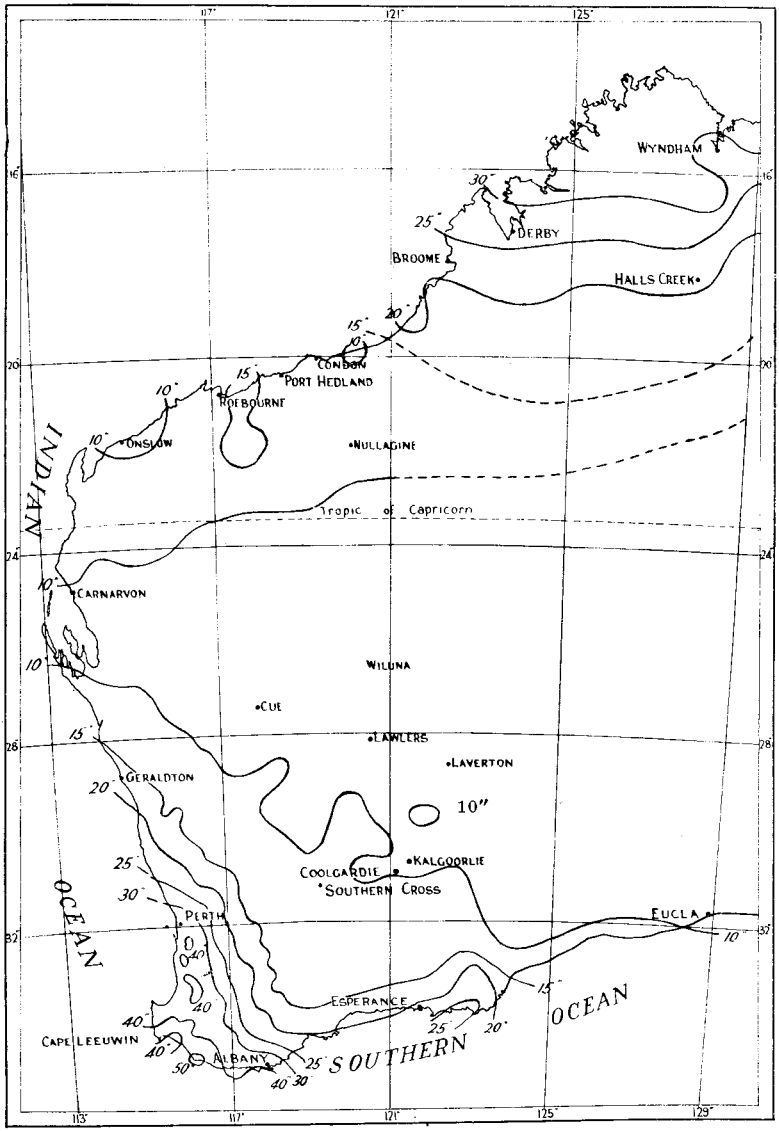


Fig. 3.—Average Rainfall Map of Western Australia, revised to 1924.

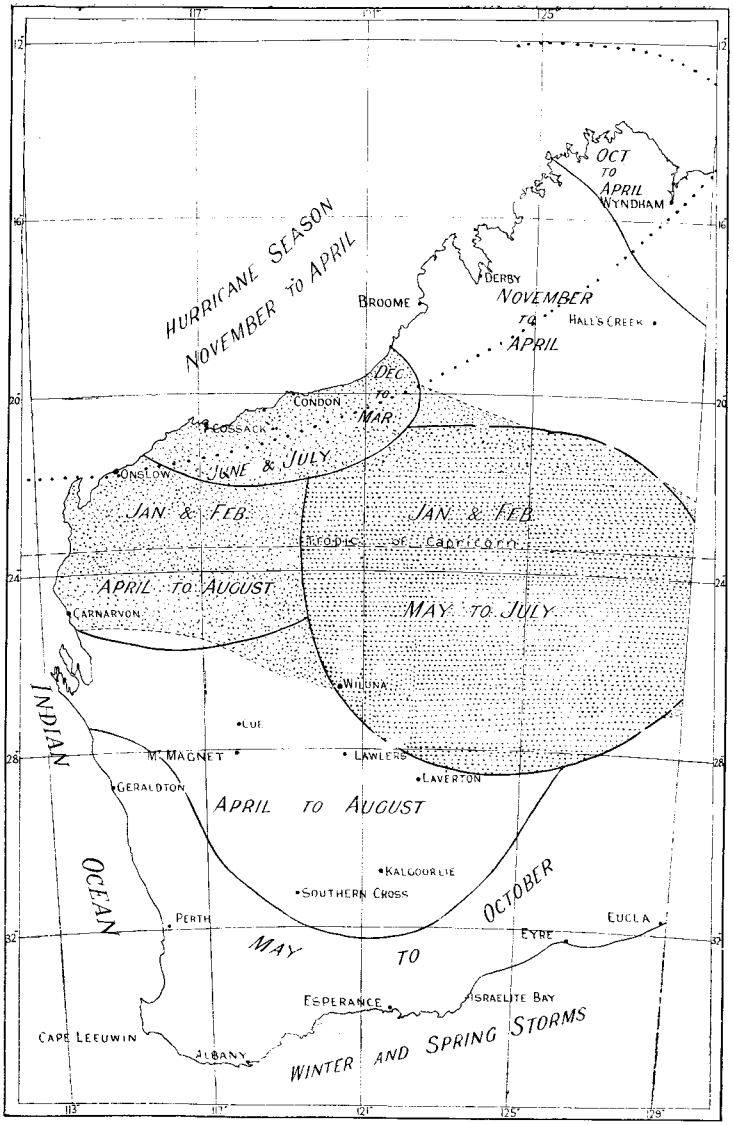


Fig. 4.—Meteorological Map of Western Australia, showing the duration of the wet seasons, and the limits of coastal storms. The periods shown on the map include those months in which the normal mean district rainfall exceeds the prevailing monthly value. The dot-shaded areas have no single well-marked wet season but are subject to both summer and winter rain-producing influences.

The following table is taken from page 43 of Bulletin 1 (revised to 1928) of the Commonwealth Bureau of Meteorology:—

Average Annual Rainfall Distribution.

Average Annual Rainfall.	Western Australia.
	sq. mls.
Under 10 inches	486,952
10–15 ,, ...	255,092
15–20 ,, ...	94,101
20–25 ,, ...	44,340
25–30 ,, ...	31,990
30–40 ,, ...	59,520
Over 40 ,, ...	3,925
Total area ...	975,920

The table shows that almost half the State has a rainfall of under 10 inches per annum, a fact that has to be borne in mind in planning the economic development of the country.

The country is divided into the summer rain belt (in the northern half of the State) and the winter rain belt (in the southern half of the State).

In the summer rain belt some phenomenal falls of rain have been recorded. The following records are taken from the Bulletin just referred to (pp. 46 and 47).

Heavy Rainfalls—Western Australia, up to 1927, inclusive.

Name of Town or Locality.	Date.	Amount.	Name of Town or Locality.	Date.	Amount.
		ins.			ins.
Alice Downs ...	15 Mar., 1922	10·58	Point Torment ...	17 Dec., 1906	11·86
Balla Balla ...	21 Mar., 1899	14·40	Port George IV. ...	17 Jan., 1915	11·24
Bamboo Creek ...	22 Mar., 1899	10·10	Roebourne ...	3 Apr., 1898	11·44
Boodarie	3 Jan., 1896	10·03	Do.	6 Mar., 1900	10·32
Do. ...	21 Jan., 1896	14·53	Roebuck Plains ...	5 Jan., 1917	14·01
Booloogooroo ...	17 Jan., 1923	10·96	Do. do. ...	6 Jan., 1917	22·36
Broome	6 Jan., 1917	14·00	Springvale ...	14 Mar., 1922	12·25
Carlton	11 Jan., 1903	10·64	Tambray	6 Mar., 1900	11·00
Cossack	3 Apr., 1898	12·82	Do.	3 Mar., 1903	10·47
Do.	16 Apr., 1900	13·23	Thangoo	17–19 Feb., 1896	24·18
Croydon	3 Mar., 1903	12·00			
Derby	29 Dec., 1898	13·09	Do.	28 Dec., 1898	11·15
Do.	7 Jan., 1917	16·47	Whim Creek ...	3 Apr., 1898	29·41
Exmouth Gulf ...	2 Feb., 1918	12·50	Do. do. ...	21 Mar., 1899	18·17
Fortescue	3 May, 1890	23·36	Do. do. ...	6 Mar., 1900	10·03
Frazier Downs ...	3 Mar., 1916	11·25	Do. do. ...	3 Mar., 1903	10·44
Gnaraloo	20 Mar., 1923	11·00	Winderrie ...	17 Jan., 1923	14·23
Kerdiadary ...	7 Feb., 1901	12·00	Woodstock ...	21 Jan., 1912	13·00
Meda	2 Mar., 1916	10·55	Wyndham ...	27 Jan., 1890	11·60
Millstream ...	5 Mar., 1900	10·00	Do.	4 Mar., 1919	12·50
Minilya	15 Jan., 1923	11·50	Yardie Creek ...	3 Feb., 1918	10·00
Obagama	28 Feb., 1910	12·00	Yeeda	2 Mar., 1916	10·70
Do.	24 Dec., 1920	13·02	Do.	6 Jan., 1917	10·20
Pilbara	2 Apr., 1898	14·04	Do.	7 Jan., 1917	11·75
Point Cloates ...	20 Jan., 1909	10·87			

The localities mentioned are all in the north-western portion of the State, and they are due to the cyclonic storms which in the summer months pass south-westerly from Cambridge Gulf with continually increasing force. They are greatest near Cossack and Onslow. Such falls are important agents in modifying the land surface,

In the winter rain belt, although the bulk of the rain falls in the winter months, yet the heaviest falls are probably in the summer, when they are frequently accompanied by thunderstorms.

The rainfall in Western Australia is mainly governed by the winds, the chief of which are the south-east trades and the westerlies. The former in Western Australia blow from land to sea, and consequently the rainfall is very light, not only in the interior, but also at the north end of the western coast, where the lightest coastal rain in Australia occurs. The winds also, by reason of their general movement towards the equator, gradually approach warmer regions, which further tends to keep rains from falling.

In the winter the south-east trade winds move north, and the westerly winds also move north and bring the reliable rains of the south-west.

The fairly heavy rains in the Kimberley district are due to "monsoonal" winds in summer.

The evaporation in the arid interior is enormous. Thus at Coolgardie, with a mean rainfall of 10.06 inches, the mean annual evaporation is 84.41 inches; at Laverton with a mean annual rainfall of 9.67 inches, the mean annual evaporation is 142.17 inches. At Perth the mean annual rainfall is 34.37 inches, and the mean annual evaporation is 65.87 inches. The graphs (fig. 5) illustrate these facts.

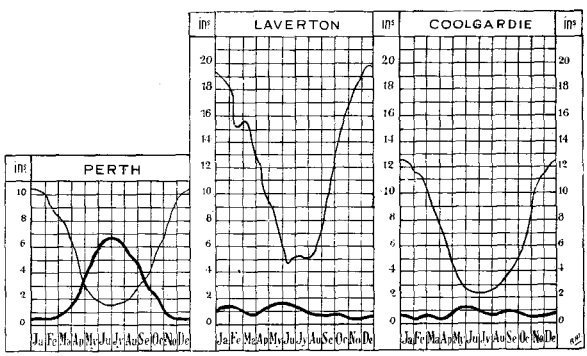


Fig. 5.—Graphs showing monthly fluctuations of Mean Rainfall and Mean Evaporation at Perth, Laverton and Coolgardie, Western Australia. Thin lines denote evaporation; thick lines denote rainfall.

In addition to evaporation a fairly large portion of the rain finds its way beneath the surface of the ground, and to such an extent does this take place in Euclonia, where porous limestones outcrop, that there is practically no run-off (except at times of very heavy rainfall), and the country remains level.

TEMPERATURE.

Over such a vast area as the State of Western Australia occupies, there are naturally great differences in the temperature. Fig 6, taken

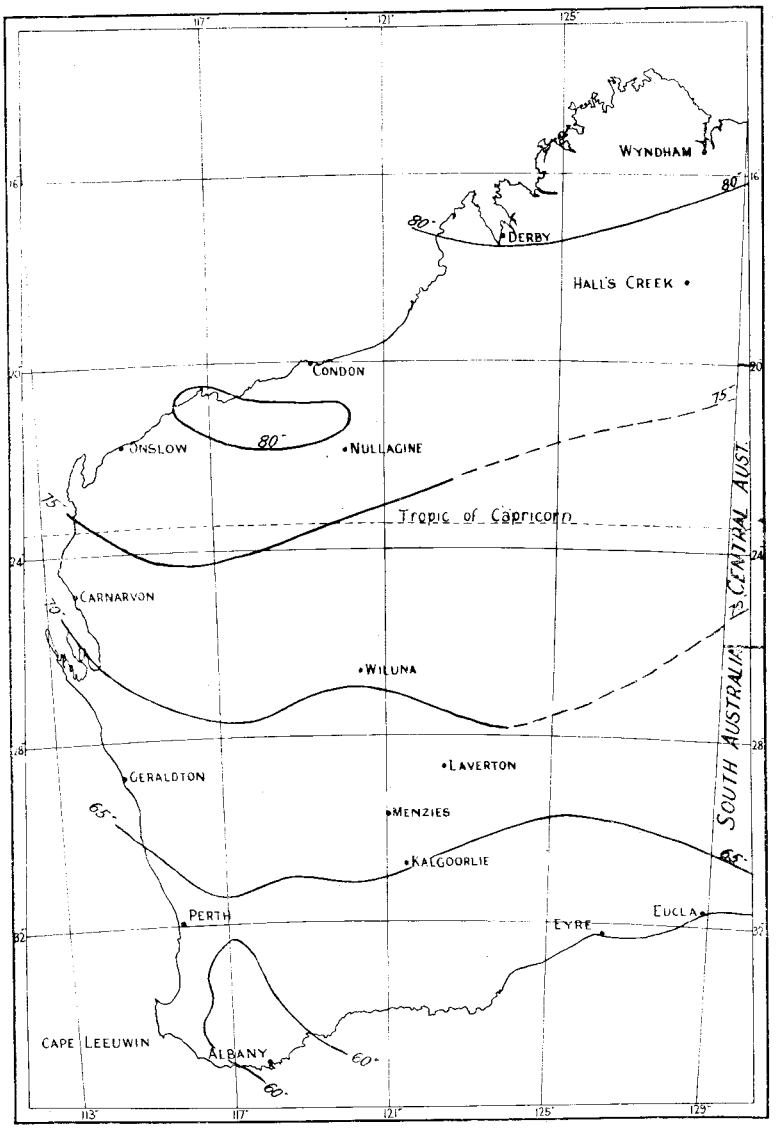


Fig. 6.—Temperature Map of Western Australia, showing the average yearly temperature, revised to 1925. (From the map compiled by the Commonwealth Weather Bureau.)

from a map prepared by the Commonwealth Meteorologist, shows the average yearly temperature for Western Australia to 1925. There is a gradual increase in the temperature from south to north, and the various belts, trending on the whole about east-north-east, are roughly parallel to one another.

"The extreme range of shade temperature in summer and winter in a very large part of Australia amounts to probably only 81°." (Bulletin 1, revised to 1928, of the Meteorological Bureau, p. 41.) "Only 81°" is stated because the range of temperature in some other countries, notably in Siberia and North America, is much higher than in Australia.

Passing southwards "the extreme range of temperature increases gradually on the coast, and in a more pronounced manner inland." (Ibid., p. 41.)

So far as known the hottest area in the continent is apparently situated about Marble Bar and Nullagine in the north-west of Western Australia (ibid., p. 41); the maximum shade temperature there during the summer exceeds 100° F. continuously for days and weeks, the greatest record in this way being 104 consecutive days at Marble Bar in 1921-22. (Ibid., p. 52.)

WINDS.

As mentioned under "Rainfall," the chief winds in Western Australia are the south-east trades and the westerlies. The former in winter occur north of about latitude 30°. In summer they move north and thus make room for the westerlies, which have been pushed to the south in the summer. These westerlies are very important, as they bring the reliable winter rains in the south-western portion of the State. The south-east trade winds are, on the other hand, in Western Australia dry winds, and the low rainfall over the country traversed by them is a result. The absence of rain in those areas enables the wind to play an important part in the formation of the surface features, as will be shown subsequently. According, however, to the observations of Talbot and Clarke (*a*, 42, 43), for some distance south of latitude 26° S., the winds blow in all directions, that portion of the country being apparently too far south to feel the effect of the steady south-east trade winds, which blow in lower latitudes.

The variableness of the winds in one area and their regularity in another have an important influence on the direction of the sand ridges in those parts, as will be shown later.

The next winds in importance are the monsoonal winds of the north-western portion of the State, which, as cyclones, cause enormous quantities of rain to be precipitated in a very short time (see the record

of great rainfalls under "Rainfall" above). These cyclones are popularly known as "Willi Willies," and are peculiar to the north-western coast from the months of November to April inclusive. "They apparently originate in the ocean, in the vicinity of Cambridge Gulf, and travel in a south-westerly direction, with continually increasing force, displaying their greatest energy near Cossack and Onslow, between latitudes 20° and 22° south. The winds in these storms, like those from the north-east tropics, are very violent and destructive, causing great havoc among the pearl fishers. The greatest velocities are usually to be found in the south-eastern quadrant of the cyclones, with north-east to east winds. After leaving the north-west coast, these storms either travel southwards, following the coast-line, or cross the continent to the Great Australian Bight. When they take the latter course their track is marked by torrential rains, as much as 29.41 inches, for example, being recorded at Whim Creek from one such occurrence. Falls of 10 inches and over have frequently been recorded in the northern interior of Western Australia from similar storms." (Bulletin 1, revised to 1928, of the Meteorological Bureau, pp. 48 and 55.)

In the winter months cyclonic storms also affect the south-western parts of Western Australia. (Ibid., p. 48.)

On the western coast there are land and sea breezes. The land breezes blow from the north-east and the sea breezes from the south-west. (Ibid., p. 28.)

The sea breezes help to build up coastal sand dunes and coastal bars, and the land breezes blow part of the sand back into the sea, and so minimise to some extent the effect of the winds from the sea.

Reference should also be made to the spiral winds which in summer traverse the interior of the State. These winds lift large quantities of dust, and by this means their characteristics can be observed. These dust whirls, as they are termed, are columns of dust-carrying air, ranging in height from a few feet to many thousands of feet probably. In the higher columns the diameter of the whirl is small compared with its height. These air columns move across the country in different directions, and may travel miles before dying out. The direction of rotation is both clockwise and anti-clockwise.

PART III.—VEGETATION.

CONTENTS.

Types and Distribution of the Vegetation. The Effect of Rainfall, Temperature and Geology on the Nature and Distribution of the Vegetation.

Rainfall, temperature, altitude above sea-level and the lithological character of the surface rocks are the principal factors that control the vegetation of a country. In Western Australia rainfall is the most important factor of all, and as there is great variation in the average annual rainfall throughout the State, there is considerable diversity in the types of vegetation.

The Forests Department of Western Australia has issued a valuable vegetation map of the State (published with Bulletin No. 42 (1928) of the Department). A copy of that map is here reproduced (Pl. I) on which the principal isohyets are also inserted, in order to enable any correlation as to vegetation and rainfall to be made.

TYPES AND DISTRIBUTION OF THE VEGETATION.

The general types of vegetation and their distribution are shown on the map referred to (Pl. I.). The following are the chief types classified, with notes of their distribution added.

(A) *Sclerophyllous Types* (undergrowth, harsh-leaved shrubs)

(1) Low rainfall tropical woodlands. Eucalypts form the dominant tree species.
The extreme north of North Kimberley.

(2) Low rainfall temperate forests and woodlands, with belts of sand heaths and mallee (Salmon gum forest and sand plains). Eucalypts form the dominant tree species.
The southern half of Salinaland, and the western portion of Murchisonia.

(3) Sclerophyllous forest (Jarrah forest). Eucalypts form the dominant tree species.
Swanland.

(*B*) *Temperate Eucalyptus Rain Forest* (Karri forest). Eucalypts form the dominant tree species.
The extreme south-west of Swanland.

(*C*) *Savannah Types* (undergrowth herbaceous, principally grasses)

(1) Savannah forests and woodland.
North Kimberley (except the extreme north); the northern portion of Ordland; the western portion of Fitzroyland; and portions of Swanland.

(2) Savannah.

The eastern portion of Pilbaraland; the northern and north-western portions of Sandland; most of Fitzroyland; and the southern portion of Ordland.

(3) Mulga (Acacia) bush.

The southern portion of Sandland; the northern half of Salinaland; and the greater portion of Murchisonia.

(D) *Treeless Regions*.

(1) Saltbush plains (Nullarbor Plains) Euclonia.

(2) Desert with spinifex and belts of low shrubs.
The central portion of Sandland.

(*E*) *Subsidiary Types.*

(1) Fringing forests. Throughout the savannah woodland region of North Kimberley and Fitzroyland, tropical rain forests occur in narrow belts fringing the principal watercourses.

(2) Mangrove formations. Mangroves occur from Carnarvon northwards along the coast, but they only develop as distinct forest formations in the estuaries northwards from Derby.

For further details reference should be made to the Bulletin referred to of the Forests Department, and to the descriptions of the vegetation given in the chapters in this work on the physiographic divisions of the State.

THE EFFECT OF RAINFALL, TEMPERATURE AND GEOLOGY ON THE NATURE AND DISTRIBUTION OF THE VEGETATION.

In regard to rainfall, by far the greater part of the country lies between the 10-inch isohyet (running from Shark Bay south-easterly to the southern coast), and the 20-inch isohyet, which cuts across the Fitzroy River in the north; and there are four great vegetative groups within this area, viz.: (1) The treeless saltbush plains of Euclonia (Nullarbor Plains). (2) The great belt of mulga (Acacia) scrub extending from the South Australian border to Shark Bay and thence north to Onslow. (3) The savannahs of Pilbaraland and of the extreme northern and western portions of Sandland. (4) The spinifex belt of central Sandland. A small (eastern) portion of the salmon-gum forest is also within the same area.

In North Kimberley the average annual rainfall appears to be about 30 inches, and within this area are mainly the savannah forests and woodlands with the low rainfall tropical woodlands in the extreme north.

The south-western portion of the State west of the 15-inch isohyet presents an interesting correlation between rainfall and vegetation. See Pl. III., which is a copy of Map No. 2 of Bulletin No. 42 of the State Forests Department. Thus the 15-inch isohyet corresponds very closely with the boundary between the sand plain and salmon gum zones on the east, and the wandoo-mallet-swamp yate zone on the west; the 25-inch isohyet corresponds fairly well with the boundary between the wandoo zone on the east and the jarrah zone on the west; and the 40-inch isohyet approximately separates the jarrah zone from the karri zone.

The tuart zones shown on the map are apparently due to the characters of the underlying rocks, as will be noticed below.

In a general way, therefore, the vegetation varies with the isohyets.

Temperature, however, may also play an important part in the distribution of Western Australian vegetation. Fig. 6 shows how the mean annual temperature rises with decrease of latitude. Similarly, the vegetation is distributed in roughly parallel east and west bands with, in some instances, a swing round to the north at the western coasts. Thus, beginning at the southern coast, there is the great salmon gum belt (which, however, is flanked by the treeless, saltbush Nullarbor Plains), then the vast mulga belt, then the immense savannah belt which, however, is flanked on the east by the spinifex belt. North of the savannah belt is the savannah forests and woodlands belt, which, in turn, is bounded on the extreme north by the low rainfall tropical woodlands.

The extreme south-western belt of jarrah and karri and associated trees is not an east and west trending belt. It follows the coast-line, and its divisions are apparently clearly due to the difference of rainfall.

The lithological character and geological structure of the underlying rocks always affect the nature of the vegetation in detail; but looking at the matter broadly, it may be said that differences in the lithology and geological structure of the rocks in some places affect, and in other places do not affect, the nature of the vegetation. Examples of the influence of these features in producing different vegetation in adjacent areas of practically the same rainfall, temperature and altitude above sea-level, are the Tertiary limestone rocks of the treeless Nullarbor Plains on the one hand, and the sandstones and other sedimentary rocks to the north on the other hand. The Eucla Limestone permits the surface water to pass rapidly through the rocks, and hence there is no reservoir of water for trees as in the other belt.

Similarly, the difference in vegetation between the major part of Pilbaraland (granite, greenstone, lava flows and sediments), and the extensive belt of central Sandland (sandstones chiefly) is explicable

only by the difference in the lithology of the rocks of the respective areas, since the rainfall, temperature and altitude above sea-level are substantially the same.

The tuart of the western coast in the vicinity of Perth grows on and is restricted to the coastal limestone. Hence it is a striking example of the effect of the lithological character of the underlying rocks.

On the other hand, the great mulga belt passes over granite and greenstone country in the west and sedimentary rocks in the east. In detail, however, there are differences in the belt, as even the granite and greenstone have distinctive vegetation in places, which fact is of value in geological mapping.

Again, the central salmon gum belt and the central mulga belt have the same rocks (granites and greenstones); yet the difference between the two types of vegetation is pronounced. Temperature and, in a minor degree, rainfall are probably responsible for the difference.

The rocks of the jarrah, karri and associated belts are substantially the same (granite chiefly, often capped by laterite), yet, as noticed above, there is a succession of different belts, due apparently to differences of rainfall. Similarly, the rocks of the savannah forests and woodlands of the greater portion of the Kimberley district are the same as those of the low rainfall tropical woodland of the extreme north.

In considering the effect of the lithology and geological structure, reference should be made to the geological map of the State (Plate II.)

The difference in altitude above sea-level between the various portions of Western Australia is not so pronounced as to bring about any substantial differences in the vegetation.

It may be noticed, as is to be expected, that some of the types overlap each other. For example, the spinifex belt overlaps the mulga and savannah belts. The division between others is fairly sharp, as, for example, the salmon gum and mulga belts.



PART IV.—OUTLINE OF GEOLOGY.

CONTENTS.

General Remarks. The Geological Formations of the State. Archaeozoic. Proterozoic. Palaeozoic (Cambrian, Devonian and Carboniferous, including Permo-Carboniferous). Mesozoic. (Jurassic and Cretaceous). Cainozoic. Post-Tertiary or Quaternary.

GENERAL REMARKS.

The following particulars are inserted for the purpose of making more intelligible the references in this work to the various geological

formations of the State in connection with physiographic descriptions or problems. The sketch of the geology here given is based mainly on the summaries given by A. Gibb Maitland (*k* and *j*) and on the geological map recently issued by the Geological Survey under the direction of the present Government Geologist, Mr. Blatchford, a copy of which is reproduced in this report (Pl. II.). The work of Blatchford (*g*), Wade, and Talbot (*d* and *e*) has also been made use of.

The scale of the map referred to necessarily prevents the delineation of details, but the broad outlines of the geology of the State are clearly shown. The most striking features observable from a perusal of the map are (1) the fact that the major part of the geological formations belong either to the Pre-Cambrian or Palaeozoic periods, the Mesozoic and Cainozoic rocks being limited to a narrow fringe along the southern, western and north-western coastlines, except in the extreme south-east of the State, where the Mesozoic and Cainozoic occupy a considerable area; and (2) the great area of granitic rocks, with the associated greenstones, in the southern half of the State, and the enormous preponderance of sediments in the northern half. The sediments mentioned, however, conceal to some extent granite and greenstone.

The granite and greenstone series is generally regarded as of Pre-Cambrian age, and if the Nullagine Series belongs also to the same category, as suggested by Maitland (*k*, 18) and now accepted by Talbot,* then the major portion of the surface (omitting the recent superficial deposits) of Western Australia, is covered by rocks of Pre-Cambrian age, which, however, does not imply that they are all of the same age.

THE GEOLOGICAL FORMATIONS OF THE STATE.

A brief account of the main geological features of the State may now be given.

Archaeozoic.

The Archaeozoic rocks are, according to Maitland, the oldest known in Western Australia, and they occupy the area in the southern half of the State shown on the map as granite and greenstone. Comparatively small scattered areas occur in the north-west and also in the Kimberley district. The rocks of this formation really comprise an immense variety of igneous (both basic and acid), sedimentary and metamorphic rocks, the last named being the alteration products of the other two groups. The sedimentary rocks have been so crushed and squeezed that their original horizontal position has been changed to the vertical or close to the vertical. In other rocks, such as the granites and greenstones, the crushing and squeezing have developed foliation planes, which are also vertical or close to the vertical. The

*Personal communication.

strike of the stratification planes of the sedimentary and of the foliation planes of the metamorphic rocks is the same, and in the southern half of the State, where the major portion of the rocks is exposed, it is about north-north-west. This predominant direction affects the present configuration of the country, and with wonder we recognize that the structural characters given to the rocks many millions of years ago exercise a powerful influence on the shape of the land to-day. It may be noted that there is a great arc of Pre-Cambrian rocks forming a narrow belt stretching from between Collier Bay and King Sound south-eastwards to the McClintock Range and thence north-north-east to the Carr-Boyd Range.

Proterozoic.

The dominant group of rocks in this division is the Nullagine Series, which is widely spread over the State from Marble Bar southwards, and is the prevailing series in the Kimberley district. They are chiefly sedimentary and altered sedimentary rocks, and comprise conglomerates, grits, sandstones, shales, quartzites, slates, and schists, as well as igneous rocks, which are either interbedded with the sediments or have intruded the latter as dykes, bosses or sills. Most of the rocks are practically horizontal, and rest upon the upturned and worn down edges of the older beds.

Palaeozoic.

Cambrian.—The Cambrian rocks are, so far as known, restricted in Western Australia to the Kimberley district. A narrow belt extends from the Albert Edward Range north-north-eastwards to the vicinity of Mt. John. Wade (14) has classified the rocks of this belt as Lower Cambrian, although, he states, they may well pass downward into the Pre-Cambrian.

The rocks forming the Lower Cambrian Series mentioned above are mainly or entirely sediments (quartzites, sandstones, grits, conglomerates, limestones and shales).

There is very little information as to the strike of the Cambrian rocks, but from the general north-north-east trend of the outcrops of the Lower Cambrian Series it is probable that the strike also runs in that direction.

In addition to the sediments, the basalt flows of the Antrim Plateau in the extreme south-east of the Kimberley district, and those to the north in the lower and middle Ord River basin, are regarded as of Cambrian age.

Devonian.—Devonian rocks occur in the Napier Range and at Mt. Pierre in the Kimberley district, and consist of grits, conglomerates, limestones and shales, with some interbedded lava flows, breccias and ashes. Some of the limestones are hard and crystalline.

Carboniferous (including Permo-Carboniferous).—Carboniferous (including Permo-Carboniferous) rocks are found in the Kimberley, Gascoyne, Irwin River, and Collie districts and far to the south of Kimberley in the great arid belt to the Tropic of Capricorn. The rocks are divided into an Upper and Lower Series. Blatchford's map (*g*) shows that the Lower Series is a narrow belt forming almost a complete semicircle. In the Kimberley district north of the Fitzroy River this belt runs south-eastwards to Christmas Creek, and comprises the Napier, Oscar, and Geikie Ranges. It continues south-easterly to about the Musgrave Ranges, which are not far from the eastern boundary of the State. It runs then south to the Tropic of Capricorn, and then turns to the west-north-west and continues to a little north of Lake Disappointment. How much farther it can be traced will be determined by subsequent exploration. Probably a good deal of the mapping of this belt is tentative only, but nevertheless, the main features are no doubt substantially correct.

This great semicircle is in striking contrast with the semicircle of Pre-Cambrian metamorphic rocks in Kimberley, which is concave to the northern coast as already noted.

Within the semicircle of the Lower Carboniferous rocks is a great area of rocks, which are probably mainly Upper Carboniferous in age. This area is very arid and forms a large portion of the Western Australian desert. From the structure of the country it appears to form a great basin in the older rocks which rise to the north and to the south.

In the Lower Carboniferous rocks of the Kimberley district, limestones, and in the Upper Carboniferous, sandstones, predominate. Ice-scratched boulders and pebbles occur in some of the beds.

The Carboniferous rocks of the Gascoyne district call for no special remark. They are divided into an Upper (or sandstone) and a Lower (or limestone) Series, and they occur in the valleys of the Wooramel, Gascoyne, Lyons, Minilya, and Lyndon Rivers. They form a narrow north and south-trending belt close to the coast line. The sandstones and limestones are exposed in the scarps of the Kennedy and Moogooloo Ranges. Glacial beds also occur in the Gascoyne Carboniferous rocks.

The Irwin River and Collie River rocks are sediments of Carboniferous age, but they call for no special remark.

Mesozoic.

Jurassic.—The Jurassic system in Western Australia forms narrow bands near the coast of sedimentary rocks, comprising limestone, clays, sandstones, conglomerates and lignites. One belt extends from about Gingin to Fortescue. A similar band runs along the Eighty-Mile Beach past Broome to about Derby. They have also been reported from the Cape Riche district, to the east of Albany.

The Jurassic strata are usually horizontal or slightly undulating (Maitland, *k*, 38).

Cretaceous.—Cretaceous marine rocks occur in patches in a narrow area to the north of Perth, the best known locality in this band being at Gingin. The rocks are sedimentary, and at Gingin they consist of chalky limestones, marls, and shales, the whole series dipping to the north at an angle of 8deg. to 9deg. (Maitland *k*, 39.)

Cretaceous rocks have been proved to be beneath the Tertiary limestone of Eucla nia, and an extensive outcrop occurs to the north of the Nullarbor Plain, where they are described as forming table-topped hills (Maitland, *k*, 39).

Cainozoic.

Cainozoic marine sedimentary rocks occur along the western coast, but the rocks appear to have been but little examined. A striking outcrop forms the Cape Range, west of Exmouth Gulf. The rocks are regarded as of Oligocene age and rise 1,000 feet above sea-level (Clapp, *a*, 64).

In the neighbourhood of Albany, Miocene marine Tertiary beds occur. Similar rocks also occur in the neighbourhood of Cape Riche and Norseman. A sponge spicule bed of probably Miocene age also occurs at the head of Lake Cowan (Clarke, *a*, 12 and 13). The Nullarbor Plains in the south-east of the State are composed of practically horizontal marine limestones of Miocene age.

Tertiary basalt occurs at Bunbury and at other localities in the south-west of the State.

Post Tertiary or Quaternary.

Amongst Post-Tertiary deposits the Coastal Limestone, which mainly represents old consolidated sand dunes, occurs along considerable lengths of the western and southern coasts, fine outcrops occurring especially near Albany.

Laterite is extensively developed in the interior and on the Darling Plateau as thin surface caps on the underlying rocks. Its age has not been definitely fixed.

Sand dunes are common along the southern, western, and north-north-western coasts, and in the interior vast areas are covered with sand ridges. Some of the rivers have extensive alluvial deposits along their valleys, forming wide plains.

PART V.—A GENERAL ACCOUNT OF THE EFFECT OF CLIMATE, VEGETATION, GEOLOGY AND OCEAN CURRENTS IN THE FORMATION OF THE PHYSICAL FEATURES OF WESTERN AUSTRALIA.

CONTENTS.

Climate. (a) Rainfall. (b) Temperature. (c) The Wind. Vegetation. Geology. Ocean Currents.

CLIMATE.

(a) *Rainfall.*

Within the 10-inch belt of rainfall there are practically no streams except at the coastal end of the belt. That fact is a direct result of the low rainfall. The coastal end of the belt, which lies between Carnarvon and Shark Bay, is traversed by the upper Murchison, the upper Ashburton and its tributaries, the Gascoyne, the Lyons and the Wooramel Rivers. Those rivers are some of the longest in the State, but they probably have the most ill-defined channels and are the most free from canyons of any rivers in the State. They usually flow through broad elevated plains, and doubtless dry up more rapidly than any other rivers of the State Such phenomena would be expected in an area of such low rainfall

Within the 10 to 15-inch belt are the lower Ashburton, the greater portion of the Minilya, almost all the Fortescue, and the De Grey-Ridley with its numerous tributaries. The channels of those streams are, as a rule, well-defined, and they possess numerous canyons, such as the great gorge of the Fortescue and the immature valleys of the Oakover, Nullagine and other rivers.

Within the 15 to 50-inch belt, which is the western portion of Swanland, where the isohyets run about north-west and cut the western coast at acute angles, the streams, as they are traced southwards from about Geraldton, are comparatively few and short, but as the south-western corner of the area is approached, where the rainfall is heaviest they increase both in number and size. The longest river of the belt, the Blackwood-Arthur, which has many tributaries, is in the extreme south-west. Eastwards from Albany, where the average yearly rainfall is 37 inches (Statistical Register of Western Australia for 1926-27, Part V., p. 71), to Israelite Bay, the rainfall diminishes to an average of about 10 inches per annum, and as it does so the streams become shorter until they die out at Israelite Bay, which is approximately the western end of the Eucla Limestone Plateau.

On the north-north-west coast there are two belts, one with a 10 to 15-inch rainfall, stretching from Condon to Wallal, and the second with a 15 to 20-inch rainfall, stretching from Wallal to Lagrange. From the rainfall, rivers would be expected here, but there is none.

The reasons for their absence must be geological. The rocks are sediments, evidently highly porous sandstones, which absorb the rain. The abundance of blown sand, which is due to the aridity of the climate and to the nature of the rocks, also causes difficulty in the formation of rivers owing to a large proportion of the rain that falls being absorbed by the sand.

In the Kimberley district the 20 to 30-inch belt includes the greater portions of the valleys of the Fitzroy and the Ord Rivers, and the belt of more than 30 inches includes North Kimberley. The Fitzroy and Ord River systems, notwithstanding the lower rainfall, are more greatly developed than those of North Kimberley, but here again the geological structure of the Fitzroy and Ord valleys has probably favoured their growth, whereas in the North Kimberley valleys the geological structure is not so favourable.

In the great arid belt of the centre and east the scarcity of rain is the chief cause of the absence of rivers, although of course drainage channels exist. There are probably more of such channels in the centre (Salinaland) than in the east (Sandland). The rainfall statistics are not at present sufficient to say whether more rain falls in Salinaland than in Sandland, but the difference in the number of drainage channels is probably largely accounted for by the difference in the component rocks of the respective areas, those of Salinaland being largely composed of granitic rocks with basic and sedimentary rocks in subordinate distribution. In Sandland, so far as known, sediments, mainly sandstones or other siliceous rocks, predominate; and these yield, upon disintegration, enormous quantities of sand, through which the rain soaks. There is much less sand and more clay in Salinaland than in Sandland, and consequently the rain can form drainage channels, although nothing that can be called a river.

In considering generally the effect of the yearly quantity of rain that falls in a given area on the topography, consideration must be given to the nature of the falls. Thus a comparatively light annual fall, made up of heavy individual falls, will cause more erosion than a greater annual fall distributed throughout the year in light falls, although light falls tend to remove fine detritus from higher to lower lands.

As shown above, geological structure and the lithological composition of the rocks must always be taken into consideration, and these characters are strong enough in places to withstand relatively the power of the rain.

(*b*) *Temperature.*

In the arid interior the high summer day temperatures, with the rapid fall at night owing to the great radiation of heat, are especially favourable to the work of insolation; and this is particularly well shown on the bare knobs of granite that rise above the general surface

of the country, and also in the greenstone, haematite-quartzite and quartz ridges and hills, from the shattered surfaces of which streams of angular rock debris often stretch for some distance out on to the plains.

In other parts, wherever the rocks are exposed at the surface and high temperatures occur, insolation acts as a powerful disintegrating agent.

In the drier parts of the country the high temperature brings about rapid evaporation of the surface water, and in consequence the deposition of various salts (common salt, gypsum and others) takes place, and salt lakes or salinas are formed. In the same parts, high temperatures also favour the action of capillarity, which brings in solution to the surface various mineral substances, which are there deposited as hard caps, very resistant to erosion, which when broken result in the formation of mesas and buttes. Examples of such caps are the various forms of laterite, ferruginous, siliceous and aluminous, and to a less extent, travertine.

High temperatures acting similarly through capillarity also favour the crystallization of salts at the surface, with the resulting disintegration of the rocks.

(*c*) *The Wind.*

In a moist climate, the effect of the wind on the topography of a country, away from the sea coast, is practically nil.

On the sea coast of course sand dunes are built up in favourable places, and these dunes may march inland, burying houses unless a halt is effected. The wind also assists in the natural reclamation of the land from the sea by the capping of a wave-built bar with a sand dune, thus making a more effective bar than that built by the waves alone.

It is, however in the interior of a country with an arid climate and high temperatures, and possessing rocks that disintegrate into siliceous sand, that the wind works with great effect. Such conditions obtain in the great inland belt about the centre and east of Western Australia. The wind has a certain corrasive power there, but its greatest power is in its deflative capacity. The immense number of sand ridges and the vast areas over which they are spread are monuments of the power of the wind in modifying the face of the country.

The wind also removes fine dust from exposed surfaces, and either re-deposits it in other areas or "exports" it out of the country altogether.

Dust whirls are rotating columns of dust which pass across the country frequently in the summer time. The height of many must be thousands of feet. By their agency an immense quantity of dust is lifted from the surface of the ground and transported elsewhere.

VEGETATION.

From the point of view of erosion the extent to which the surface of the ground is covered by vegetation of any kind is of importance.

Where there is abundant vegetation, the soil is largely protected from erosion; the rocks are not generally exposed at the surface; much of the rain water soaks into the ground instead of running off and is thereby conserved for the replenishment of streams; springs often result; the rivers flow for longer periods; there is less erosion by rain on the hillsides; less flood action by rivers; and the corrasive and deflative action of the wind is at a minimum.

Where the vegetation is scanty, the rocks are often widely exposed, resulting in their rapid disintegration by insolation; the detritus is swept away by wind and rain; the run off is rapid, often resulting in floods; springs are fewer; and rivers dry up faster.

Both these sets of results may of course be modified by other factors, such as temperature, altitude above sea-level, and the geological character of the country. Also in the areas covered by sparse vegetation, which are usually inland, the results mentioned are offset to some extent by the rainfall, if low, as it usually is, doing less erosive work than it would do if the fall equalled that of the areas of abundant vegetation.

In the areas of sparse vegetation, erosion also is largely checked by the accumulation of detritus spread widely over the country either in the form of sand ridges or of deposits due to rain and rivers. Thus Nature in these areas tends to establish an equilibrium by means of this accumulation of detritus, whereas in the wetter regions the detritus is carried largely to the sea.

The general principles mentioned are illustrated in Western Australia. In the extreme south-west, where the rainfall is heaviest, there are dense forests, with an undergrowth practically completely covering the surface of the ground. Erosion in that country is almost entirely confined to the action of rain and rivers. In the arid 10-inch rainfall belt of the interior where the vegetation is comparatively scanty, the rocks for limited areas are much exposed, and insolation is active. The wind has also been able to pile up sand ridges (especially where the rocks on disintegration yield much sand) which in turn, however, protect (temporarily or permanently) the ground beneath from further erosion, as does also the detritus due to rain which is spread over large areas of the country, forming plains.

The remaining portions of the State are intermediate, in their vegetative characters, between the arid centre and east, and the south-west, and similarly the topographic effects are also intermediate.

The geological characters which may influence the topography of a country are geological structures and the composition and texture of the rocks. The two last named qualities in turn determine their "hardness," that is, their power to resist erosion.

Amongst geological structures that are important from the aspect now discussed are faults, folds, joints and stratification and foliation planes. Associated with these features are strike and dip. In addition to those phenomena, the arrangement of the different rock masses to one another (such as whether sediments have been intruded by a batholith of granite, or whether the great sedimentary and metamorphic masses occupy bands parallel to one another) is important.

The part in Western Australian topography played by fairly recent faults is shown by the fault scarps throughout the State, such as the Darling Fault Scarp, and the scarps bounding the Stirling Range.

Folds have been of little account in the development of Western Australian surface features, since it is only the older rocks, as a rule, that have been folded, and the effects of the folds have long since been removed by erosion. This does not apply to folds on a great scale, as, for instance, the great basin between Fitzroyland and Pilbaraland occupied by Carboniferous rocks.

An example of a great fold shown at the surface is the Cape Range anticline in Tertiary rocks, which rise over 1,000 feet above sea-level (Clapp, *a*, 64).

The influence on the topography of great bands of sediments or metamorphic rocks is shown in Fitzroyland and Ordland, where the main streams, broadly speaking, follow the strike of those great rock masses.

Joints play a minor part, but the resulting effects can be seen in the wall-like masses of granite and basalt along the sea-coast of parts of Swanland.

The strike of the stratification and foliation planes determines the courses of ridges of hard rocks, and the dip may influence the angle of slope of the sides of the ridges. These features are well shown in the haematite-quartzite ridges of the goldfields.

The composition and texture of the rocks and their resulting "hardness" or "softness" may affect in a big way the evolution of the surface features, or they may be restricted to earth sculpture in detail. As an example of the former the comparatively easily eroded granite of the centre and north-west now forms great plains from which rise ridges and island-hills of the much more resistant greenstone, haematite-quartzite and quartz. Another but very different example on a great scale may be given. As already noted, the rocks of Sandland are largely sandstones, which have broken down into loose sand,

which the wind has swept up into innumerable ridges occupying hundreds of square miles of country. As an example of detail the coastal limestone common around Perth may be cited. That rock is very uneven in its toughness, due to the unequal precipitation through it of calcium carbonate. As a result the limestone weathers into a cavernous, jagged rock.

OCEAN CURRENTS.

The ocean waves in association with the ocean currents and tides may cut a coast-line back into cliffs or may deposit material which causes a coast-line to advance. Sand may be thrown up on the beach by the waves, which the wind may seize and pile up into dunes. These processes are so well known that there is no necessity here to give illustrations from the Western Australian coast line.

It is desired, however, to point out that, on the western coast, the ocean currents in association with the wind have directly influenced some of the coastal features. The Western Australian current (fig. 7) flows northwards along the western coast, and the westerly winds are diverted in the same direction. Much of the coast line is composed of sand dunes and of sand bars which have diverted the courses of streams from their normal directions to a direction parallel to that of the coast, and which have also formed similarly parallel lagoons.

There appears to be a general tendency for the lagoons to have their mouths (where such exist) opening to the north, and the rivers to be diverted in the same direction, an example of which is the Greenough River north of Perth.

If such features should on further examination be found to predominate, then it is suggested that the reason therefor is the action of the Western Australian current assisted by the wind, which travels in the same direction.

An examination of a map shows that at Shark Bay the Peron Peninsula and the one to the west of Freycinet Estuary point to the north. Dirk Hartog's Island is in the same straight line as the peninsula just referred to, and Dorre and Bernier Islands to the north break up the entrance to Shark Bay into a number of channels; farther north, Exmouth Gulf opens to the north. The rocks forming the Cape Range to the west of Exmouth Gulf are of Oligocene age and those of the Shark Bay peninsulas and islands are also believed to be of Tertiary age, but there seems to be little definite information concerning them. It is difficult to account for the peculiar features of Shark Bay and Exmouth Gulf. The islands and peninsulas by their distribution suggest that they have been built up in the present seas by the action of the waves, currents and winds, but if their component rocks are of Tertiary age and of marine origin, this could not be the case. A detailed examination of these areas would be very interesting from both a geological and a geographical point of view.

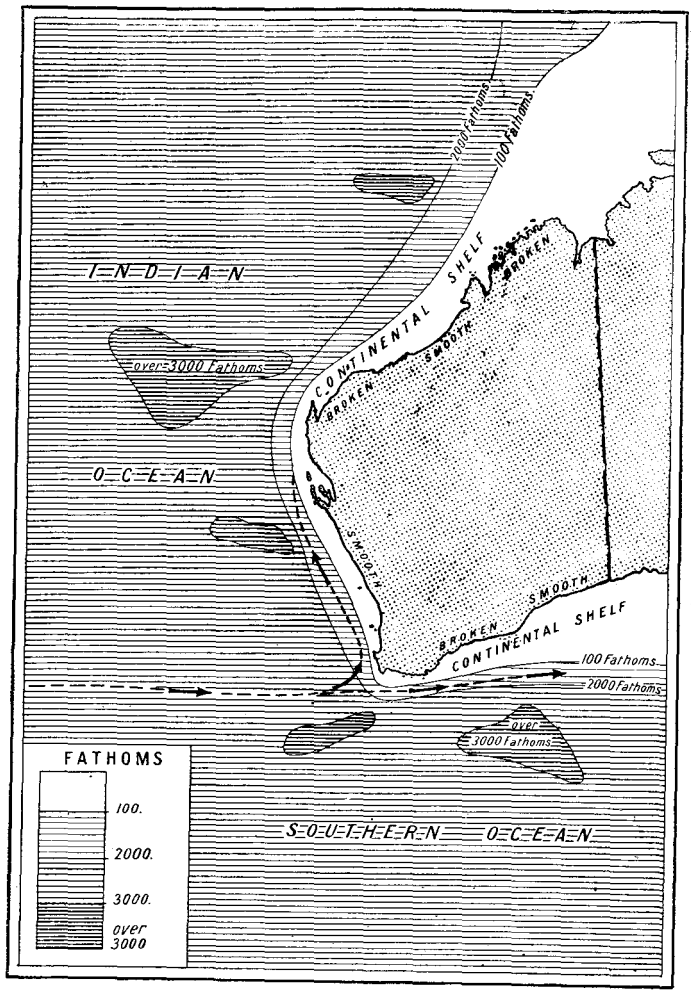


Fig. 7.—Map showing the coast line of Western Australia and the contour of the ocean floor. Note the widening of the continental shelf on the northern and southern coast lines. The arrows show the direction of the currents. (From McLintock's "The Swan Geography.")

PART VI.—THE PHYSIOGRAPHIC DIVISIONS.

CHAPTER I.

THE PHYSIOGRAPHIC CLASSIFICATION OF WESTERN AUSTRALIA.

CONTENTS.

Old Classification. Subdivision of the Kimberley Division. Subdivision of the North-West Division. Other Divisions. Table of Physiographic Divisions.

OLD CLASSIFICATION.

In the first edition of this work the State was divided into six physiographic divisions, which correspond, in the main, with the official divisions, thereby showing, if the physiographic grouping were correct, that whoever so divided the State officially must have recognized its broad distinctive physical features. The divisions classified physiographically were: (1) The Northern or Kimberley Division, (2) The North-West Division, (3) The South-West Division, (4) The South-East or Eucla Division, (5) The Central or Salt Lake Division, (6) The Eastern Division.

Our knowledge has progressed so considerably in recent years that the writer proposes to create new divisions by the partition of some of the existing ones (see fig. 8).

THE SUBDIVISION OF THE KIMBERLEY DIVISION.

The differences between the physical features of the various portions of the division are so considerable as to warrant creating three new physiographic divisions instead of the original one.

The three new divisions may be named—

1. North Kimberley.
2. Fitzroyland or West Kimberley.
3. Ordland or East Kimberley.

These three belts are substantially the same as those selected by Clarke (*b*) as three of the natural regions of Western Australia, North Kimberley, Fitzroy and Antrim respectively. For the physiographic division the name "Fitzroyland," however, has been adopted in preference to "Fitzroy," as the latter name is applied to the chief river of the division.

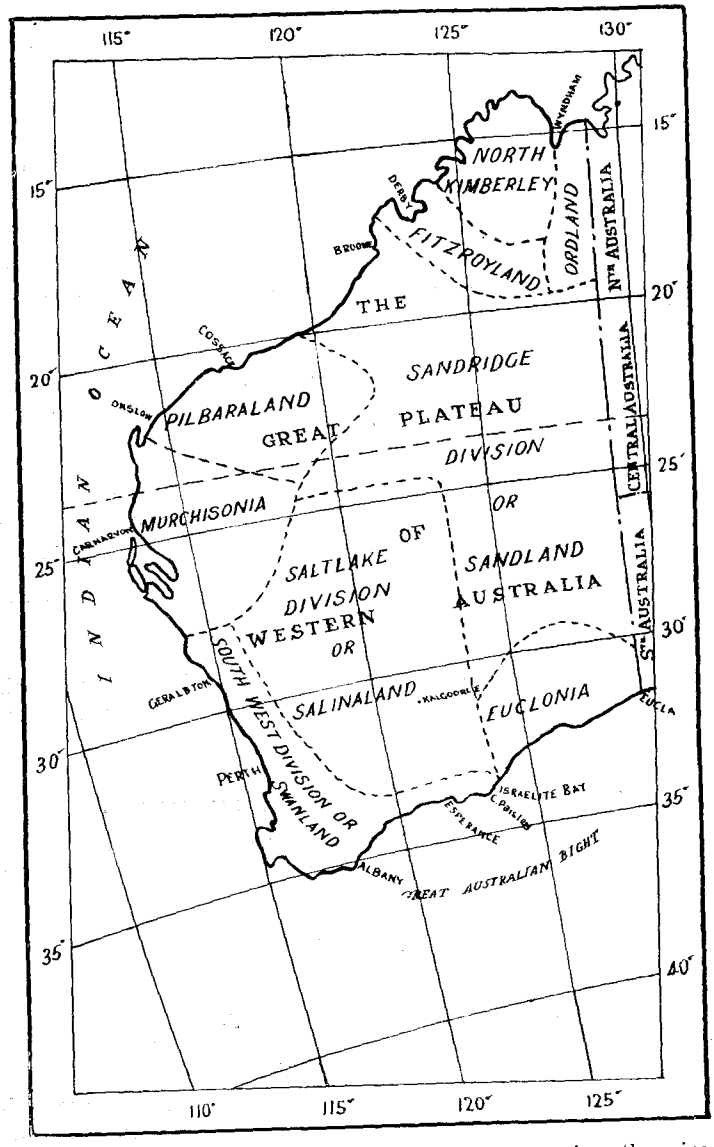


Fig. 8.—Outline Map of Western Australia, showing the nine physiographic divisions. With the exception of narrow coastal strips, the whole of Western Australia is a plateau, called the "Great Plateau of Western Australia."

"Ordland" has also been adopted in preference to "Antrim," as the area which it represents is chiefly the basin of the Ord River, rather than the Antrim Plateau, the physical features of which are continued into North Australia. Fitzroyland and Ordland correspond roughly with what have come to be known as "West Kimberley" and "East Kimberley" respectively.

The differences are most marked between North Kimberley (a plateau dissected only to early maturity) on the one hand, and Fitzroyland and Ordland (plateaux maturely dissected) on the other hand.

The three belts referred to are, as a whole, well marked off from the remainder of the State and have much in common, so that together they may be known as the "Kimberley District." By that term the area as a whole can still retain the name by which it has been known for so long.

THE SUBDIVISION OF THE NORTH-WEST DIVISION.

The extension of our knowledge has suggested the advisability of making two physiographic units or divisions instead of one. The names proposed for the two new divisions are—

1. Pilbaraland.
2. Murchisonia.

The two divisions have been created in consequence of the differences between the topographic forms in the north (well-defined valleys—such as those of the Shaw and Oakover Rivers, indicating early maturity—and numerous water gaps) and in the south (ill-defined mature valleys—such as those of the Murchison and Gascoyne Rivers—and few water gaps). Such differences are due in part to the differences in the geology of the respective areas, but probably mainly to differences in the amount and in the seasonal distribution of the rainfall. Between the two extreme types are the valleys of the Fortescue and Ashburton Rivers, but such valleys have sufficient characteristics of the northern type to be included with the latter. (See Talbot, *e*, 10.)

The differences in the coast lines of the respective areas also indicate the necessity for a subdivision of the original North-West Division.

It is proposed to use the term "North-West District" to comprise Pilbaraland and Murchisonia, and so retain the name which has for so long been in use.

OTHER DIVISIONS.

The remaining divisions have been retained substantially without change in their boundaries, although changes of name are suggested as appear from the table below.

TABLE OF PHYSIOGRAPHIC DIVISIONS.

The following table shows the old and the new physiographic divisions:—

Old Divisions.	New Divisions.
1. Northern or Kimberley Division	1. North Kimberley } Forming the Kimberley District and comprising the original Kimberley Division. 2. Fitzroyland or West Kimberley } 3. Ordland or East Kimberley }
2. North-West Division	4. Pilbaraland } Forming the North-West District and comprising the original North-West Division 5. Murchisonia }
3. South-West Division	6. South-West Division or Swanland
4. Central or Salt Lake Division	7. Salt Lake Division or Salinaland
5. Eastern Division	8. Sand Ridge Division or Sandland
6. South-East or Eucla Division	9. Euclonia

It may here be mentioned that the first named five new divisions, together with Salinaland and Euclonia, form the "sparselands" of Western Australia, as defined by Griffith Taylor (*b*, 2, fig. 1), that is to say, sparsely settled regions, as contrasted with Swanland, with its comparatively dense population, on the one hand, and the uninhabited Sandland, which is part of Taylor's "Western Desert," on the other hand.

CHAPTER II.

NORTH KIMBERLEY.

CONTENTS.

Boundaries. Literature. Rainfall. Temperature and Humidity. Vegetation. Geology. Contour. The Plateau and Scarps. Rivers. Coast Line. Economic Aspects.

Reference should be made to the first chapter of this Part in regard to the creation of this physiographic division.

BOUNDARIES.

The division is bounded on the south-west by the south-western edge of the King Leopold Plateau, and on the east by a line forming approximately the western watershed of the Ord River; and extends north and west from these lines respectively to the coast. (See Pl. II. and figs. 8 and 9.)

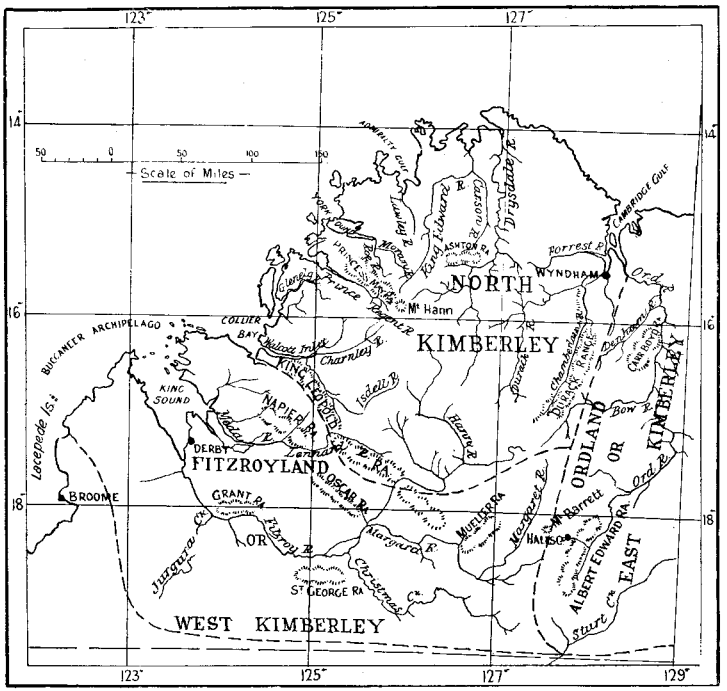


Fig. 9.—Outline Map of the Kimberley District, showing the three physiographic divisions of North Kimberley, Fitzroyland or West Kimberley, and Ordland or East Kimberley.

The belt is substantially the same as the natural region to which Clarke (*b*, 129) has given the same name.

Blatchford (*g*, 12) has referred to North Kimberley as the "northern plateau." The present writer in the first edition of this work (*b*) added "northern" as an alternative name to the Kimberley Division as there defined. To avoid confusion it is well to discontinue the use of the word "northern." The southern portion of the North Kimberley Division has been referred to by Maitland (*l*, 83) as the "King Leopold Plateau."

LITERATURE.

North Kimberley forms a vast area of which comparatively little is known even topographically. Geologically, it is almost unknown. The most valuable general descriptions of the country are those by Brockman and Crossland and by Easton, all of whom are surveyors, and each of whom has given graphic accounts of his journeys and of the difficulties of travel owing to the ruggedness of the country, and, in consequence, its inaccessibility in many places. It is also to them that we are indebted for what we know of the geology, although Maitland (*b,* 8 and 9, *l,* 83, and *j,* 41) has briefly referred to it.

RAINFALL.

The average annual rainfall of the division is over 30 inches, the bulk of which falls in the summer months. The quantity of rain that falls and its seasonal distribution make the country a well watered one, practically free from drought. Erosion by rivers should be active, although in the dry season (the winter) some of the streams contract to chains of pools (Easton, 39).

TEMPERATURE AND HUMIDITY.

Fig. 6 shows that the mean annual temperature of North Kimberley is over 80° F., but of course the temperature and the humidity will frequently vary according to the altitude and the locality; along the coast, and inland along the valleys, the air is apt to be moderately humid.

VEGETATION.

The vegetation, notwithstanding that the area is well within the tropics, is, as Easton (42) points out, of a non-tropical character, the reason for this being the comparatively low rainfall. Easton describes the vegetation as consisting of savannahs and very lightly timbered forests which are devoid of undergrowth, in place of which grow succulent grasses and herbage (Easton, 42). The area comprises the low rainfall tropical woodlands (A1) of the extreme north, and the savannah forests and woodlands (C1) referred to in the chapter on the vegetation of the State.

Easton (42) remarks that the lines of demarcation between the various types of vegetation are very distinct, and are to a large extent governed by the geological nature of the country. Thus the basaltic country is almost invariably timbered with box and coolibah (*Eucalyptus microtheca*) and bloodwoods (*Eucalyptus pyrophora* and *terminalis*) are also fairly common. It carries fine grasses (see fig. 10). The sandstone country bears various timbers such as woollybutt (*Eucalyptus miniata*), messmate (*Eucalyptus tetrodonta*) and the cypress pine (*Callitris verrucosa*). The grasses of the sandstone areas are usually of a poor type, but the other small plants are of good feeding value, practically every plant being edible (see fig. 11).

Mangroves occur rather extensively in the estuaries.



Fig. 10.—Typical Basaltic Grassland, vicinity of Calder River, North Kimberley.

Over the greater portion of the area the rocks are mainly lava flows and massive sandstones, which are practically horizontal or but gently folded (Blatchford, *g*, 23) and apparently interbedded with one

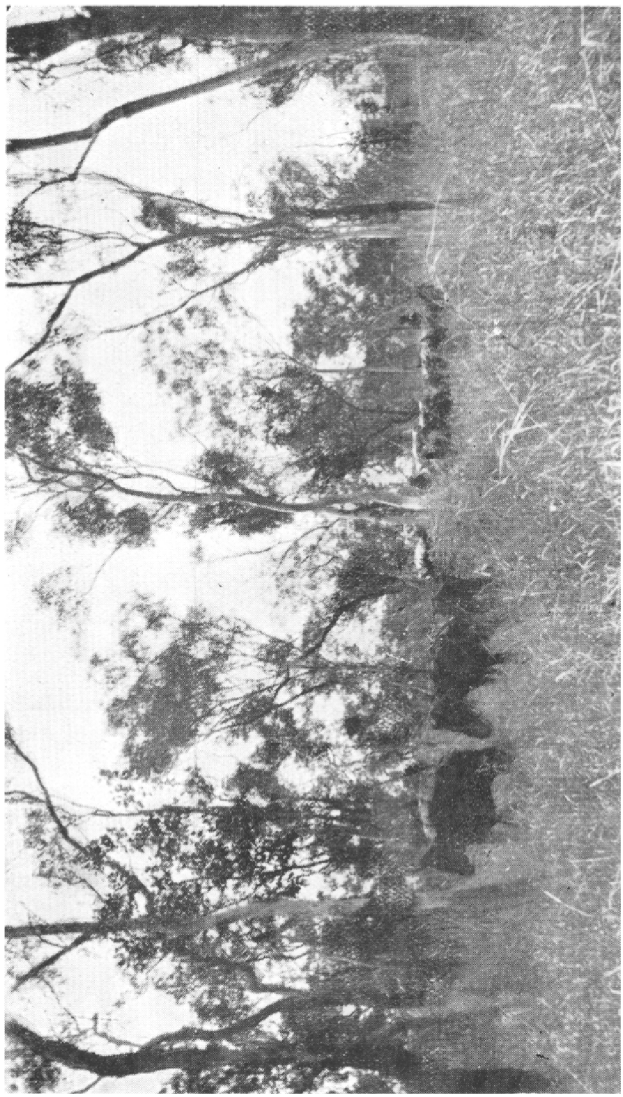


Fig. 11.—Typical Sandstone Tableland Country, North Kimberley.

another, although from Crossland's (Brockman and Crossland, 14) and Easton's descriptions, one gathers that the sandstone usually overlies the basalt. Maitland (*l*, 83) refers to volcanic breccias and lava flows

as occurring on the King Leopold Plateau. The age of the sedimentary and volcanic rocks is regarded as Nullagine.

On the eastern side of the area are two narrow parallel belts of different rocks. The westerly is granite, and the easterly is formed of old crystalline rocks of Pre-Cambrian age. A part of each of these belts is included in North Kimberley, and the remainder in Ordland.

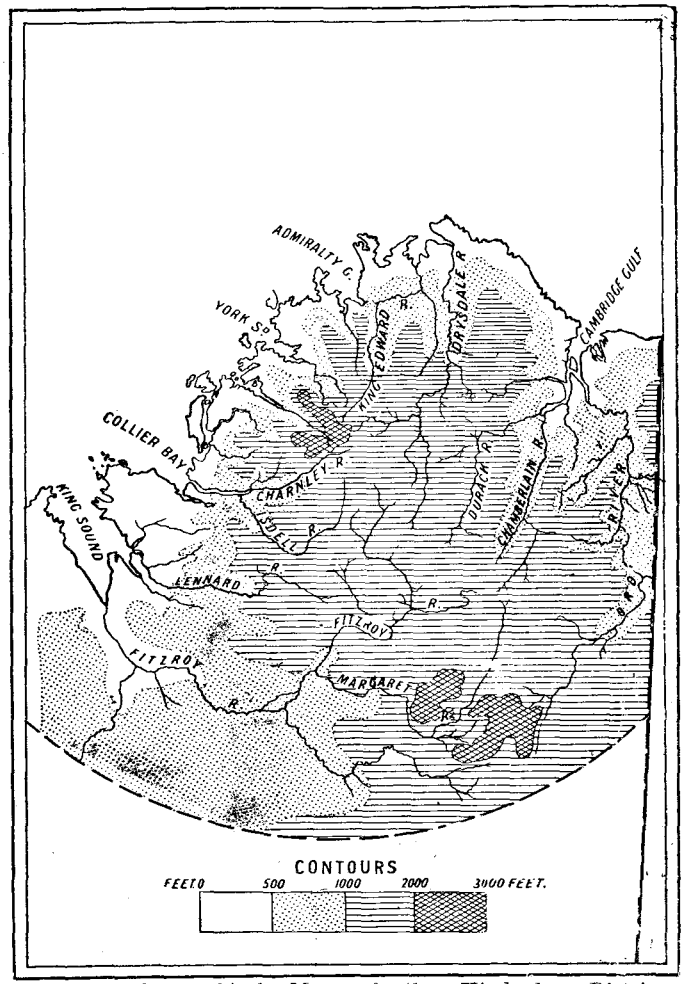


Fig. 12.—Orographical Map of the Kimberley District. (From McLintock's "The Swan Geography.")

CONTOUR.

The orographical map of Australia published in 1918 by the Commonwealth Meteorological Bureau indicates (fig. 12) that the greater

portion of North Kimberley is between the 1,000 and 2,000 feet contours. A small area including Mt. Hann* is shown as between 2,000 and 3,000 feet; and along the western and northern coasts there are narrow parallel areas of from 500 to 1,000 feet, and from sea-level to 500 feet. The 500 to 1,000 feet areas pass well up the valleys of the Chamberlain-Pentecost River and of one of its tributaries, the Salmond River.

The pronounced bending in places of the contour lines inland is due to the fact that they follow river valleys, which have been fairly deeply cut.

The orographical map referred to is admittedly very approximate, but nevertheless the main features are probably correct.

THE PLATEAU AND SCARPS.

North Kimberley is the remains of a plateau which is in course of vigorous dissection by a great number of streams, some of which are of considerable length. On the maps numerous "ranges" are marked such as the Princess May, Synnott, Artesian, Durack and Phillips. These are evidently merely the ridges between the river systems, and they would be better described as "ridges" or "plateaux" according to whether they are respectively narrow or broad in proportion to their length. (See Pl. V. and figs. 9 and 13.)

For the reasons stated when treating of the origin of the Great Plateau as a whole, the surface of the plateau of North Kimberley is regarded as a plain of erosion, which since its formation has been uplifted to its present height and then dissected to its present stage of erosion. The weight of evidence suggests that the surface of the plateau is an old peneplain, and it may, therefore, be termed the "North Kimberley Peneplain" or "North Kimberley Plateau," the latter term being non-committal in regard to its origin.

The general characters of the north-western (coastal) portions of the plateau have been well described by Basedow (240-243).

According to the recent investigations of Blatchford (*g*, 10, 12 and 23) and Wade (24 and 38) the plateau is probably part of a great horst, the south-western face of which is bounded by a great line of cliffs beyond the boundaries of North Kimberley as defined in this work. The line of cliffs forms a great fault scarp which is subsequently referred to as the "Napier-Geikie Fault Scarp."

The eastern boundary of the plateau cannot be definitely stated. The plateau probably passes into Ordland where it may terminate by a fault scarp or by a monoclinal fold, since the Ord Plateau appears to be considerably lower than the North Kimberley Plateau, and Blatchford (*g*, 11) refers to an extensive fault line which is traversed by the upper Ord River, which runs in a north-north-easterly direction, and

* Not shown on Fig. 12.

also (24) to a fault scarp which is apparently along the same line of fault. The writer has termed this scarp the "Ord Fault Scarp." At Mt. John it turns into a monoclinal fold.

The effect of differential erosion where no fault or monoclinal fold has been proved must not be overlooked, especially as the structure of much of Ordland is apparently more favourable to erosion than North Kimberley. Further investigation, however, is apparently required in connection with the fault scarp and its possible extension northwards.

So far no fault scarps have been recorded along or near the western or northern coasts of the plateau, and it would appear that the country gradually falls from the interior, thus tending to lose near the coasts its plateau character.

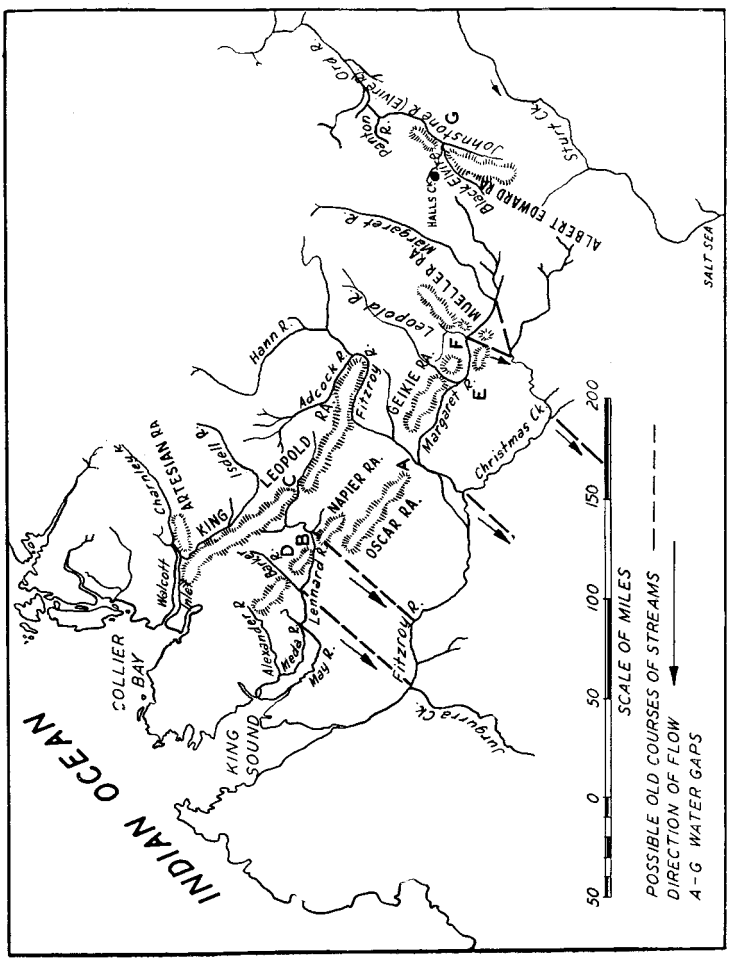


Fig. 13.—Outline Map of the chief rivers of Fitzroyland, together with adjacent ones in Ordland and North Kimberley, showing the possible old south-west flowing consequent streams, now broken up by subsequent streams, and also some of the numerous water gaps of the district.

A. Water Gap of the Fitzroy River. Geikie Canyon. B. Water Gap of the Lennard River. Devil's Pass.
C. Water Gap of the Lennard River. Bell Gorge. D. Water Gap of the Barker River. Napier Gorge.
E. Water Gap of the Margaret River. Krauss Gorge. F. Water Gap of the Margaret River. Mueller Gorge.
G. Water Gap of the Black Elvire River. Albert Edward Gorge.

The radial arrangement of the streams about Mt. Hann suggests that North Kimberley is mostly a flat dome or elevated conoplain (see fig. 9).

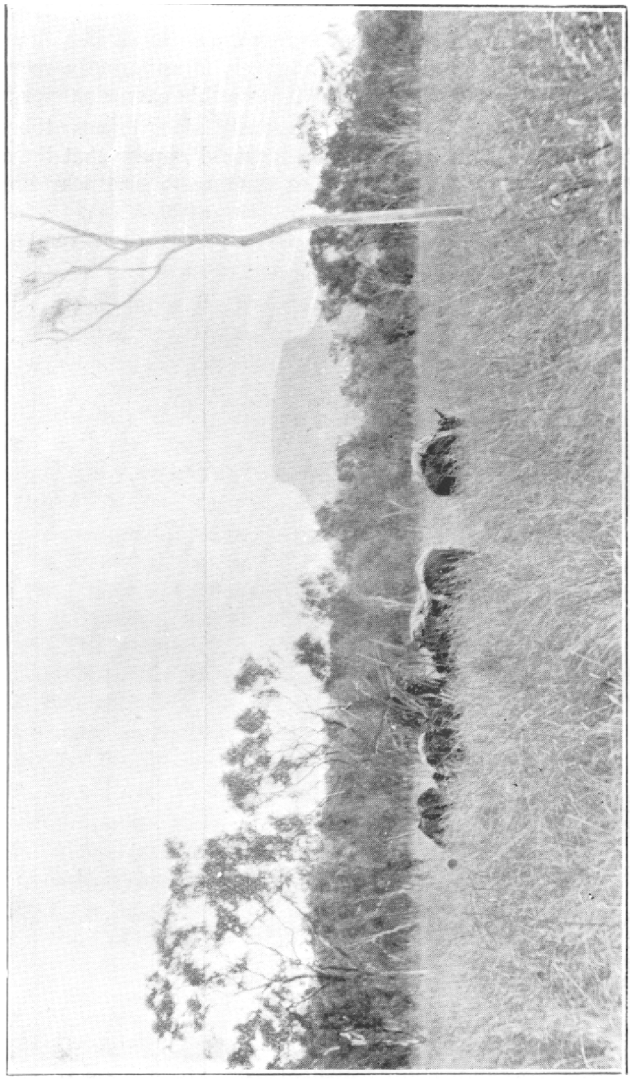


Fig. 14.—Mt. Hann, North Kimberley—A monadnock on the Great Plateau.

Low coastal plains are absent, as Easton has shown (25) that the harbours are mostly bordered by high, practically inaccessible cliffs.

The best known residual of the plateau is Mt. Hann (see fig. 14), which is an important landmark, as it is from its neighbourhood that

so many of the streams of the plateau radiate. According to Easton (6) Mt. Hann is 2,800 feet above sea-level and is 800 feet above "its base," that is, above the general level of the plateau. There must be many other monadnocks or residuals of erosion, such at Mt. Agnes, 2,300 feet above sea-level.

RIVERS.

The principal rivers of the division are the Charnley and Isdell; the Prince Regent; the King Edward; the Drysdale; the Durack; the Chamberlain-Pentecost and the Hann. (See Pl. V. and fig. 9.) The problems of the development of the rivers are discussed in the Part treating of the drainage systems of the State. Their principal characteristics may, however, be briefly stated here. They are:—Deep narrow gorges in the upper portions of most of the streams, with a widening of the valleys and the development of extensive alluvial plains, in their lower portions, but a maintenance throughout of the wall-like sides of the valleys, which as a whole indicate early maturity; a radial arrangement of all the main streams (except the Durack and Chamberlain-Pentecost Rivers) from about the neighbourhood of Mt. Hann; and a coincidence of direction probably of the two last named rivers with the strike of the rocks they traverse, the two rivers being probably longitudinal.

The basalt and sandstone of the division have favoured the development of the canyons which are such characteristic features. Most of the canyons are very rugged, and some are so inaccessible that long detours are necessary to reach certain parts of the country.

COAST LINE.

The coast line is an extremely broken one with many harbours and islands. Its character is due to a recent relative subsidence of the land by means of which the ends of the valleys, which had deeply dissected the country, were drowned. Since this positive displacement there has apparently been a slight negative displacement (elevation).

According to Easton (25) the harbours are in many places flanked by precipitous sandstone cliffs which rise hundreds of feet above sea-level. These cliffs render the harbours inaccessible from the land, and most of them are consequently useless as ports. Some of them are very deep and almost landlocked.

The harbours are rias and they form a wonderful scenic group, which collectively may be called the "Kimberley Sounds." Judging

by the photographs (figs. 15, 16, and 17) of some of these sounds, the latter are in some respects and on a small scale comparable with (but without suggesting, however, that they have been occupied by glaciers) the famous similar features in other parts of the world, the most notable of which are the Scottish sea lochs, the Norwegian fiords and

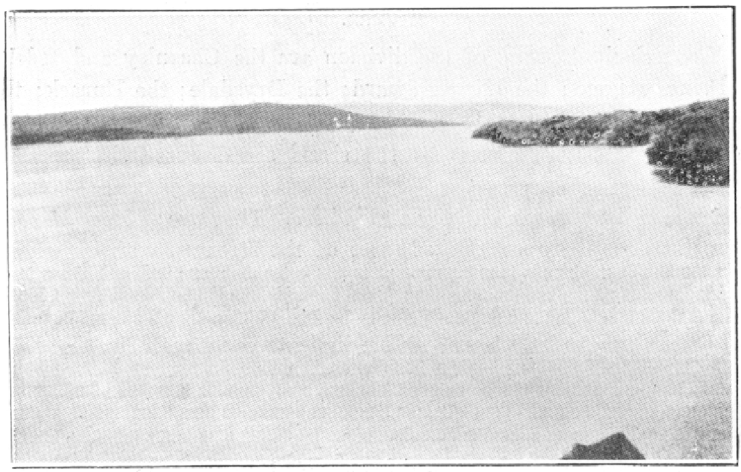


Fig. 15.—The mouth of the Prince Regent River, North Kimberley. The river valley has been "drowned."

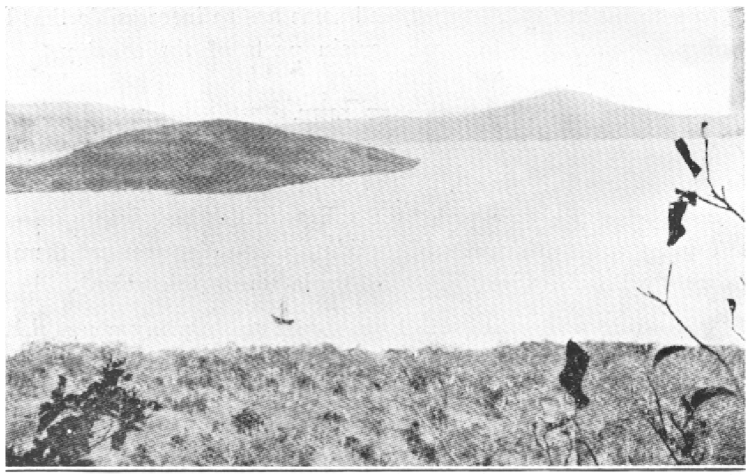


Fig. 16.—Rothsay Water, at the mouth of the Prince Regent River. North Kimberley. A "drowned" valley.

the sounds of the western coast of the south island of New Zealand. The scenic effect of the Kimberley sounds is marred to some extent by the occurrence of mangove swamps along the shores in places. Accu-

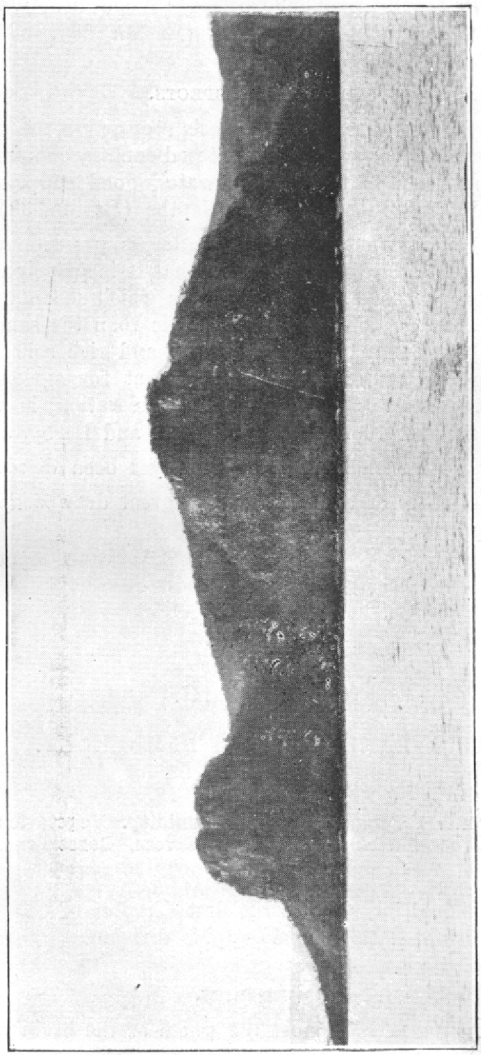


Fig. 17.—The high cliffed coast of Prince Frederick Harbour, North Kimberley. The rocks are probably horizontally bedded sandstones.

rate charts will be required in order to traverse safely the very broken coast.

One of the most remarkable features pertaining to the coast is the height of the tides. Thus at Walcott Inlet, near the junction of the

Charnley and Calder Rivers, the rise and fall of the tide is about 15 feet (Brockman and Crossland, 9); at King Sound (Derby), which is just beyond the boundaries of North Kimberley, it is 46 feet, and at Wyndham on Cambridge Gulf 20 feet (Woodward, *f*, 5); and at Prince Frederick Harbour it is 28 feet (Easton, 29).

ECONOMIC ASPECTS.

So far as known there is no artesian or sub-artesian water in North Kimberley, but in such a well-watered country this is of no consequence. In addition to the surface water, good supplies of water can be obtained from wells at shallow depths (Easton, 30).

Easton (7) states that North Kimberley is pre-eminently a pastoral country of high feeding value, and that it is principally suitable for cattle, although there are large areas on which sheep would thrive (32). The grasses are better on the basaltic than the sandstone soils (42 & 43). There are extensive river flats and rich soils, but at the time of writing (1921) Easton considered that for agricultural purposes the country was not worth serious consideration, in view of the rich and more accessible land near Wyndham and Derby.

Practically no minerals of value have yet been discovered.

The inaccessibility of the country is a great drawback to its commercial development.

CHAPTER III.

FITZROYLAND OR WEST KIMBERLEY.

CONTENTS.

Boundaries. Rainfall, Temperature and Humidity. Vegetation. Contour. General Characteristics and Geology. Rivers. Coast Line. Economic Aspects.

Reference should be made to the first Chapter of this Part in regard to the creation of this physiographic division.

BOUNDARIES.

The division comprises almost the whole of the basin of the Fitzroy River and its tributaries; and also the basins of the Lennard, May and Meda Rivers. Its north-western boundary is the King Leopold Range; its eastern boundary is the watershed between the Margaret River and the basin of the Ord River; its southern boundary is ill-defined, as it passes into the country to the south without any

distinct line of demarcation, but the boundary can be fixed by a line connecting the heads of all the southern tributaries (which, according to the maps, are few) of the Fitzroy River; its western boundary is the coast line extending approximately from a short distance south of King Sound to the south-east corner of Collier Bay. (See figs. 8 and 9.)

The area is largely the same as the natural region of Fitzroy (Clarke, *b*) which thus corresponds with a purely physical classification. Fitzroyland also corresponds with what has come to be known as "West Kimberley."

The comparatively narrow strip between the King Leopold Range and the Napier, Geikie, Oscar and Grant Ranges, is included in the division so as to bring within the latter as much as possible of the Fitzroy River basin. The country referred to is distinct from that of North Kimberley and also from that to the south-west. In some respects it would be preferable to include it in North Kimberley but, for the reasons stated, it is placed in Fitzroyland.

RAINFALL, TEMPERATURE, AND HUMIDITY.

The average annual rainfall is from 20 to 30 inches, almost all of which falls in summer.

The mean annual temperature is from 75° to 80° F. (see fig. 6). The humidity is probably moderately high at the coast, but decreases inland as the country rises.

VEGETATION.

The vegetation chiefly belongs to two main types, viz., that growing on the alluvial flats of the lower courses of the rivers, and that of the "pindan sands." The former areas are mainly grasslands, and the latter are covered by low sclerophyllous woodlands (C. A. Gardner in Clarke, *b*, 129), the savannah forests and woodlands (C1) referred to in the chapter on "Vegetation." Some details of the pindan sands vegetation according to Clapp and to Hobler have been noted below under the heading "General Characteristics and Geology."

The vegetation on the more elevated north-eastern belt consists of savannahs (C2) and savannah forests and woodlands (C1).

Mangroves occur along the coast.

CONTOUR.

The orographical map of the Commonwealth Weather Bureau (see fig. 12) shows that most of the Fitzroy basin is between the 500 and 1,000 feet contours. The northern portion, extending to the King Leo-

pold Range, is between the 1,000 and 2,000 feet contours, and small areas near the headwaters of the Margaret and Elvire Rivers are between 2,000 and 3,000 feet above sea-level.

GENERAL CHARACTERISTICS AND GEOLOGY.

The geology and topography of Fitzroyland are fairly well known, the country having been geologically examined by Hardman (*a* and *b*), Woodward (*c*), Jack (*a*), Blatchford (*g*), Wade and Clapp (*a*) some of whom have only recently traversed the area in consequence of the possibility of obtaining oil in payable quantities.

Judging by Blatchford's description (*g*, 10) that portion of Fitzroyland which lies to the south-west of the Napier, Geikie and other ranges, was originally a plateau, but lower than the North Kimberley Plateau and the country to the north-east of the ranges just referred to, through being downfaulted along the southern side of those ranges. The Fitzroy Plateau (for so it may be referred to) has, however, suffered more erosion than the North Kimberley Plateau, for the plateau character is now indicated over its greater portion only by scattered ridges and hills, the tops of which are the remnants of the original plateau.

The southern portion of the area is occupied by extensive alluvial plains formed by the Fitzroy River and its tributaries, and by what are known as "pindan sands," which are described by Clapp (*a*, 64) as consisting of "level to gently rising unconsolidated sands, often rising to several hundred feet above sea-level at distances from the coast, and in general sloping upwards against older formations." They are, he states, generally covered with a thick growth of shrubs or low trees of many varieties known collectively as "pindan." Hobler (5) also notes that above the alluvial plains and flood level of the rivers is higher country ("pindan country") which carries good grass, "buck" and soft spinifex, bluebush, etc., as well as some stunted gums, bloodwood and large bushes.

Towards the north of the division are some prominent ridges such, for example, as the Napier, Geikie, Oscar and Rough Ranges, which follow the general north-west trend of the division, and which, as Blatchford (*g*, 22) states, lie on the northern or north-eastern rim of the Fitzroy basin. In the east, another group of ridges occur, comprising the Mueller, Lubbock and Ramsay Ranges.

Monadnocks or residuals of the previous cycle of erosion doubtless occur, but the writer has no knowledge of any record of same.

An interesting group of hills occurring in the basin of the Fitzroy and near the river itself has been described by Blatchford (*g*, 20 and 21) and marked on his geological map of Kimberley. They are formed of leucitite which has pushed through the Upper Carboniferous strata in the form of volcanic necks. They now form isolated knolls of

different shape from that of the sandstone hills amongst which they stand, the top being more pointed and their form such that they are usually distinguishable even at a distance (fig. 18). One of the best known is Machell's Pyramid, north of the Fitzroy River, which forms a conspicuous landmark for miles around.

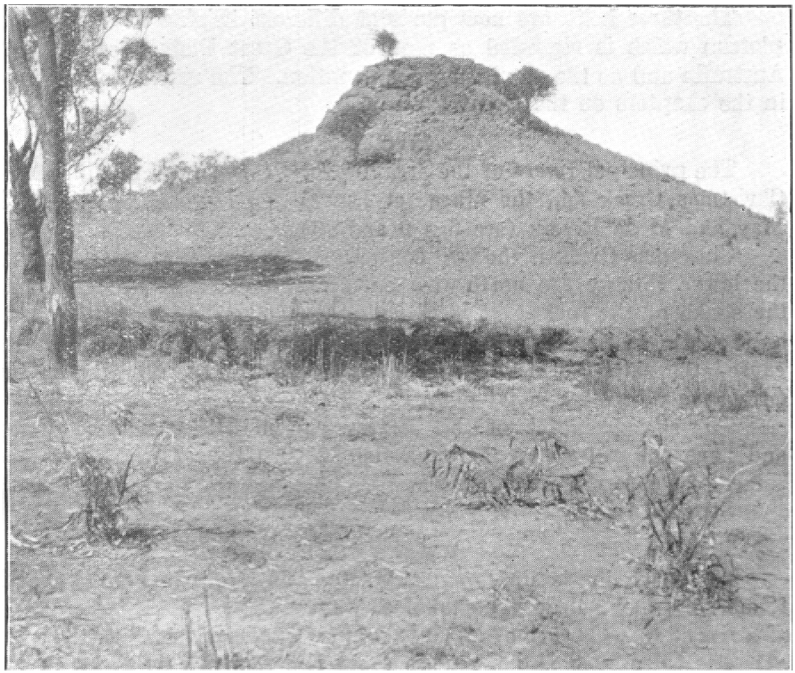


Fig. 18.—Leucitite volcanic neck, Christmas Creek, Fitzroyland. The leucitite is more resistant to erosion than the strata through which it has passed; hence it projects well above the surrounding country.

There are three main rock groups which have left their impress on the topography. Along the north-eastern boundary there is a comparatively narrow belt of ancient Pre-Cambrian crystalline rocks abutting on the north-east, the King Leopold Range. This belt is apparently a fair height above sea-level, and is not much traversed by streams.

The second belt comprises the Napier, Oscar, Geikie and Rough Ranges, and is composed mainly of massive Lower Carboniferous limestones which are bounded on their south-western side by a fault scarp (which, as Blatchford has given no name for it, may be termed the "Napier-Geikie Fault Scarp"); but on the north the slope to the first belt is gentle (Blatchford, *g*, 22).

The third belt, lying to the south-west of the limestone ridges just referred to, is by far the most extensive. The rocks are Upper Carboniferous sediments (limestones, shales, grits and sandstones), the strike of which is about north-west. It is to this belt that Blatchford's description of a relatively low-lying area, with scattered ridges and hills, particularly applies. The belt forms the basin of the lower Fitzroy River and of Christmas Creek.

The three belts are now parts at different heights of a dissected plateau which is regarded as part of the Great Plateau of Western Australia and as the result of peneplanation. The matter is discussed in the chapters on the Great Plateau.

RIVERS.

The principal rivers of the area are the Fitzroy and its tributaries, Christmas Creek and the Margaret River; and the Barker, Lennard, May and Meda Rivers (see figs 9 and 13).

Christmas Creek is the real continuation of the Fitzroy, and it and the lower Fitzroy are north-west flowing and parallel in direction to the strike of the rocks. It is probably the latter fact, aided perhaps by the comparative softness of the rocks and the low altitude, that has caused the extensive denudation already referred to, resulting in the formation of wide alluvial plains.

The streams north of the Fitzroy run mostly across the strike, and have cut water gaps through the Lower Carboniferous limestone ridges of the second belt of rocks.

Streams from the south are few and mostly insignificant.

COAST LINE.

The coast line is similar in character and origin to that of North Kimberley, being deeply indented and with many islands, as a result of a recent submergence of an early maturely dissected area (see fig. 9).

The tides have also the same great rise and fall as noted in the chapter on North Kimberley.

ECONOMIC ASPECTS.

Fitzroyland carries artesian water, the artesian area being part of the Desert Basin (see Maitland, *k*, 86, and fig. 29, p. 85, and fig. 19 of this work). The area as a whole is well watered, especially to the north of the Fitzroy River, and good well water can be obtained at shallow depths.

No minerals of economic value have been found in payable quantities in the area. The minerals which have been recorded, such as the ores of copper and lead, occur within the belt of old crystalline rocks in the north of the area.

Petroleum has been found in the division, although not yet in sufficient quantity to be of commercial value. The ground, however, is still being tested.

The alluvial plains have rich deep soils, which may later be used for agriculture. The district as a whole is well suited for cattle raising, the natural pastures being valuable for this purpose.

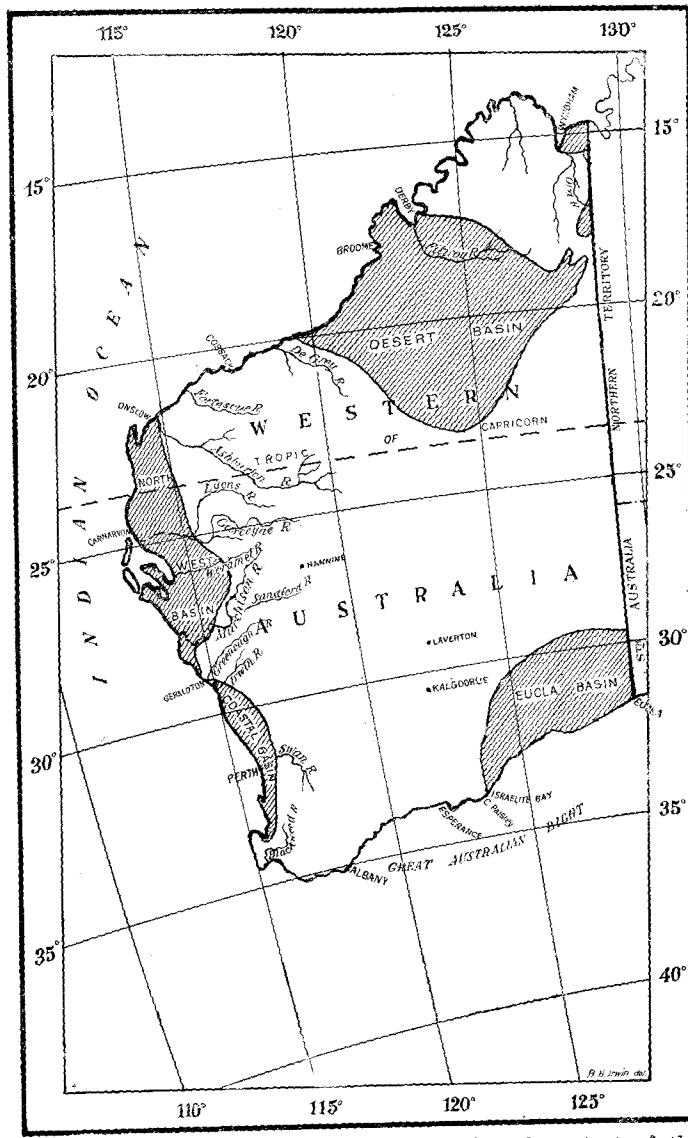


Fig. 19.—Map of Western Australia, showing the extent of the known Artesian Basins.

CHAPTER IV.

ORDLAND OR EAST KIMBERLEY.

CONTENTS.

Boundaries. Rainfall. Temperature and Humidity. Vegetation. Geology. Contour. The Plateaux and Scarps. Rivers. Coast Line. Economic Aspects.

Reference should be made to the first chapter of this Part in regard to the creation of this physiographic division.

BOUNDARIES.

The division is small and may be defined as chiefly the basin of the Ord River without, however, in every case including the whole of its tributaries, as some of the latter rise, according to Blatchford (*g*, 11) on the eastern flank of North Kimberley. Blatchford includes Ordland with the greater part of Fitroyland in his account of the physiography of Kimberley, but as there are considerable physical differences between the two areas, it has been deemed advisable to separate them. The division corresponds roughly with the Antrim natural region of Clarke (*b*, 130 and map), but "Ordland" has been adopted as its name in preference to "Antrim" for the reasons stated in the first chapter of this Part.

The boundaries of the division are sufficiently indicated by the map (figs. 8 and 9), and by the fact that the division is practically coincident with the basin of the Ord River and the basin of Sturt Creek to its junction with its tributary, Wolf Creek, at which point the change to the desert of Sandland begins to take place. (See Carnegie, 361-362.)

RAINFALL.

The average annual rainfall shows a variation of from 15 to 20 inches in the south to over 30 inches in the north, the isohyets bending to the north in a rather remarkable manner (see fig. 3). The rainfall is, as throughout North Kimberley and Fitzroyland, of the summer monsoonal type.

TEMPERATURE AND HUMIDITY.

The mean annual temperature of the division is between 75° and 80° F. in the southern portion, and over 80° F. in the northern. The humidity is moderately high at the coast, but decreases inland as would be expected.

VEGETATION.

The vegetation in regard to timber is usually stunted except along the river courses (Blatchford, *g*, 10). The alluvial plains are well grassed, and the country as a whole is well suited for pastoral purposes (see fig. 20).

In the north the vegetation belongs to the savannah forests and woodlands, and in the south to the savannah type (C1 and C2 of the divisions referred to in the chapter on the vegetation of the State).



Fig. 20.—Black Soil Plains of the lower Ord River valley, Ordland.

GEOLOGY.

The rocks of the area vary much in character, and by them alone a physiographic unit would be precluded. In the south-east (the Antrim Plateau) and in the central-east there are large patches of basalt; in the south the rocks are Nullagine and Cambrian sediments (limestones, sandstones, mudstones and shales). Farther north, Pre-Cambrian crystalline rocks occur, as also a belt of Pre-Cambrian metamorphic rocks.

The boundaries of the rock formations may be seen on the geological map (Pl. II.).

The geological structure of the country has influenced river development as shown when treating of the drainage systems of the division.

CONTOUR.

The general elevation of Ordland is considerably lower than that of North Kimberley, and is akin to the greater part of Fitzroyland in this respect.

The Commonwealth Weather Bureau's map (see fig. 12) shows that most of the basin of the Ord River is between the 500 and 1,000 feet contours, and that the Antrim Plateau and the country at the head of the Ord River basin are between the 1,000 and 2,000 feet contours.

THE PLATEAUX AND SCARPS.

A good deal of information bearing on the physical geography of the division is available in Hardman's report (*b*).

Ordland is similar to the greater part of Fitzroyland in that there has apparently been a comparatively low plateau (which may be termed the Ord Plateau) which has been so eroded that its character has been largely obliterated. The surface of the plateau is the tops of the scattered hills and ridges which rise from the low-lying country.

The agents of erosion have been the Ord River and its tributaries, along the courses of which, as the result of that erosion, extensive alluvial plains in the northern portion have been developed. In the south the country is less dissected, and canyons exist.

The Antrim Plateau in the south-east appears to constitute a separate and distinct feature from the remainder of the division. Clarke (*b*, 130) describes the belt as open "downs," and states that the component rocks "tend to wear away into great open rolling expanses above which rise a few buttes and small mesas like Mt. Panton.

The Ord Plateau is regarded by the writer as part of the Great Plateau of Western Australia.

Monadnocks or residuals of erosion doubtless occur, but there are no records.

In the southern portion of the division is the fault-scarp, noted by Blatchford (*g*, 24) which runs northwards from east of Hall's Creek township towards Mt. John, and which may be termed the "Ord Fault Scarp." At Mt. John it turns into a monoclinal fold.

RIVERS.

The Ord is the main stream, and its principal tributaries are the Denham, Bow, Panton, Elvire, Nicholson, Negri, and Benn Rivers.

The valley of the lower Ord River is subject to extensive floods in the wet season, the country being often inundated for miles (Blatchford, *g*, 11).

Sturt Creek is independent of the Ord River, and flows in the reverse direction into Gregory's Salt Sea.

The river systems are further described in the chapter on the rivers of Ordland.

COAST LINE.

The coast line is typified by Cambridge Gulf representing the drowning of the ends of valleys, and is akin to that of North Kimberley. Similarly, there is also the great fall and rise of the tide.

ECONOMIC ASPECTS.

An artesian basin, known as the Gulf Basin (see fig. 19), occurs on the eastern side and at the mouth of the Ord River at Cambridge Gulf. The basin extends into North Australia. The component rocks are of Nullagine age.

Minerals in payable quantities are practically unknown. Gold was first discovered in Western Australia in the "eighties" near Hall's Creek, but the field has not been productive.

Petroleum has been prospected for in the southern portion of the division, but so far without satisfactory results from a commercial standpoint.

The alluvial plains of the north are used for pastoral purposes.

CHAPTER V.

PILBARALAND.

CONTENTS.

Boundaries. Rainfall. Temperature and Humidity. Vegetation. Geology. Contour. The Plateaux and Scarps. Rivers. Coast Line. Economic Aspects.

Reference should be made to the introductory chapter of this Part in regard to the creation of this physiographic division.

BOUNDARIES.

Pilbaraland is named from the portion north of the Forteseue River where the Pilbara and West Pilbara goldfields occur. The

division comprises the basin of the Ashburton River, and the whole of the river basins to the north as far as and including that of the De Grey-Ridley River. It is bounded on the west by the coast, and on the east by a line joining the sources of all the included rivers. As here defined, Pilbaraland corresponds to some extent with Griffith Taylor's "Pilbara" (*b*, 2, map, and 18).

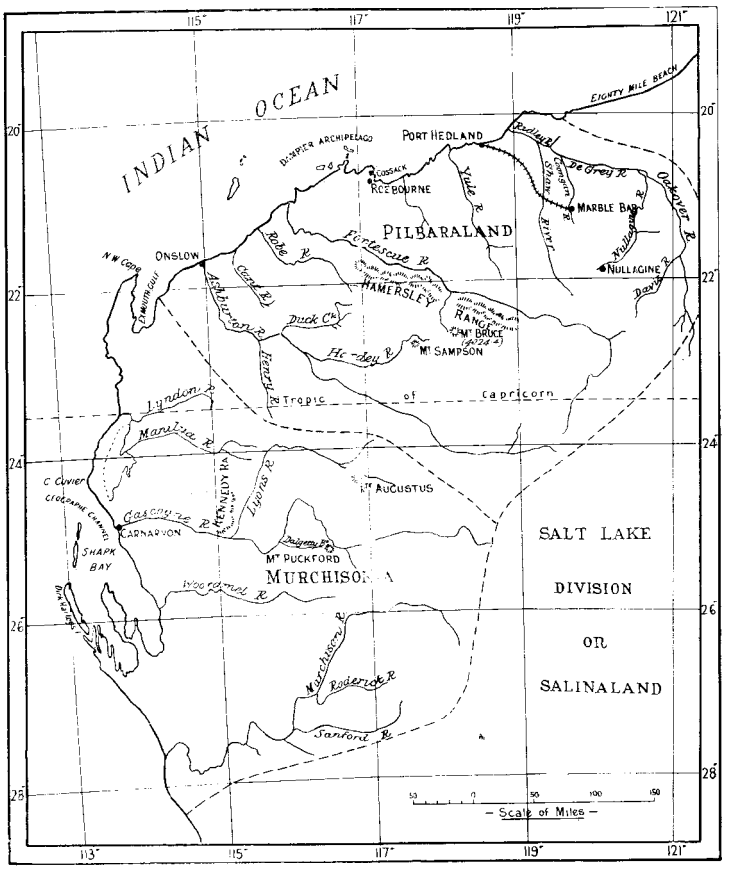


Fig. 21.—Outline Map of the North-West District, showing the two physiographic divisions of Pilbaraland and Murchisonia.

Pilbaraland is also included in Clarke's North-West natural region (Clarke, *b*, Pl. XV., and 127), but that region includes an area of interior drainage with an absence of defined river courses. Such area is therefore excluded from the division now described (See figs. 8 and 21).

RAINFALL.

The average annual rainfall for the lower Ashburton River basin, and for the basins of the Fortescue and of all rivers to the north, is from 10 to 15 inches. The upper Ashburton River is within the 10-inch belt.

Enormous quantities of rain are often precipitated in a single fall. In this connection reference may be made to the table under "Rainfall" in the Part on Climate. Such falls immensely facilitate erosion. The cyclonic storms which in summer may devastate the coast have also been described under the same heading.

TEMPERATURE AND HUMIDITY.

The mean annual temperature is between 75° and 80° F. (fig. 6). Marble Bar has the greatest number of consecutive days with the shade temperature over 100° F., in Australia. Near the coast the humidity is very great.

VEGETATION.

The vegetation is mainly spinifex and associated plants, the spinifex being largely of the soft variety. Shrubs and trees are comparatively scarce (Clarke, *b*, 127), a fact which influences the erosion of the country and the quantity of water available as surface supplies.

On the vegetation map published in Bulletin 42 of the Forests Department of Western Australia, the vegetation over the greater part of the country is classified as savannah (C2 of the table given in the Part in this work on the vegetation of the State), with a small area in the west classified as mulga (C3). The savannah vegetation is that described above, and the mulga is a scrub of acacias from 10 to 15 feet high. (See Pl. I.)

GEOLOGY.

The rocks of Pilbaraland (see geological map, Pl. II.), are, with the exception of a narrow fringe of rocks of Jurassic and Tertiary age, all very ancient. The chief groups of interest from a physiographic standpoint are: (1) Granite, (2) Greenstones, (3) The rocks of the Nullagine Series, and (4) The rocks of the Ashburton Beds.

Granite and greenstone are associated, but the granite occupies wide, and the greenstone fairly restricted areas. They are freely developed to the north of the Fortescue River, and to a less extent south of the headwaters of the latter river and along the lower course of the Ashburton River. They are regarded as of Archaeozoic age (Maitland, *k*, 14).

The Nullagine Series occupies much ground north and south of the Fortescue River. The component rocks are younger than the granite

and greenstone, and north of the Fortescue River they rest unconformably upon strata known as the Mosquito Creek beds. In the Ashburton River district the Nullagine Beds also rest unconformably upon the Ashburton beds (Maitland, *k*, 22) which are now tentatively placed with the Mosquito Creek Series.

The Nullagine Series (of Proterozoic age) consists of sandstones, quartzites, conglomerates and dolomitic limestones, together with interbedded lavas, ashes and agglomerates. The strata are, as a rule, practically horizontal; but they are in places arranged in a series of broad anticlinal folds. Dolerite intrusions in the form of dykes and sills also occur which may form prominent features in the landscape.

The Ashburton Beds extensively outcrop along the valley of the Ashburton River and its tributaries. Maitland (*k*, 19) states that they consist mainly of quartzites, micaceous slates and conglomerates, which have been folded and contorted, and which have been invaded by granitic rocks. The Ashburton Beds are also considered to be Proterozoic (Maitland, *k*, 14), although much older than the Nullagine Series.

CONTOUR.

The division forms a dissected plateau and comprises the highest land in the State, in the vicinity of Mt. Bruce (4,024 feet), between the Fortescue and Ashburton Rivers. The orographical map, published by the Commonwealth Weather Bureau (fig. 22) shows that there is mostly a steady rise from the coast to the highest area, and that thence the country falls away steadily inland, that is, to the east and south.

The plateau therefore forms a vast flat dome or conoplain, with, however, some tectonic breaks, as will be shown below.

THE PLATEAUX AND SCARPS.

Pilbaraland is a dissected plateau as stated above. It is an old plain of erosion which has been uplifted, and during the present cycle of erosion dissected by stream action.

Many of the "Mounts" shown on the maps (such as Mt. Bruce and Mt. Vigors) are no doubt monadnocks or residuals of the previous cycle of erosion, and thus stand above the general level of the plateau. The information at present available is too scanty to state what is the highest point of the actual plateau (that is, omitting the monadnocks), but it is probably over 3,000 feet above sea-level.

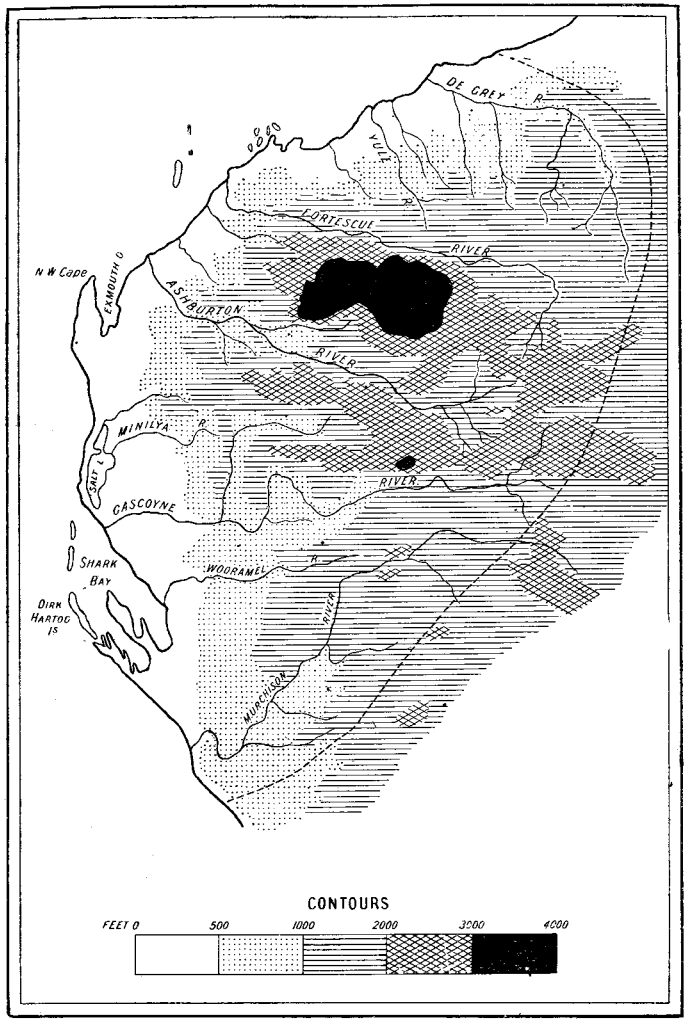


Fig. 22.—Orographical Map of Pilbaraland and Murchisonia. (From. McLintock's "The Swan Geography.")

The degree of dissection of the plateau naturally varies. In the lower portions of the main streams extensive alluvial plains have been developed, but higher upstream the topography may be described as mature or early mature. Taken as a whole, the degree of dissection is such that the original character of the country as a plateau is not at all masked. It is a high belt traversed by streams with deep valleys, many of which are, in places, canyons.

The plateau is part of the Great Plateau of Western Australia, and as it is considered to be (for reasons stated in the discussion of the origin of the Great Plateau as a whole) an uplifted peneplain, it may be referred to as the "Pilbara Plateau or Peneplain" Various portions of the plateau bear different names, as appear below.

The plateau in places has been block-faulted, especially in the area between the upper Fortescue and the upper Ashburton Rivers. (See figs. 21, 23, 24, and 25.) The writer in the first edition of this work suggested that the northern scarp of the Hamersley Plateau facing the Fortescue River valley was a fault scarp, and that farther north were two more north-facing scarps, the West Pilbara and Coastal Scarps, which, he suggested, might be fault scarps and indicate step-faulting towards the coast. Since then no further knowledge has been obtained regarding the two last-named scarps, but the eastern portion of the Hamersley scarp, as a fault scarp, has been confirmed by Talbot (*d,* Pls. II., X. and XIII.), to whose splendid work we owe so much of the recent additions to our knowledge of the geology and topography of Western Australia.*

Talbot (*d* and *e,* and *d,* Pl. II.) has shown that the great high area bounded by the westward-flowing Fortescue and Ashburton Rivers on the north and south respectively, and by the upper Hardey River and the north-flowing branch of the Fortescue River on the west and east respectively, has been much block-faulted.

In the area referred to, that portion of the Pilbara Plateau, which Talbot has named the Hamersley-Ophthalmia Plateau, occurs. Commencing on the south side of the Fortescue River, opposite the Coodiadarri Hills, it is bounded on the north by the eastern end of the Hamersley Scarp, and on the south by the scarp of the so-called Ophthalmia Range, which may be termed the Ophthalmia Scarp. On the east the plateau has not been traced, but it may pass into the lower country without any faulting; on the west the plateau has not actually

* The western portion of the Hamersley Scarp will doubtless be found to be a fault scarp, as it is in continuation of the eastern portion.

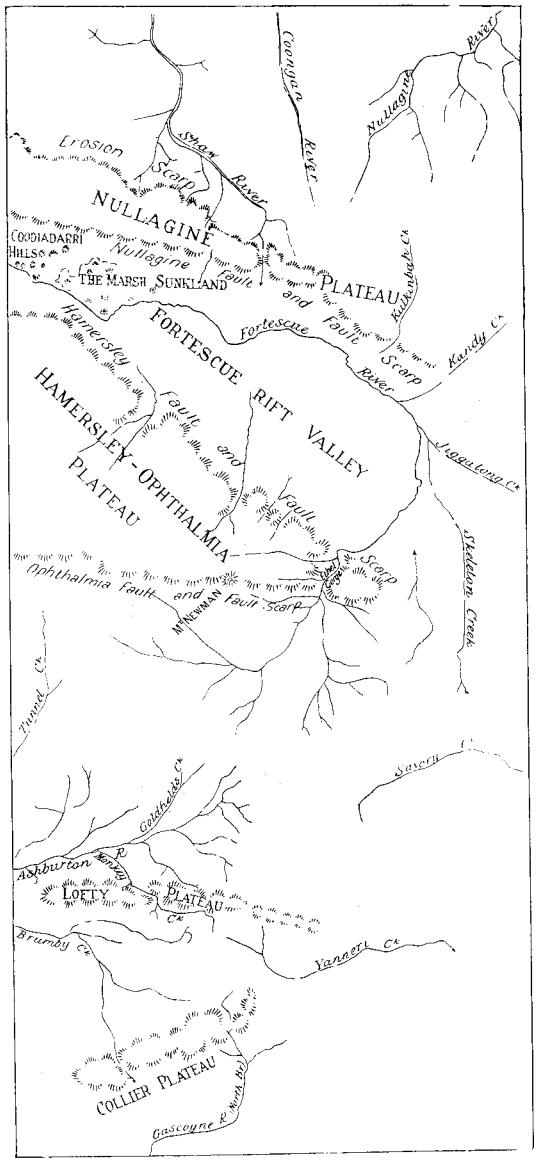
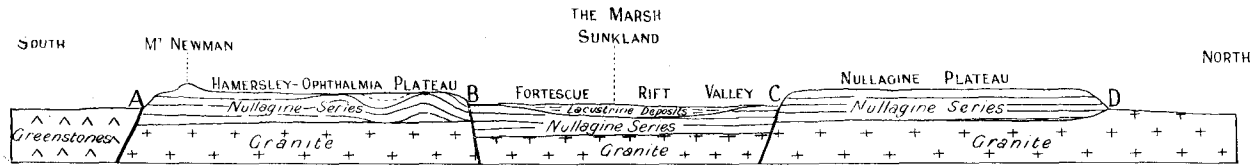


Fig. 23.—Map of the south-eastern portion of Pilbaraland, showing the Hamersley and Nullagine Fault Scarps forming the boundaries of the rift valley of the Fortescue River, with the Marsh Sunkland on the floor of the valley; also the Nullagine Plateau, the western portion of which is bounded on the north by an erosion scarp between the Nullagine rocks on the south and the granite on the north; also the Hamersley-Ophthalmia Plateau, bounded on the north-east by the Hamersley Fault Scarp, and on the south by the Ophthalmia Fault Scarp; and also the Lofty and Collier Plateaux, which are bounded by erosion scarps. Note how the north-flowing rivers cut far back towards the Nullagine Fault Scarp. (Adapted from Frontispiece, Bull. 83, G.S.W.A., Talbot.)



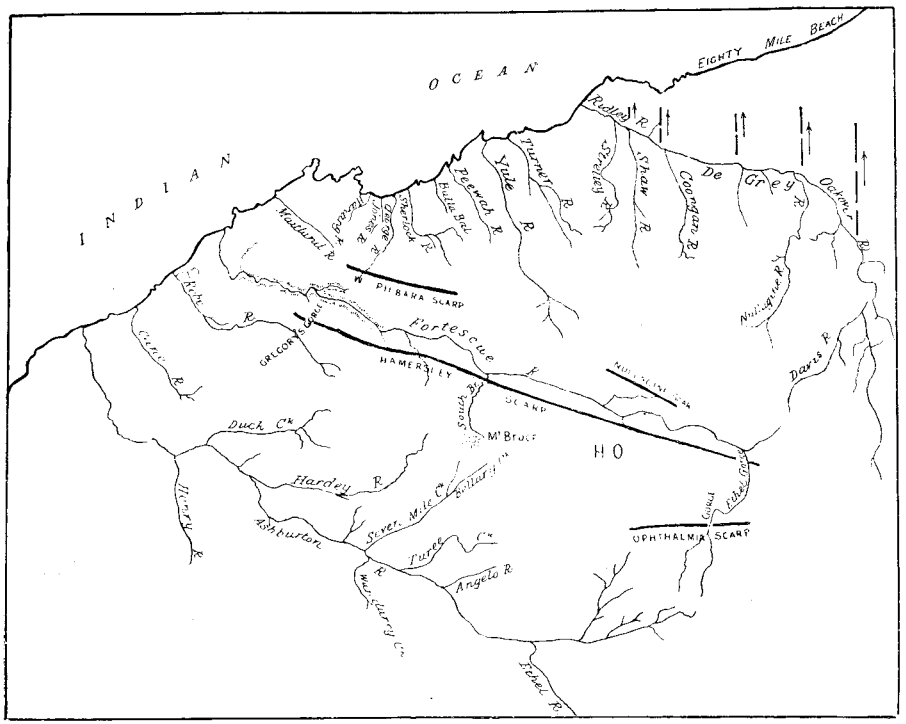
A Ophthalmia Fault and Fault Scarp

B Hamersley Fault and Fault Scarp

C Nullagine Fault and Fault Scarp

D Erosion Scarp

Fig. 24.—Generalized section north from the vicinity of Mt. Newman across the Hamersley-Ophthalmia Plateau, the Fortescue Rift Valley and the Marsh Sunkland, the Nullagine Plateau, and the granite plains to the north; and also showing the Ophthalmia, Hamersley and Nullagine Fault Scarps, with an erosion scarp. (Based on Talbot, Bull. 83, G.S.W.A., Pls. X. and XIII., omitting certain details.)



Scarps (mostly fault). Possible old courses of streams.

Direction of flow. H.O.: Hamersley Ophthalmia Plateau.

Fig. 25.—Map showing the parallel courses of the Ashburton, the Fortescue and the De Grey-Ridley Rivers, and suggesting the originally independent character of the principal affluents of the De Grey River. The Nullagine, Hamersley and Ophthalmia Fault Scarps, and the West Pilbara Scarp (possibly a fault scarp) are also shown; the two first named scarps indicate that the Fortescue River is in part a rift valley.

been traced, but there is another great scarp extending eastwards from Mt. Samson in a line with the so-called Ophthalmia Range. The Hamersley Scarp continues westwards to the north of Mt. Samson, so that there is little doubt that the Hamersley-Ophthalmia Plateau continues westwards as far as Mt. Samson. It is therefore proposed to apply the term "Hamersley-Ophthalmia Plateau" to the whole of this area. It is highly probable that it extends farther west so as to embrace the country in which Mts. Margaret, McRae and Brockman occur.

As the Hamersley Scarp is a fault scarp, it may be termed the "Hamersley Fault Scarp," and as the Ophthalmia Scarp is also a fault scarp (Talbot, *d*, 47), it may be termed the "Ophthalmia Fault Scarp."

The Hamersley-Ophthalmia Plateau is breached by the Ethel Gorge, in which runs the north-flowing branch of the Fortescue River; and is otherwise well dissected. (See fig. 26.)

North of the Fortescue River, Talbot (*d*, 47) notes another plateau which he terms the "Northern Plateau." It extends northwards between the Coongan and Nullagine Rivers, and it also occupies practically the whole of the Oakover River basin. The plateau has been trenched by steep-sided valleys indicating early maturity. The present writer suggests that as the term "Northern" is too vague, the plateau be named the "Nullagine Plateau," which includes in its southern portion the so-called Chichester Ranges. The plateau is bounded on the south by a low escarpment, which runs east-south-easterly, immediately to the north of and parallel to the Fortescue River. Talbot's map (*d*, Pl. II.) shows the escarpment to be a fault scarp, and as it has not been named by him, it may be termed the Nullagine Fault Scarp. On the north there is a more or less east-south-east trending escarpment formed at the junction of the granite with the more elevated Nullagine Series (fig. 24). The escarpment is evidently due to the differential erosion. There is no information as to the termination of the plateau in other directions.

Nearly all the streams on the Hamersley-Ophthalmia and Nullagine Plateaux flow northwards (Talbot, *d*, 47). Although not stated by Talbot this fact indicates that these two fault blocks have been tilted to the north, which also explains why the streams are so few and short on the southern flanks of the respective plateaux.

The Fortescue River at and to the east of the Coodiadarri Hills has, according to Talbot (*d*, Pls. II. and XIII.) fault scarps on each

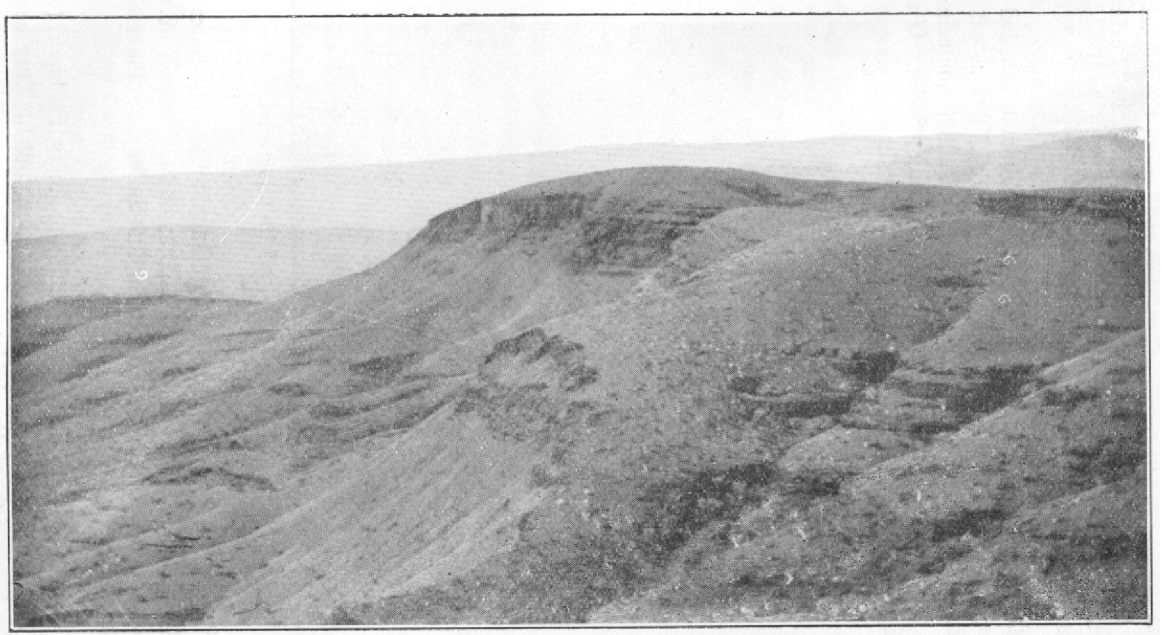


Fig. 26.—General View of the Hamersley Range, Pilbaraland, showing the "range" to be a plateau in the course of dissection.

of its valley sides (figs. 23 and 24). The river therefore in this portion of its course runs in a rift valley, thus confirming the suggestion of the writer, in the first edition of this work, that the Fortescue River ran along a fault line. The Fortescue Rift Valley, as it may be termed, is dealt with more fully in Part VII., Chapter IV.

Another dissected plateau—irregularly shaped, and bounded by fault scarps—has been described by Talbot (*e*, 25 and 26) as extending westwards across the Turee and Seven Mile Creeks (tributaries of the right bank of the Ashburton River) to the Hardey River. It may be named the "Turee Plateau" (fig. 27), and is perhaps a westward-

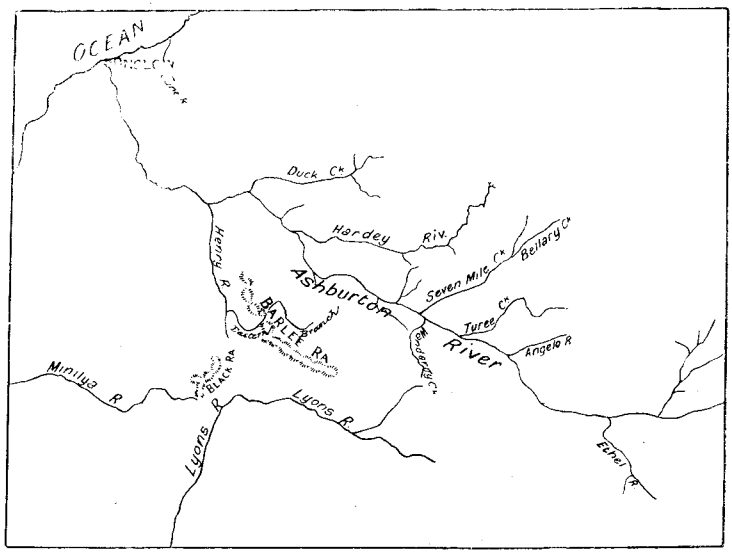


Fig. 27.—The Ashburton River and its tributaries.

trending "peninsula" of the Hamersley-Ophthalmia Plateau. Some of the scarps bounding the plateau, such as those at the junction of the Ashburton Beds with the overlying Nullagine Series, are suggestive of erosion scarps.

Two further plateaux, the Collier and the Lofty Plateaux (fig. 23), have also been described by Talbot (*d*, 42 and 46). They occur between the headwaters of the Ashburton and Gascoyne Rivers. The Collier Plateau is the more northerly one, and is a narrow, east-north-east-trending belt, between 2,500 and 2,750 feet above sea-level (*d*, Pl.

I.) with a steep escarpment to the south, to the east and to the north. It is capped by quartzite, which is a surface feature only. The Lofty Plateau is a narrow east-trending area similar to the Collier Plateau, but between 2,000 and 2,250 feet in height (*d*, Pl. I.). It has been cut through by Monkey Creek, a southern tributary of the Ashburton River. Both plateaux appear to be entirely due to erosion.

As investigation proceeds, further subdivision of the Pilbara Plateau will doubtless be necessary, and probably more block-faulting will be discovered.

The plateaux described above south of the Fortescue River are formed of Nullagine sedimentary rocks. The Nullagine Plateau consists also mainly of rocks of the same series, but lava flows as well as sediments outcrop. Talbot (*d*, 46 and 49) notes that where the strata are horizontal or nearly so, flat-topped tablelands occur, but where folds occur, the hills and ridges are rounded.

North of the Fortescue River the granite, which occupies large areas, has been reduced in many places to a plain, above which rise some scattered hills of the same rock and also ridges of dolerite, which are intrusive into the granite as dykes, and some of which outcrop for considerable distances, such, for instance, as the ridge which extends from the Western Shaw River northwards for 34 miles, its northern limit not being then reached (Talbot, *d*, 131-132). Water gaps frequently traverse these dykes.

The granite, however, has not everywhere been reduced almost to a plain. The country forming the divide between the branches of the Nullagine River and those of the Davis River to the east is described by Talbot (*d*, 134) as a mass of broken rocky hills of granite.

RIVERS.

The principal rivers are the Fortescue and the Ashburton (which are amongst the longest in the State) in the southern portion; and the Yule, Shaw, Coongan, De Grey-Ridley and Oakover in the north (fig. 25). In the lower courses of the larger rivers, such as the Ashburton and the Fortescue, and their principal tributaries, the streams meander through extensive flood plains, whereas in their upper portions they have only reached maturity or early maturity, and in many places traverse gorges. During the dry season the river beds may become

dry or contain but a chain of pools. A marked feature of the north-flowing streams is the number of water gaps they pass through (fig. 28.)

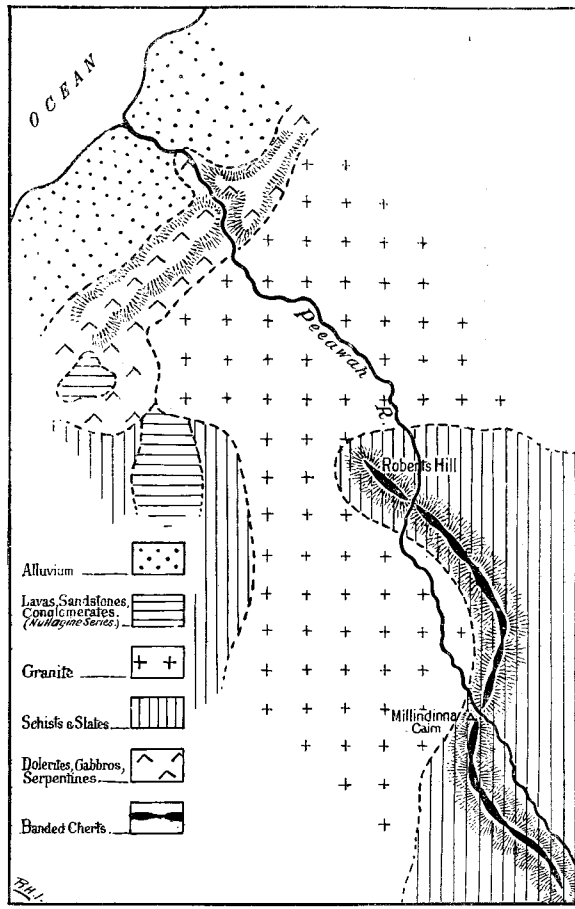


Fig. 28.—Plan showing the two water-gaps through banded cherts, and another gap through gabbroid rocks of the Peeawah River, Pilbaraland. (From Woodward's geological map, Bulletin 41, G.S.W.A., Pl. I.)

COAST LINE.

The coast line is a more or less broken one with an abundance of islands. Its contour suggests recent submergence, but if that has taken place the result is very different from the deeply indented coast-line of North Kimberley, Fitzroyland and Ordland. It may be that the

lower portion of the rivers in Pilbaraland had reached a much later stage of development than those of the other divisions mentioned, so that when submergence or drowning in Pilbaraland took place, the resulting coast line was much less irregular in outline than those just referred to.

Tidal phenomena are marked. Thus Woodward (*f*, 5) records a rise and fall of 18 feet at Cossack, and Montgomery (*d*, 121) notes that at Port Hedland there is a rise of over 20 feet in the tide.

ECONOMIC ASPECTS.

No artesian water is found in Pilbaraland, the North-West artesian basin (fig. 19) just touching the southern boundary. Well water, however, can probably be obtained almost anywhere at depths to about 100 feet.

The more or less featureless coast line provides few harbours, which, in an area where cyclonic storms are prevalent in the summer months, is particularly unfortunate.

Amongst minerals, gold, copper, tin, asbestos and tantalum ores occur, and Wodgina is the chief source of supply of tantalum (Simpson, *d*, 457).

Most of the country is used for pastoral purposes.

Communication with the rest of Australia has been hampered by the absence of railways and the long sea journeys that are necessary to reach the country from the more settled parts. Transport has had to be by sea, or by horse or camel overland, and the development of the country has been consequently hindered to some extent. In recent years, however, the motor car and the aeroplane have remedied these defects somewhat.

CHAPTER VI.

MURCHISONIA.

CONTENTS.

Boundaries. Rainfall. Temperature and Humidity. Vegetation. Geology. The Plateaux and Scarps. Contour. Rivers. Coast Line. Economic Aspects.

Reference should be made to the first chapter of this Part in regard to the creation of this physiographic division.

BOUNDARIES.

"Murchisonia" has been adopted from the name of one of the division's principal rivers (the Murchison) and owing to the fact that the name "Murchison district" is so well established. But as the area

now included comprises more than the portion usually known as the Murchison district, "Murchisonia" is suggested so as to include this additional area.

Murchisonia comprises all the river systems south of the Ashburton River, as far south as and including the Murchison River. Its western boundary is the coast line, and its eastern, a line connecting the sources of the included rivers. (See figs 8 and 21.)

Murchisonia, as here defined, corresponds to some extent with Griffith Taylor's "Murchison" (*b*, 2 (map) and 19). It includes Clarke's "Carnarvon" and parts of his "North-West" and "Murchison" natural regions (Clarke, *b*, Pl. XV. and 124). Carnarvon, as Clarke points out (*b*, 125) coincides with the North-West artesian basin, and thus is distinct from the surrounding country. Its topographic forms, however, so far as known, appear to be much the same as those of the adjacent country, and it is not therefore made a separate division. The North-West and Murchison natural regions, as defined by Clarke, also include areas of interior drainage with an absence of defined river courses. Such areas are consequently excluded from the division now described.

As our knowledge of the country progresses, the necessary splitting up into further physiographic divisions can take place, but it is inadvisable to multiply the units until the known facts require it.

RAINFALL.

The rainfall of the greater part of Murchisonia is not more than ten inches (fig. 3), and it is this low rainfall which no doubt partly accounts for the slow vertical corrasion by the rivers, as stated below. The rain is precipitated mainly in the winter, and although there are some heavy falls, they do not equal those farther north.

TEMPERATURE AND HUMIDITY.

The mean annual temperature is from 65° to 70° F. in the south, and from 70° F. to 75° F. in the north of the area. (fig. 6). Except near the coast, the humidity is low.

VEGETATION.

The vegetation is characterized by the predominance of the "mulga" scrub, dwarf trees of the acacia family (Clarke, *b*, 124). It belongs to the mulga type (C3) referred to in the chapter on the vegetation of the State. The leaves of the trees are eaten by stock. It should also be noted that after moderately heavy rains, the ground becomes carpeted for miles by everlastings and other small flowering plants (fig. 29).

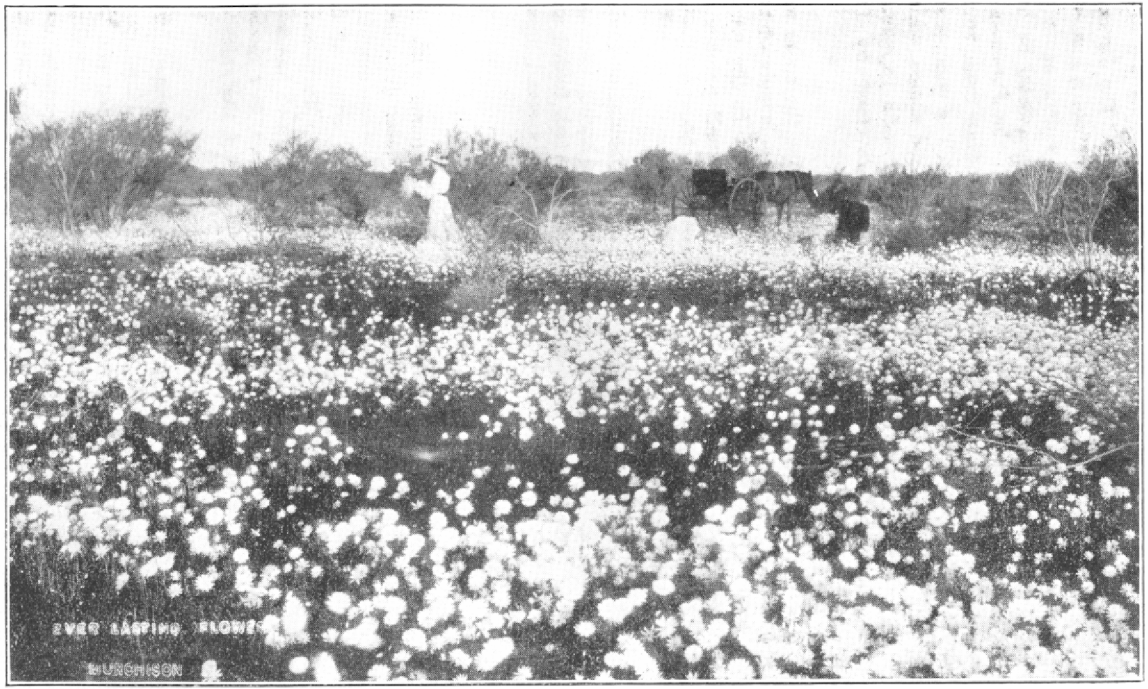


Fig. 29.—Wildflowers in Murchisonia after good rains. ''Mulga'' scrub in the background.

GEOLOGY.

The rocks of Murchisonia are fairly varied. Along the coast is a narrow fringe of Tertiary sedimentary rocks, adjoining which is a band of Jurassic sediments (limestones, sandstones, clays, etc.) The Jurassic rocks south of Shark Bay form a moderately broad band which immediately north of that locality becomes very narrow, but widens again as the Ashburton River is approached. The beds are horizontal or but gently undulating (Maitland, *k*, 36). To the east of the Jurassics a fairly wide belt of Carboniferous rocks occurs, extending from north of the Murchison River to about the Lyndon River. The component rocks are limestones, sandstones, grits, conglomerates and shales, which frequently have a slight westerly dip and a north and south (approximately) strike. These Carboniferous rocks are traversed by the Wooramel, Gascoyne, Minilya and Lyndon Rivers.

East of the Tertiary, Mesozoic and Palaeozoic belts, the rocks are regarded as all Pre-Cambrian. In the north they consist largely of the Nullagine Series (mainly sediments) with some granite. In the south, granite predominates, and it is associated with some small patches of greenstone. Along the upper Gascoyne River the Ashburton Series occurs.

As a rule, all the sedimentary rocks are either horizontal or folded into broad gentle folds so that few of the strata are highly inclined. The Ashburton Series, however is in places much contorted, folded and metamorphosed, but those rocks occupy a comparatively small area.

THE PLATEAUX AND SCARPS.

Murchisonia was originally a plateau, being continuous with the Pilbara Plateau in the north and the Darling Plateau (later described) in the south; but the original plateau has been much more denuded. and consequently is less recognizable as a plateau than either of the other plateaux just mentioned. The present surface of Murchisonia appears to be a new, but still moderately high plateau, which has been formed owing to the dissection of the old (upper) plateau, to a moderate depth only, by rivers, and to wide lateral erosion of the sides of the river valleys.

Above the surface of the new plateau rise numerous isolated hills and ridges; some are residuals of the old plateau, and some (the higher ones) are residuals of the earlier cycle of erosion which formed the old plateau. The new plateau appears to be an example of "levelling without base-levelling," and it has been formed because vertical corrasion has only kept pace with wide lateral erosion, and thus the topographic relief is as described above. The agents effecting this lateral erosion have been the rivers in the course of their meanders, the rain, and, to some extent, the wind.

Except for the small greenstone belts the rocks of the area are not very resistant to erosion, but a feature of the plateau is the tendency of the Jurassic sandstones to weather into flat-topped hills.

The old and new plateaux correspond with similar features in Salinaland. The old plateau is regarded as part of the Great Plateau of Western Australia, and as being an uplifted peneplain. It may be termed the Murchison Plateau or Peneplain.

No definite fault scarps are as yet known to occur in Murchisonia, but Clapp (*a*, 53) states that a scarp forms the eastern face of the Kennedy Range (through which the Gascoyne River passes in a canyon); that the scarp rises 200 to 300 feet vertically; and that the cliffs are usually abrupt and precipitous for many miles. He considers that the scarp is repeated at a smaller range south of the Gascoyne River; also at the Carrandibby Range to the south; and probably also at the Moogooloo Range north of the Minilya River, making a total distance through which the scarp may be intermittently traced of 150 miles. The general direction of the scarp is north-north-west.

Clapp (*a*, 53) notes that the rocks of the Kennedy Range are sandstones dipping west at angles of less than 5° with only slight reversals, and that the land descends gradually to the west from an altitude of approximately 1,000 feet at the top of the scarp to the coastal plain, thus illustrating what is apparently characteristic of the Murchison Plateau as a whole, viz.:—that the land rises gradually from the coast into a plateau without any sudden rise in height such as occurs in Swanland along the Darling Fault.

The origin of the scarp described by Clapp (which may be termed the "Carrandibby-Kennedy-Moogooloo Scarp) is not clear. The present writer in the first edition of this work (*b*, 119) suggested that the Kennedy Scarp was due to erosion by the lower Lyons River working along the strike of the rocks. If, however, the scarp be traceable as described by Clapp, then it is probably a fault scarp, and the fault block to the west is an extensive cuesta which may be termed the "Gascoyne Cuesta." Further examination is required to settle definitely the point.

CONTOUR.

The heights of the old and new plateaux cannot be stated with any degree of accuracy. The orographical map of Australia published in 1918 by the Commonwealth Weather Bureau (fig. 22) shows that Murchisonia is lower than Pilbaraland, that the highest land is at the heads of the rivers (especially about the upper Lyons), that the rise from the coast inland is more gradual in Murchisonia than in Pilbaraland, that the greater portion is under 2,000 feet above sea-level, and that much of it is between sea-level and 1,000 feet above that level. The heights of many points are shown on the general topographical

map of Western Australia, Pl. II., such as Mt. Augustus (3,480 feet), Mt. Gascoyne (2,589 feet), Mt. Egerton (3,262 feet), Mt. Gould (2,300 feet), Mt. Dalgety (1,705 feet), Coor-de-wandy (1,800 feet), and Mt. Murchison (1,700 feet), but whether these represent the height of the old plateau at the particular points cannot be stated. It is probable, however, that some represent the height of residuals on that plateau.

RIVERS.

The principal rivers are the Murchison, Wooramel, Gascoyne (with its tributary the Lyons), Minilya and Lyndon. Generally speaking, they are high-level streams with all the appearance of old age, the result of the processes described above, involving the formation of the new plateau. The rivers of the area are discussed more fully when treating of the drainage systems of the State, but it may be remarked here that there are few water gaps, but that there are gorges cut by the streams through the Gascoyne Cuesta.

COAST LINE.

The coast line is generally smooth, due to the building of bars and dunes, and there is no record of any recent submergence of the land. Such, however, may have taken place, but if so the present sand bars and ridges probably mask it. Research directed to the history of this coast-line might yield valuable results.

The tides have not the great rise and fall of those on the north-west and northern coasts so far as recorded, nor is the coast, except perhaps occasionally, subject to the devastating cyclonic storms of the Pilbaraland coast.

ECONOMIC ASPECTS.

Murchisonia's mineral resources are small, but it is a valuable pastoral country, although subject in parts, especially the more northern areas, to drought periods. It is fortunate in possessing a valuable and extensive artesian area which is known as the North-West Basin (fig. 19), the strata of which are of Palaeozoic, Mesozoic, Tertiary and Post Tertiary age (Maitland, *k*, 86 and fig. 29, 85). In addition, potable water is usually available from wells.

Transport and communication with the south have been by sea and overland by horses. Motor transport, however, owing to the generally level character of the country, has been extensively used, and the aeroplane is now assisting in the carriage of mails and passengers.

CHAPTER VII.

THE SOUTH-WEST DIVISION OR SWANLAND.

CONTENTS.

Boundaries. Rainfall. Temperature and Humidity. Vegetation. Geology. Contour. The Plateau and Scarps. The Swan Coastal Plain. Rivers. Coast Line. Economic Aspects. Contrasts with Murchisonia and Salinaland.

BOUNDARIES.

This division is a fairly well marked one, except that its northern boundary (the water-parting between the Murchison and the rivers to the south) is a somewhat arbitrary one. (See figs. 8, 30, and 31.)

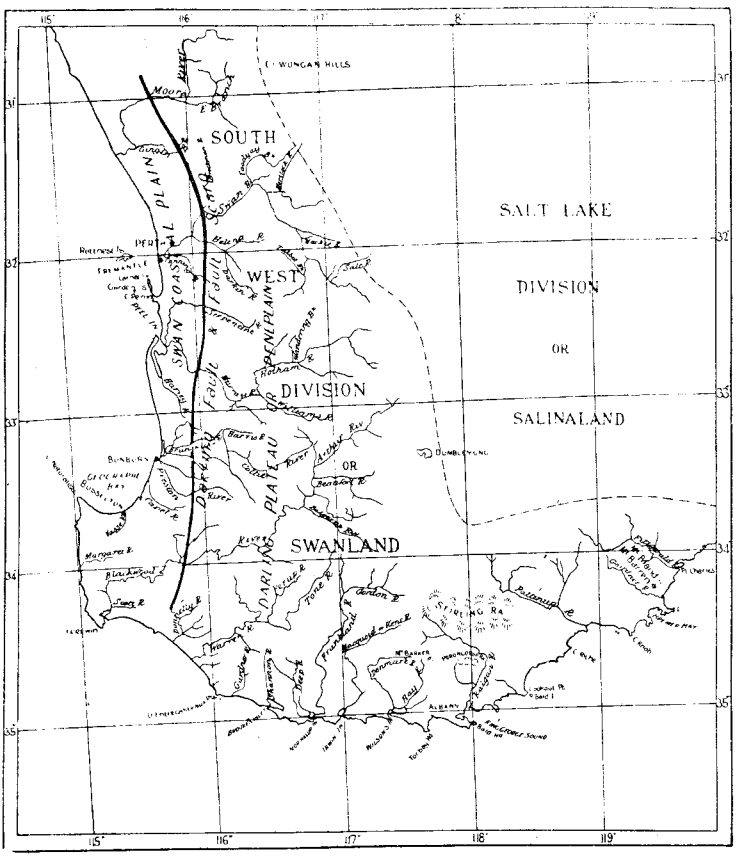


Fig. 30.—Outline Topographical Map of the southern portion of Swanland.

On the west and south, Swanland is bounded by the ocean, and on the east by the Salt Lake Division or Salinaland, the eastern boundary being a somewhat irregular boundary determined by all river systems south of the Murchison which drain to the sea. The division is fairly wide in the north on account of the length of the Greenough River, but it narrows immediately to the north of Perth, and then widens to the south. Included in the division is a narrow south coastal strip (comprising a number of short coastal streams) running from the head of the Gardiner River eastwards to about Israelite Bay.

"Swanland" is a convenient and appropriate term which has been applied by Griffith Taylor (*a*, 59) to that portion of Western Australia which is practically identical with the physiographic division here defined.

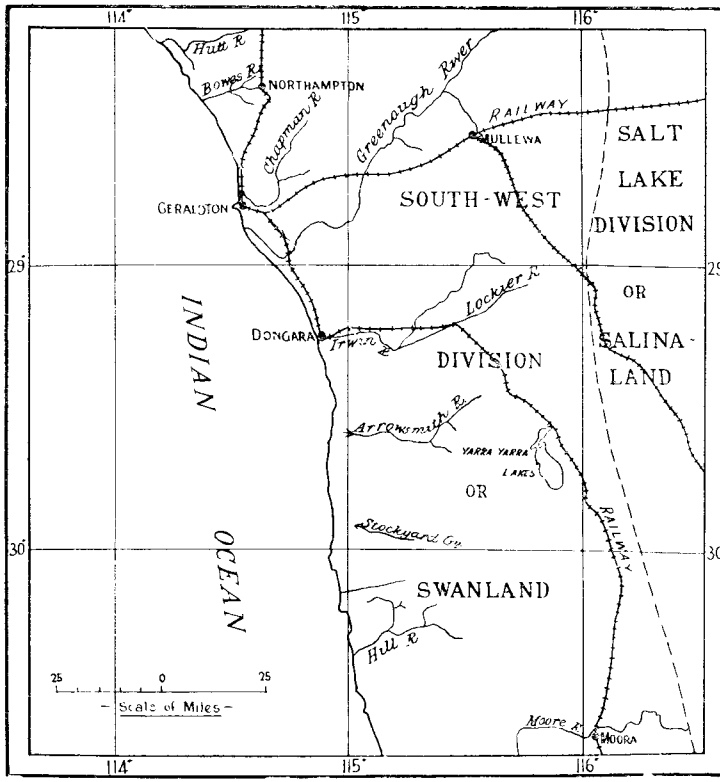


Fig. 31.—Outline Topographical Map of the northern portion of Swanland.

RAINFALL.

The average annual rainfall (fig. 3) varies from about 15 to over 50 inches, the wettest portion being in the extreme south-west and becoming less inland. The isohyets are more or less parallel to one another, but they meet the western coast at an acute angle and so show the effect of the prevailing winds. The rain falls mainly in the winter, and is very regular in its occurrence. This fact constitutes Swanland one of the most reliable wheat producers in Australia. There is a remarkable correlation between timber and rainfall in Swanland. (See Pl. III.)

TEMPERATURE AND HUMIDITY.

The mean annual temperature (see fig. 6) varies from 60° to 70° F., which thus provides a pleasant, equable and healthy climate, somewhat humid near the coast-line, with low humidity on the Darling Plateau.

VEGETATION.

The vegetation of Swanland comprises the chief forests of the State, the main forest belt, which is defined as a Temperate Eucalypt Rain Forest (Bull. 42, Forests Department of Western Australia, p. 5), commencing at about Gingin and extending along the western coast in a widening belt to the southern coast, east of Albany. The zones (see Pl. III.) in this belt (from the coast inland) are the Tuart, the Jarrah, the Wandoo, the Sand Plain, and the Salmon Gum, the principal timber in most instances giving its common name to the particular zone to which it belongs.

The karri (*Eucalyptus diversicolor*) (see fig. 32) is found in two small belts on the Naturaliste-Leeuwin Coast, and a much larger belt extending along the southern coast from the Donnelly River eastwards to Albany. North of Gingin the salmon gum forest and sand plain vegetation occur.

The tuart (*Eucalyptus gomphocephala*) is associated with the peppermint (*Agonis flexuosa*) and a floor of annual grasses of considerable grazing value (Bull. 42, p. 9). Associated with the jarrah (*E. marginata*) are a number of other trees, both tall and short, shrubs, and also the blackboy (*Xanthorrhoea Preissi*), grass-tree (*Kingia australis*),

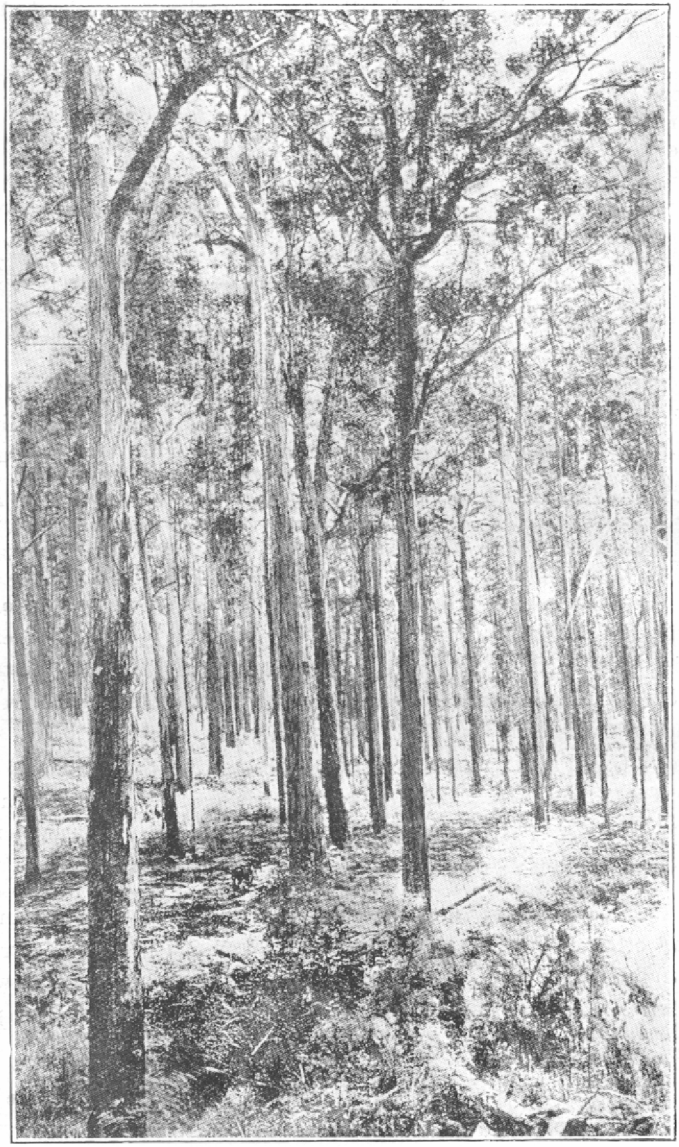


Fig. 32.—Typical Karri Forest in the south-west of Swanland.

and zamia palm (*Macrozamia Fraseri*) (see fig. 33). There is also a dense ground cover. Jarrah grows well on the laterite cap of the Darling Plateau, which is useless for agriculture (Bull. 42, p. 7).

With the wandoo (*E. redunca, var. elata*) are associated the York gum (*E. foecunda, var. loxopheba*), jam (*Acacia acuminata*), sandalwood (*Santalum spicatum*), and mallet (*E. astringens*), and also shrubs and grasses, but "in the pure wandoo type of country many of the commoner shrubs are toxic to stock, and this has retarded the development of this country for pastoral purposes." (Bull. 42, p. 9.)

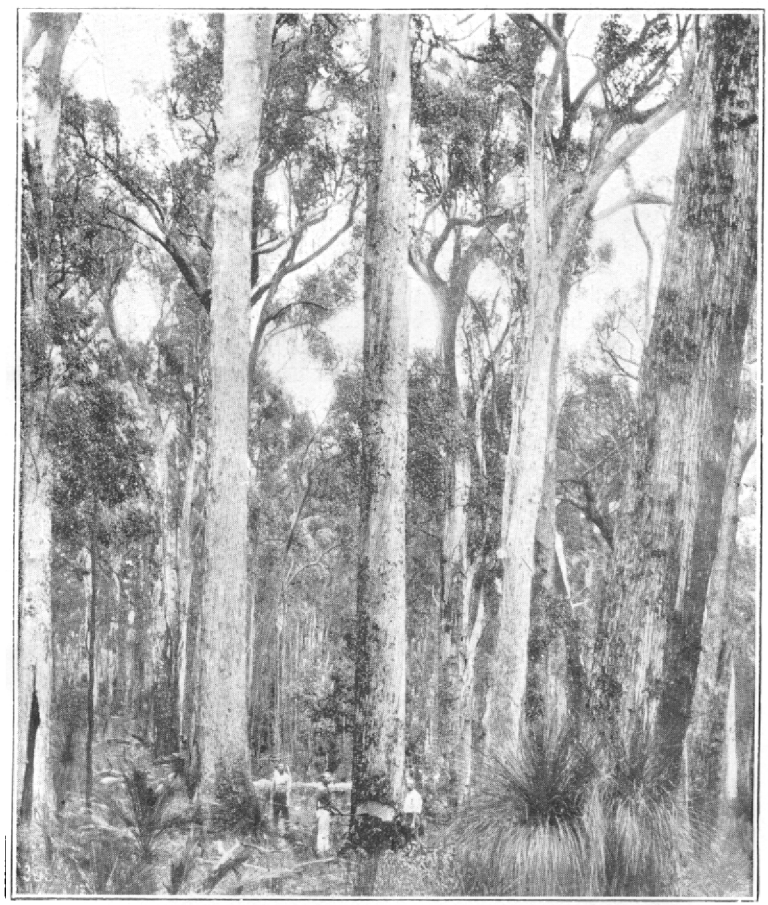


Fig. 33.—Jarrah Forest in the south-west of Swanland.

The sand-plain vegetation consists of small shrubs of various kinds. The salmon gum belt, besides the salmon gum (*E. salmonophloia*) itself comprises a number of other trees, mostly eucalypts, and in addition a number of small shrubs, some of which are useful fodder plants. Figs. 34 and 35 indicate types of vegetation common in their respective areas.

The remarkable correlation between rainfall and timber in Swanland has already been referred to.

Wood has shown that in certain parts of Swanland where the native vegetation has been destroyed rapidly, the salinity of the streams draining the area has noticeably increased. He discusses the causes thereof, also the origin of the salt, which he considers is air-borne from the sea. For a full statement of the problem and a discussion by others, reference must be to Mr. Wood's paper, which is valuable and interesting.

GEOLOGY.

The rocks of the Darling Plateau are chiefly granite (gneissic in places) seamed by the basic dykes, usually of epidiorite. Practically the whole surface of the plateau is capped by laterite a few feet thick, so that the underlying rocks can as a rule be determined only where the country has been dissected by stream action. Where the rocks are foliated the strike of the foliation planes is usually about north-north-west, this direction thus constituting the geographical "grain" of the country. The angle of inclination of the foliation planes is close to the vertical. All the rocks referred to are regarded as of Pre-Cambrian age.

In the northern portion of the area, in the basins of the Irwin, Greenough and Chapman Rivers, Carboniferous and Jurassic sedimentary rocks, and farther south, as at Gingin, Cretaceous sedimentary rocks outcrop. All these sedimentary rocks are nearly horizontal, but some are slightly folded or tilted.

Along the fault (known as the Darling Fault) separating the plateau from the Swan Coastal Plain, a narrow band of slates and quartzites, highly inclined, occurs.

The rocks of the Swan Coastal Plain consist of clays and sands largely of fluviatile origin, and also of present-forming and old hardened sand-dunes (the coastal limestone). Their distribution is referred to in the description of the physiographic elements of the plain.

CONTOUR.

The greater part of the area is a dissected plateau, which the writer has named the Darling Plateau or Peneplain (*a*, 141, *et seq.*), and which may average in height above sea-level about 1,000 feet,

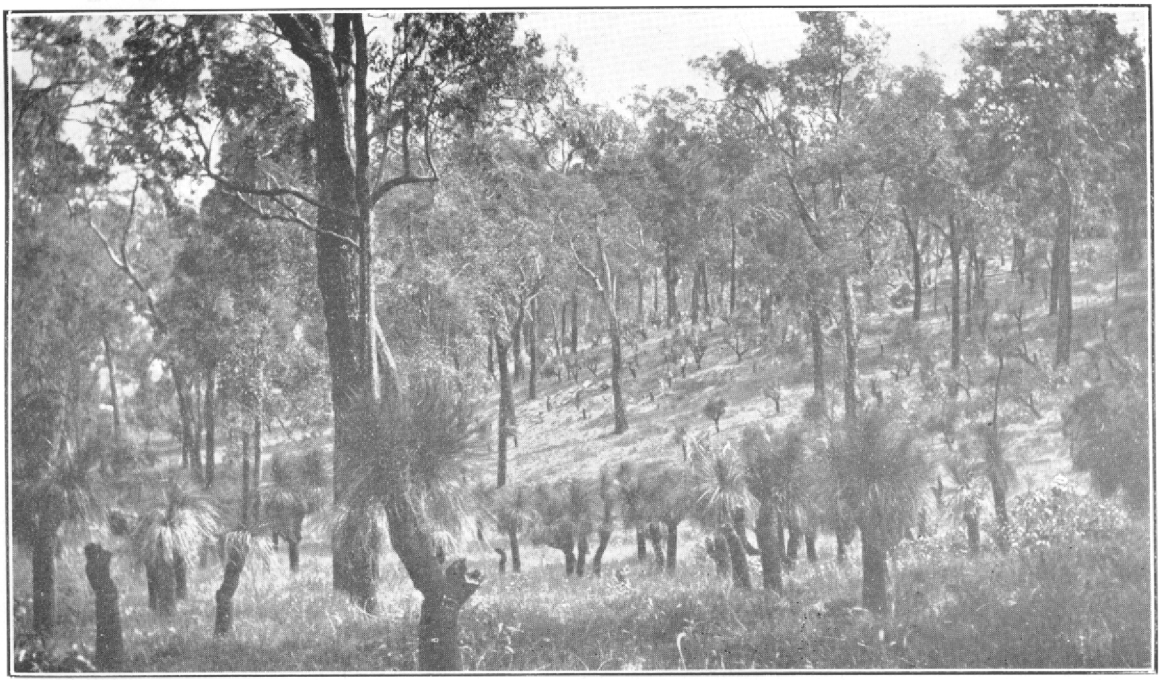


Fig. 34.—Vegetation of Swanland, Donnybrook district. "Blackboys" and eucalypts growing on gneissic granite.



Fig. 35.—Vegetation of the Sand Plain country, Northampton, in the northern portion of Swanland.

but the topographical data are too scanty to give more than an approximation to the truth. (See fig. 36 for a general view of the peneplain.)



Fig. 36.—View across the Helena Valley, showing the even skyline of the Darling Peneplain, Swanland.

The orographical map published by the Commonwealth Weather Bureau (fig. 2) shows that a large portion of the plateau lies between the 500 and 1,000 feet contours, a moderate portion between the 1,000 and 2,000 feet contours, and the Stirling Ranges between the 2,000 and 3,000 feet contours. The Swan Coastal Plain, which borders the plateau on the west, and the coastal plain along the southern coast (which may be termed the "Nornalup Coastal Plain") are shown below the 500 feet contour.

THE PLATEAU AND SCARPS.

The Darling Plateau or Peneplain is now well dissected by rivers, which are variously young, early mature or mature, but the old surface of the plateau is still largely preserved and is easily recognizable.

To the north, the plateau connects with the old plateau of Murchisonia without any break, and, similarly, on the east with the old plateau of Salinaland.

The plateau is bounded on the west by the great fault scarp, named by Saint-Smith (*a*) the "Darling Fault Scarp" (fig. 37), at the foot of which lies the low narrow strip of land bordering the Indian Ocean, which has also been named by Saint-Smith the "Swan Coastal Plain."

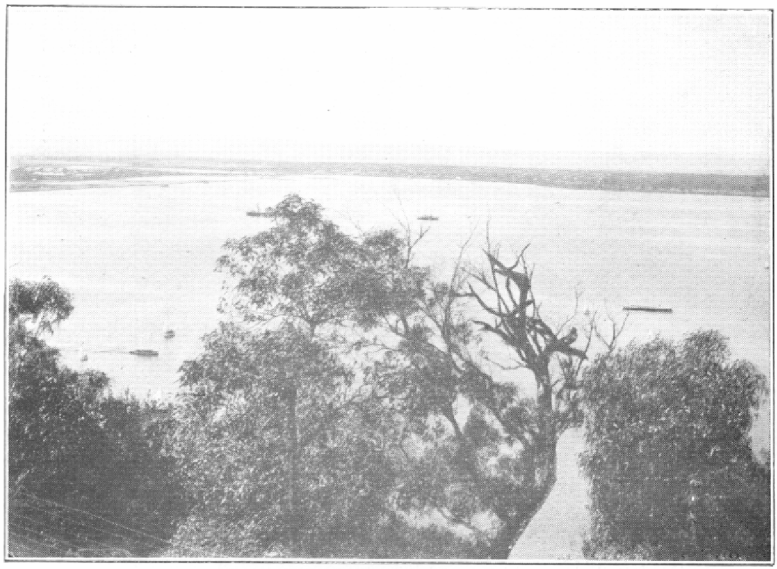


Fig. 37.—View from King's Park, Perth, looking eastwards across Perth Water, Swan River (a drowned valley), showing the Swan Coastal Plain and the Darling Fault Scarp in the distance

The fault scarp rises sharply from the Swan Coastal Plain to a height of about 800 to 1,000 feet above sea-level, and forms the western edge of the Darling Plateau and of the Great Plateau. It has been traced in a north and south direction for over 200 miles from the southern coast to beyond Gingin, north of Perth. Woodward (*r*, 10) notes that the fault bifurcates at a point a little south of the Collie River, the main (eastern) branch continuing southwards to the coast, and the other (western) branch running in a south-westerly direction towards Cape Naturaliste. The western branch he has termed the "Collie-Naturaliste Scarp" (which may be shortened to "Collie Scarp"), the scarp being observable at its junction with the main branch, but gradually becoming less in height south-westwards. (See Pl. IV. and figs. 38 and 39.)

Woodward also notes (*r*, 11) that the Darling Fault Scarp bifurcates also at Gingin, one (the easterly) branch continuing along the general direction of the fault, and the other (the westerly) branch

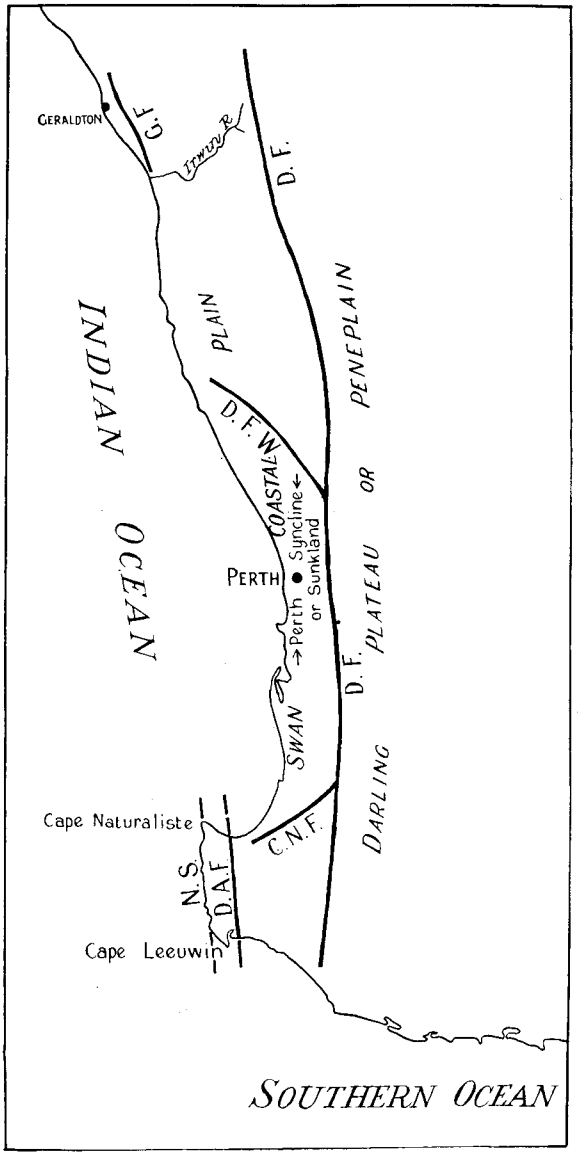
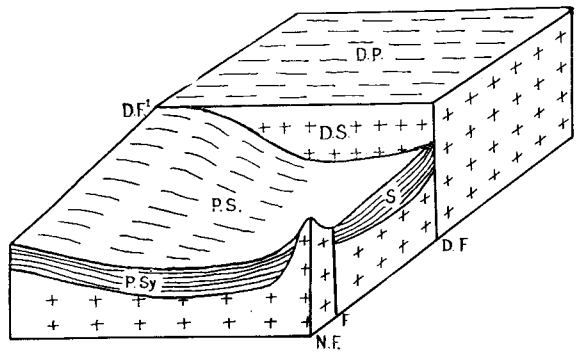


Fig. 38.—Diagrammatic plan showing various faults and fault scarps, and the Perth Syncline or Sunkland.
D.F.—Main Darling Fault and Fault Scarp.
D.F.W.—North-Western Branch of the Darling Fault and Fault Scarp.
G.F.—Geraldton Fault and Fault Scarp.
D.A.F.—Dunsborough-Augusta Fault and Fault Scarp.
N.S.—Naturaliste Scarp and Fault (?)
C.N.F.—Collie-Naturaliste Fault and Fault Scarp.

curving to the coast at the mouth of the Hill River. In both branches scarps are apparently traceable. Woolnough and Somerville (68) state that in the vicinity of the Irwin River the scarp, although less commanding than it is near Perth, is still a conspicuous feature. How far the main (easterly) branch scarp continues north of the Irwin River has not been determined, but the fault itself continues to the north of the Geraldton-Mt. Magnet railway. (See Campbell, *c*, maps and sections).



+ + Granite & other crystalline rocks. Sedimentary Rocks.
D.P. *Darling Peneplain.* D.F. *Darling Fault.* D F¹ *Darling Fault continuation*
D.S. *Darling Fault Scarp.* P.S. *Perth Sunkland.* P.Sy. *Perth Syncline*
S. *Cross Sag (?) of the Perth Syncline.* N.F. *Naturaliste Fault (?)* F *Dunsborough-Augusta Fault.*

Fig. 39.—Block diagram showing the Darling Fault and Fault Scarp (and the disappearance of the latter to the north), the probable Naturaliste Fault, the Dunsborough-Augusta Fault, the Perth Syncline and Sunkland, and the possible sag of the strata between the Darling and Dunsborough-Augusta Faults. The area represented from north to south extends from north of the Irwin River to an east and west line south of Cape Naturaliste. (*Note*: The diagram is so oriented that the line NF, F, DF is an east-west line, with NF the most westerly point along that line, and the line running from NF parallel to the text points to the north.)

The Darling Fault is evidently an old fault-line, and renewed movement along the greater part of its length has produced the scarp. Such a scarp may be termed a "revived fault scarp." Woolnough (*c*, 15) points out that the present face of the scarp is now to the east of the actual fault plane. Clarke (*c*, 24) records that in the neighbourhood of Perth "west of the scarp there is in places an abrupt slope falling immediately and steeply down to the Swan Coastal Plain. Elsewhere, particularly near the outlets of the larger streams, there is an area of successively lower hills in which are relics of a former north and south drainage." This is known as the "foothill zone."

Woolnough (*c*, 16) considers that there is a laterite platform at Ridge Hill, east of Perth, which he terms the "Ridge Hill Shelf" at about 200 feet above sea-level. This shelf, he suggests, is the remnant of a step-faulted portion of the plateau, let down by a subsidiary fault, immediately to the west of and parallel to the main Darling Fault.

During his recent visit to Australia, Professor Douglas W. Johnson suggested as alternative working hypotheses that the scarp may be due to differential erosion either (1) along an old fault plane or (2) along the axis of a monoclinal fold of the Jurassic (?), Cretaceous, and Tertiary sediments and of the underlying crystalline rocks. In either case the scarp produced by the fault or fold would be removed by erosion, and subsequent differential erosion would produce the present scarp, which if the first-named process operated would be a fault-line scarp; and if the second process operated would be what might be termed, following the analogy of the fault-line scarp, a "monoclinal fold-line scarp." (That term, however, is clumsy, and the writer therefore suggests that it be changed to "monofold-line scarp" and correspondingly the name for a scarp produced by a monoclinal fold be "monofold scarp.")

These valuable suggestions by Professor Johnson must be borne in mind in any further study of the Darling Scarp. It may, however, be permissible here to refer to other considerations which suggest that recent renewed faulting has actually occurred and is responsible for the present scarp.

The apparent fault has been traced northwards, where no scarp exists. If the scarp in the neighbourhood of Perth and elsewhere be due to erosion, there appears to be no valid reason why erosion should not have taken place in the northern area and have produced a scarp there unless it be, as suggested to the writer by Professor E. de C. Clarke, that the lower rainfall of the northern area has been insufficient to produce the scarp there by differential erosion, a point which requires consideration. The alternative to differential erosion is renewed faulting along an old fault plane, resulting in the scarp along a portion of the fault, as already suggested in this chapter. The evidence regarding the Perth Sunkland and probable rift valley set out in Chapter III. of Part XIII. favours the theory of recent faulting.

Saint-Smith (*a*, geological section) suggested a step fault along the western coast between Capes Naturaliste and Leeuwin. The scarp along this suggested fault line was referred to in the first edition of this work (*b* 164 and 165) as the Naturaliste Scarp.

Maitland (*i*, 7 and 9) suggested that along the western coast (southern end) of Western Australia there may be a rift valley, the walls of which in the extreme southern portion were the Darling Fault

Scarp on the east, and the eastern boundary of the ridge of ancient crystalline rocks from Flinders Bay to Geographe Bay on the west. The ridge is termed by Woodward (*r*, 11) the Cape Naturaliste-Leeuwin Ridge (which may be shortened to the "Naturaliste-Leeuwin Ridge") and Maitland's suggestion of a fault scarp on its eastern side, with the consequent rift valley, is confirmed. Woodward has named the scarp the "Dunsborough-Augusta Scarp." (See fig. 38.)

The existence of the last-named scarp, with its accompanying fault, and of the Naturaliste Scarp, although along the latter actual faulting has not been demonstrated, strongly suggests that the Naturaliste-Leeuwin Ridge is a horst.

Another scarp occurs near the coast at Geraldton, the face of the scarp being composed of little inclined Jurassic sandstones. This scarp, which appears to extend some miles to the north and south of Geraldton, may be due either to faulting or erosion. The straightness of its course suggests faulting. This feature is discussed in Chapter II. of Part XIII.

In the Geraldton district, where the horizontal Jurassic rocks outcrop at the surface as a plateau, and where they have been dissected by rivers, there are numerous scarps which are clearly due to erosion. Campbell (*c*, 58) points out that the steep faces are due to the hardening of the surface by the introduction of silica or iron, forming caps of quartzite or laterite respectively.

A study of the river valleys of the division has led to the conclusion that there have been distinct pauses in the relative uplift of the plateau along the Darling Fault line. Thus Woolnough (*b*, 390) describes mature longitudinal valleys, the bottoms of which are at least 200 feet below the level of the plateau. These valleys represent the erosion effected in the old peneplain after it had been uplifted for somewhat over 200 feet, a height far below the present surface of the plateau, and hence indicating a long pause in the uplift to its present height. The level at which the bottom of such valleys now stands (*i.e.*, about 200 feet below the level of the Darling Peneplain) Woolnough has termed the "Meckering Level" or "Mature Valley Level," which would be somewhere about 800 feet above sea-level.

Clarke and Williams (167) have noted high level terraces in the valley of the Helena River at heights of 250 and 450 feet above sea-level, which indicate, in their opinion, two long pauses in the uplift of the plateau.

In 1912 the present writer (*a*, 149 and 157) referred to the numerous isolated hills on the plateau, and suggested that they were monadnocks or residuals on the Darling Peneplain. Woolnough subsequently (*b*, 389) independently noted such monadnocks, amongst which are

Mount Dale, Eagle Hill and Mount Randell, forming, as he believed, the remains of a level, older and higher than the Darling Peneplain, which he named the "Mount Dale Level."

The Stirling Range has been studied by Woolnough (*d*,) and others, and its physiographical features are described in the Part on the mountains, scarps and sunklands. It is sufficient to state here that it is a huge, upraised block bounded mainly by great fault scarps. (See figs. 40 and 41.)

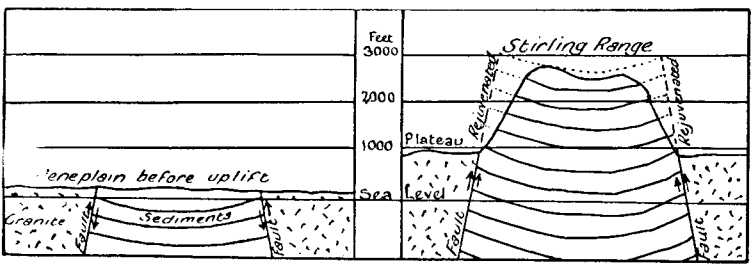


Fig. 40.

Fig. 41.

(After Woolnough). The tectonic history of the Stirling Horst, indicated diagrammatically by the figures. "Before peneplanation the sediments had dropped into a 'senkungsfeld'. This was bounded by reversed faults . . . . . During the uplift of the peneplain and its conversion into a plateau, the formations on *both* sides of the fault *moved upwards.* The sedimentary series, however, underwent greater uplift; so that the granite areas are *relatively depressed.* In this way the faults, originally *reversed* become *normal* after rejuvenation." (Woolnough.)

THE SWAN COASTAL PLAIN.

The Swan Coastal Plain has been divided by Woolnough (*c*, 15, *et seq.*) into the following physiographic elements proceeding westwards from the Darling Fault Scarp:—

(1) The Piedmont Zone, composed of flat alluvial fans or dry deltas, built up of sediments deposited by streams after their passage through the scarp. Those deposits have become practically united, except where cut through by the streams. The width of the belt is probably only from half to one mile on the average.

The soils of this zone are rich in plant food.

(2) The Sandy Plain, which is gently undulating as a rule, and which is made up chiefly of sand dunes, geologically recent, but now fixed by the growth of vegetation. Between the dunes are low-lying areas which in winter become swampy. In the Sandy Plain is a series of lakes stretching along a north and south zone. These lakes include Jandakot, Bibra, Herdsman and Monger.

(3) The Coastal Limestones, which form a continuous belt facing the coast, rising into hills and projecting seawards as rocky headlands. They are old sand dunes hardened into rock by the solution and subsequent precipitation of calcium carbonate.

(4) The Shore Line, which is composed mainly of sandy beaches backed by actively moving sand dunes.

(5) The shallow waters between Fremantle and Rottnest Island.

(6) The zone of islands and reefs extending through Carnac and Garden Islands and perhaps Rottnest Island.

The Swan Coastal Plain has been subjected in recent geological times to relative movements of depression (Jutson *a* and *b*) and, according to Somerville, and Aurousseau and Budge, of elevation. These movements are referred to in more detail in the chapter on the drainage systems of Swanland.

RIVERS.

Rivers are numerous in the division, and many of them are of a fair length. The principal ones are the Chapman, Greenough, Irwin, Arrowsmith, Moore, Swan-Avon, Murray-Williams, Collie, Blackwood-Arthur, Warren-Tone, Frankland-Gordon, Kalgan and Pallinup. (See figs. 30 and 31.)

The rivers are described in some detail in Part VII., Chapter VI., and therefore it need only be said here that those of the plateau vary in character from early to late mature, and that they show in many instances markedly rectangular courses. The Swan Coastal Plain has been dissected into wide, shallow valleys, in which old-looking rivers meander.

COAST LINE.

On the west, the coast line is remarkably smooth and even, due principally to the building up of long sand dunes (some recent and others of greater age), in regular lines, which have in places dammed up the rivers (making their lower courses run parallel to the coast) and the sea, and formed lagoons. A striking exception is the high coast from Cape Naturaliste to Cape Leeuwin, which consists mainly of granite, capped in many localities by the dune limestone. The contour here, as already stated, strongly suggests a fault. The southern coast, on the other hand, with its deep inlets and numerous islands, is indicative of the drowning of the lower ends of the river valleys, of which those of the Kalgan and King Rivers at Albany are

excellent examples (fig. 42). The lower Swan from Fremantle to Perth is also a fine example of a drowned valley on the western coast. (See figs. 37, 43 and 44.)*

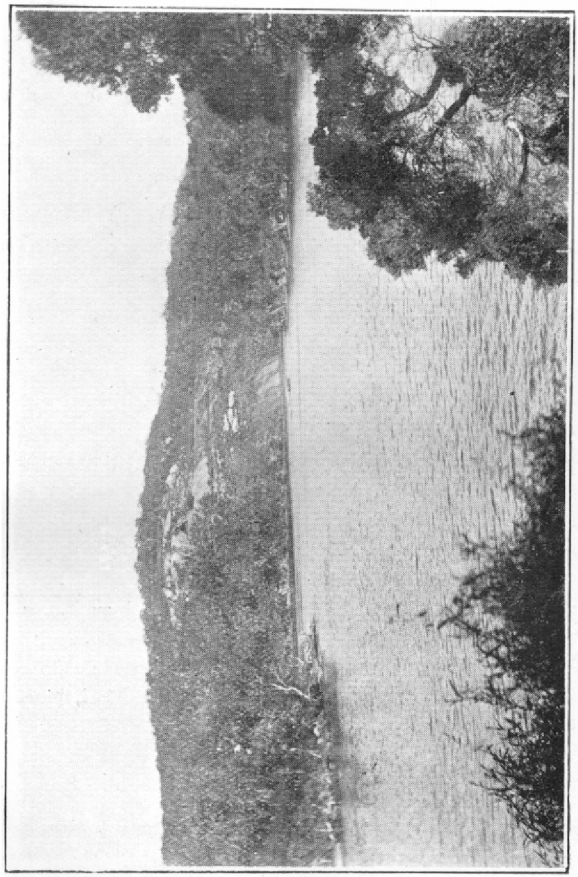


Fig. 42.—The drowned valley of the lower Kalgan River, Albany.

*Since the first edition of this work was published, the writer has made practically no further observations regarding the valley of the lower Swan River. Professor E. de C. Clarke has, however, been giving some attention to the life history of the river and he has informed the writer that he has come to the following tentative conclusions:—The sea extended from the Darling Scarp to beyond the present site of Rottnest. Then the sea floor of that area was elevated and became a plain about 300 feet above sea-level. During the period of elevation, the new land was cut back, by marine abrasion, to approximately the present coastline, only the more resistant parts, such as the present Rottnest and Garden Islands, escaping complete removal to below sea-level. Hence the sea-floor between Fremantle and Rottnest is a plain of marine abrasion. The Swan River and its tributary, the Canning, meanwhile had formed flood plains at and above their junction; and down-stream the Swan had cut its comparatively narrow valley. Subsequently there was a slight subsidence, which drowned the flood plains.

Coal occurs at Collie, where it has been worked for many years. A fair amount of tin has been obtained from Greenbushes, and copper has been extensively mined at Ravensthorpe.

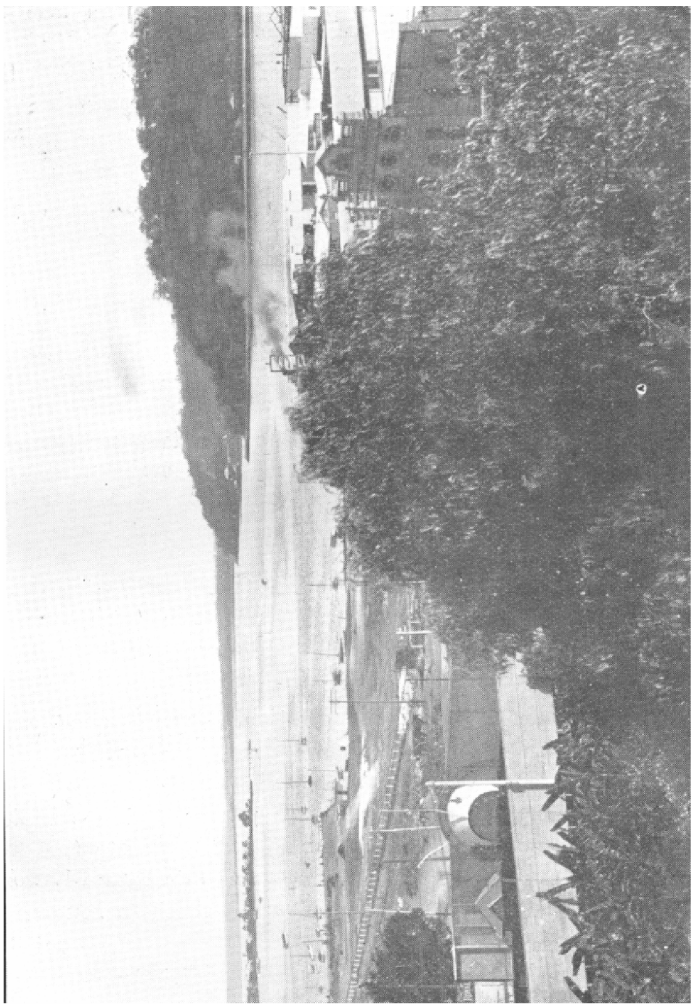


Fig. 44.—The Swan River at Perth, a drowned valley. The cliffs in the right background are composed of dune limestone, and flank King's Park.

In the Coastal Limestone there are some magnificent caves at Yallingup, near Busselton, and at the Margaret River, where, from the Mammoth Cave, numerous bones of animals, some of which are now

extinct, have been obtained. Some of the surface streams find their way into these caves (Glauert, 11). For a description of the Lake Cave, one of the most interesting of the Margaret River caves, see Blatchford (*f*). See also fig. 45 of this work.

The Swan Coastal Plain forms an artesian area known as the "Coastal Plain Basin" (fig. 19). An abundant supply of artesian water is available. Well water is also plentiful, and it can also be obtained on the plateau.

Transport by rail and road is generally fairly easy, although the numerous meandering rivers of the coastal plain render many bridges necessary. The Darling Fault Scarp makes the laying of roads and railways over it somewhat costly.

CONTRASTS WITH MURCHISONIA AND SALINALAND.

Swanland is different from Murchisonia in that the former has a greater rainfall; deep valleys; splendid timber; more cultivable land; and coal. In its northern area it approximates in character to Murchisonia, and in the east to Salinaland. The differences from the latter are that Swanland possesses a greater rainfall; exterior as contrasted with interior drainage; running streams as contrasted with practically none; finer and larger timber; coal; tin; copper; practically no gold as contrasted with an abundance in Salinaland; a trenched plateau due to normal erosion, as contrasted with an almost level one, due to arid erosion; and more cultivable and pastoral land.

CHAPTER VIII.

THE SALT LAKE DIVISION OR SALINALAND.

CONTENTS.

Boundaries. General Characteristics. Vegetation. Contour. Economic Aspects. Comparison and Contrast with other Divisions.

BOUNDARIES.

This physiographic division is the second largest, and it occupies a very considerable portion of the southern half of the State (see fig. 3). It corresponds roughly with the administrative Central Division.

The division approaches close to the sea on its southern boundary, being separated from the ocean by the narrow river-bearing strip running westerly from Israelite Bay to the mouth of the Pallinup River. On the west its boundary is the line separating the rivers of the coast, as far north as the Murchison, from the interior drainage. The division on its western side approaches close to the Great Southern and Midland railways, but recedes to the east on meeting the Murchison River basin. Its approximate northern boundary is latitude 25° (some distance north of Wiluna), and its eastern boundary is between longitudes 123° and 124°, nearly reaching to a point a little north of Cape

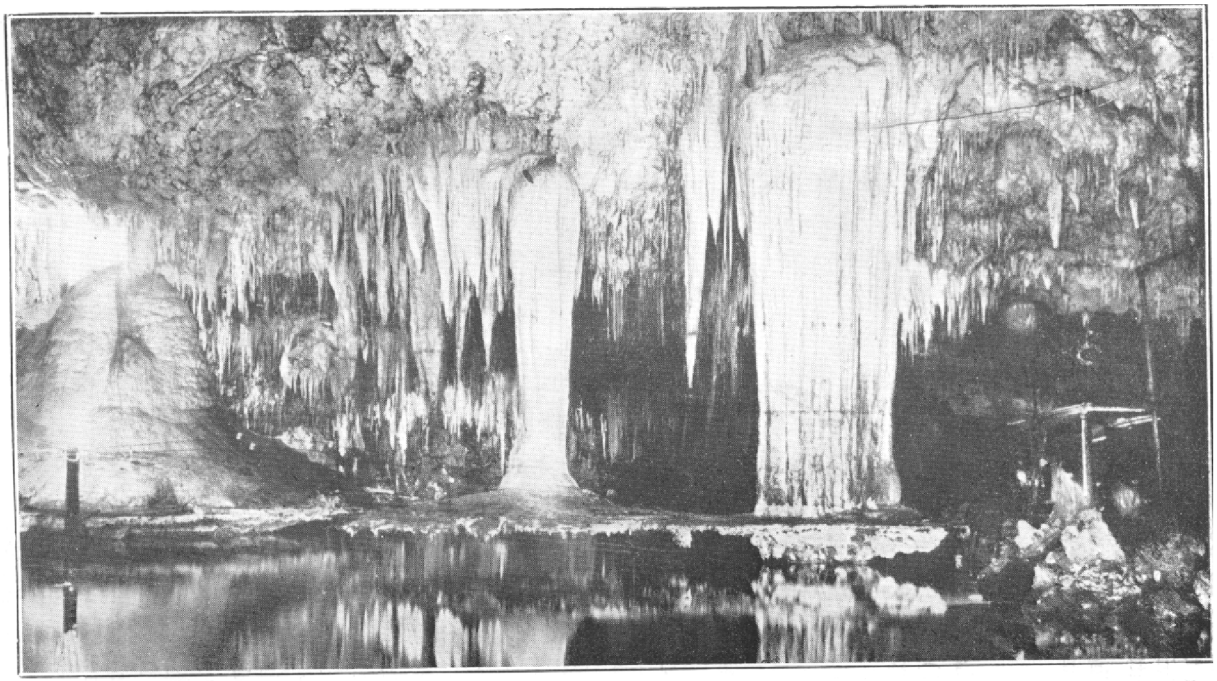


Fig. 45.—The Lake Cave, Margaret River, Swanland.

Paisley. The boundaries on the north and east are approximate only, as there are no well defined natural features to draw a sharp line between this division and Sandland, although to the north and east of the division the characteristic sand ridges and sand plains of Sandland soon attract attention.

The division comprises portions of Clarke's Kalgoorlie, Wheat Belt, and Murchison natural regions (*b*, map, and 120, 123 and 124).

GENERAL CHARACTERISTICS.

The general characteristics of Salinaland are:—

(1) The occurrence of a plateau (the "new plateau") of arid erosion (figs. 46 and 47-50). On this new plateau stand the

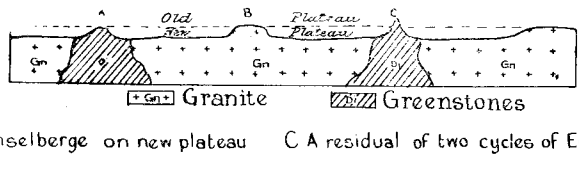


Fig. 46.—Diagrammatic Section across Salinaland, showing the formation of the new plateau and the residuals of the present and past cycles of erosion.

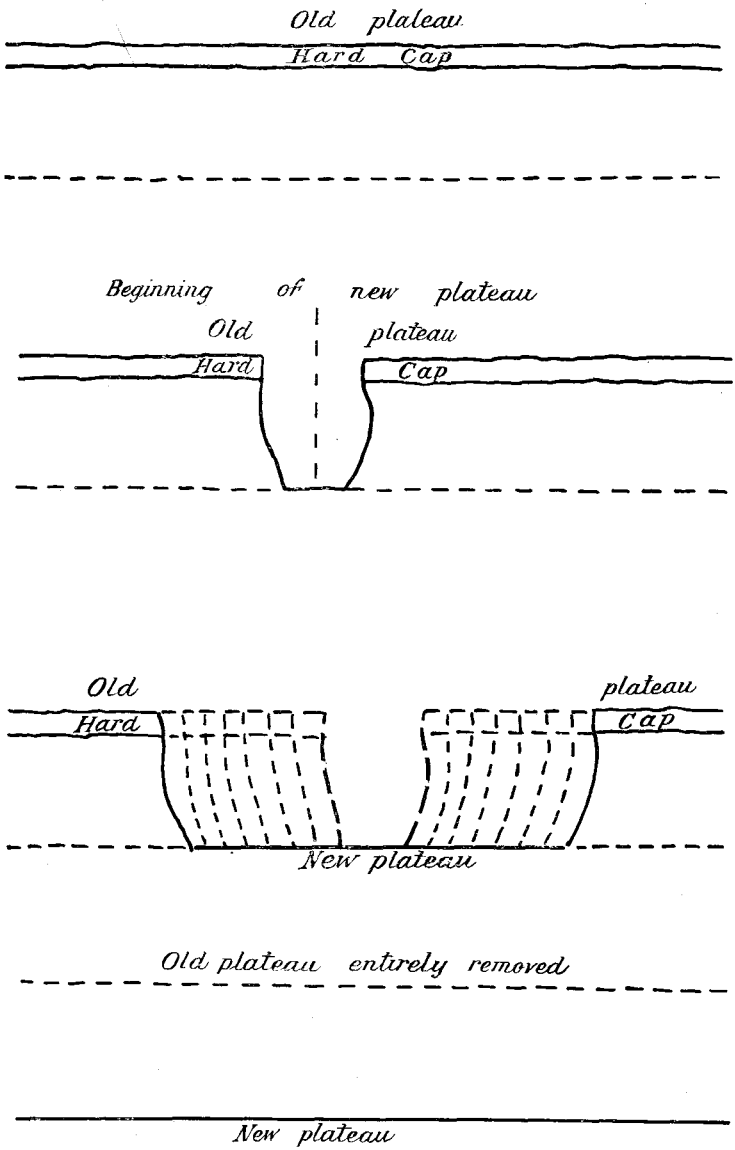
remnants of the "old plateau." Those remnants consist of flat-topped mesas and buttes, the rocks of which are commonly granite, although greenstones and practically unaltered sedimentary rocks also occur. The greenstones and granite are in many places highly decomposed, and all the different kinds of rocks may be capped by laterite, which may be siliceous, ferruginous or aluminous.

The transition between the mesas and buttes of the old plateau and the new plateau is in many places by steep cliffs which are locally termed "breakaways," the character and origin of which are discussed in Part XI., Chapter 1.

Other remains of the old plateau are isolated hills and ridges ("island hills") of various undecomposed rocks, the chief of which are granite and greenstone; their outlines are usually well rounded.

The height of the old above the new plateau is probably from 30 to 100 feet (although there are exceptional cases in which the difference may be as much as 200 feet). It must, however, be remembered that there is probably a planing down of the surface of the old plateau, and that therefore its present surface may not represent the actual original one.

The old plateau is a portion of the Great Plateau of Western Australia.



Figs. 47, 48, 49 and 50.—Diagrams, illustrating in section, the different stages in the formation in Salinaland of the new plateau, where the old plateau possesses a lateritic cap. The sections also illustrate the formation of short U-shaped canyons, and of broad flat-bottomed valleys with steep sides.

Above the old plateau, its monadnocks or residuals rise. These consist principally of rocks resistant to erosion, the chief of which are greenstones and quartz-haematite rocks.

No block-faulting in this division has been recorded.

The origin and history of the old plateau are discussed in Part VIII.

(2) No permanent streams exist, and such intermittent ones as occur cannot be dignified by the name "river." They generally run only immediately after heavy rain, and frequently lose themselves on the plains. Those that enter the salt lakes are often short. The division may be described as riverless.

(3) Such drainage as exists is almost entirely interior.

(4) The occurrence of the salt or "dry" lakes in great numbers. They are merely shallow depressions on the new plateau of various size and shapes. They are usually found along and in fact constitute the main drainage lines of the division; and they may be a few hundred yards or several miles wide (using this term where the length is much greater than the width) or in diameter (if the lake is more or less circular). The lakes may be isolated, but in some places they are strung loosely together, with divisions of varying width. They are usually dry, but, after heavy rain, a thin sheet of water may spread over their surfaces. Unless, however, the rain be continued, the water evaporates with extraordinary rapidity, leaving a deposit of salt and usually of gypsum on the floors of the lakes. The use of "dry" and "salt" as applied to these so-called lakes is thus explained.

Some lakes are wholly or in part rock-floored, others may possess detrital material of considerable thickness.

The lakes constitute the chief physiographic feature of the division, and one of the most striking physical phenomena in Western Australia (see figs. 51, 52, 53, 54, 55, 56, 57 and 58). They are of great geographical interest. Their origin is discussed in Part X.

(5) The fairly widespread occurrence of sand or sandy loam plains and, to a comparatively limited extent, of sand ridges, the latter being in many places confined to the borders of the salt lakes.

(6) The scanty rainfall (fig. 3). In the greater part of the division the average fall is about 10 inches per annum, and in the south-western portion it is from 10 to 15 inches per annum.

(7) The xerophytic vegetation, which in many places is stunted and sparse, and which over wide areas is remarkably uniform as a whole.

(8) The occurrence of very ancient rocks, which form a complex of granites, gneisses, greenstones, schists and sediments, generally regarded as of Pre-Cambrian age. Those rocks occupy practically

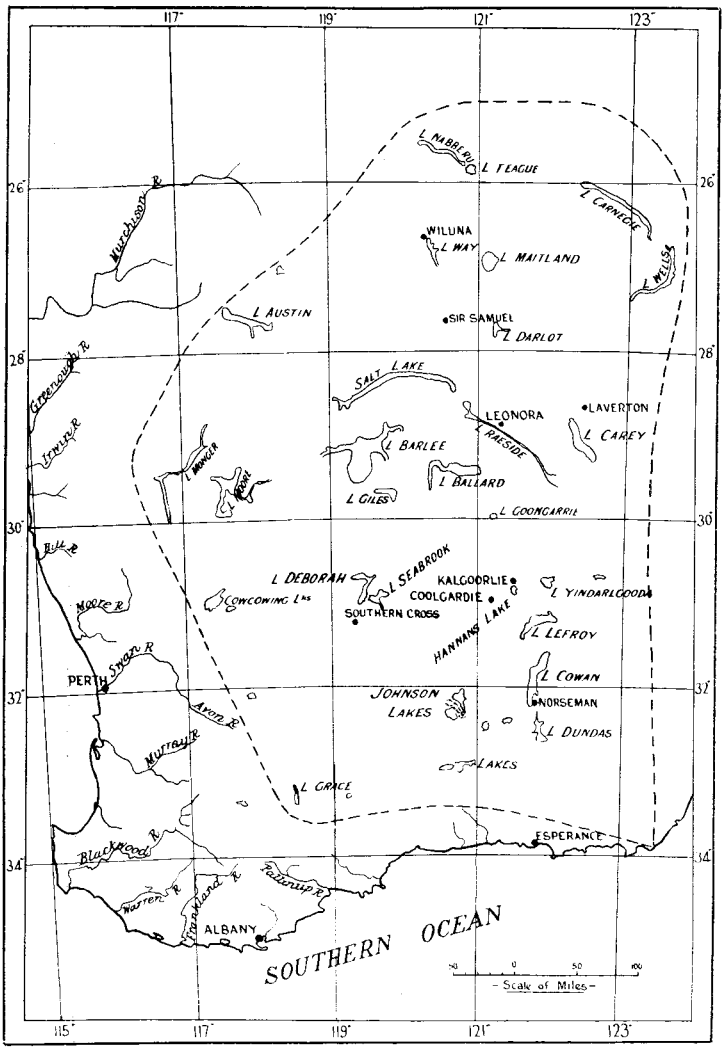


Fig. 51.—Outline Map of Salinaland, showing the principal "lakes" of the division. The broken line forms the boundaries of Salinaland.



Fig. 52.—Vegetation of Salinaland. Lake Violet (a typical salt ''lake'') with the halophytic plants characteristic of the borders of the salt ''lakes'' in the foreground.

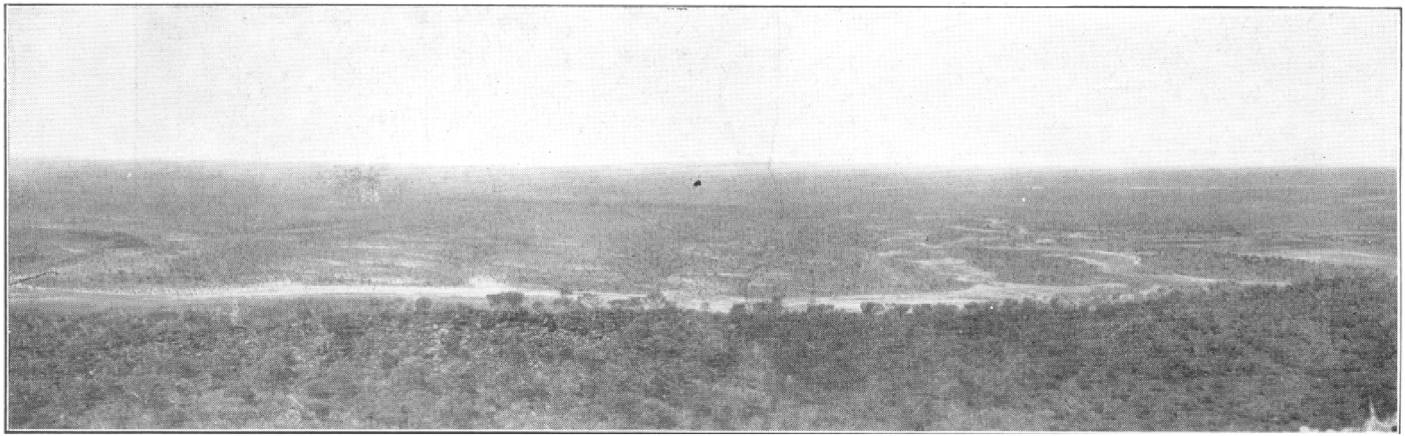


Fig. 53.—Parallel serpentine tributaries of a tributary of Lake Raeside, as seen looking east from Mt. Millicent, Yerilla district, Salinaland.

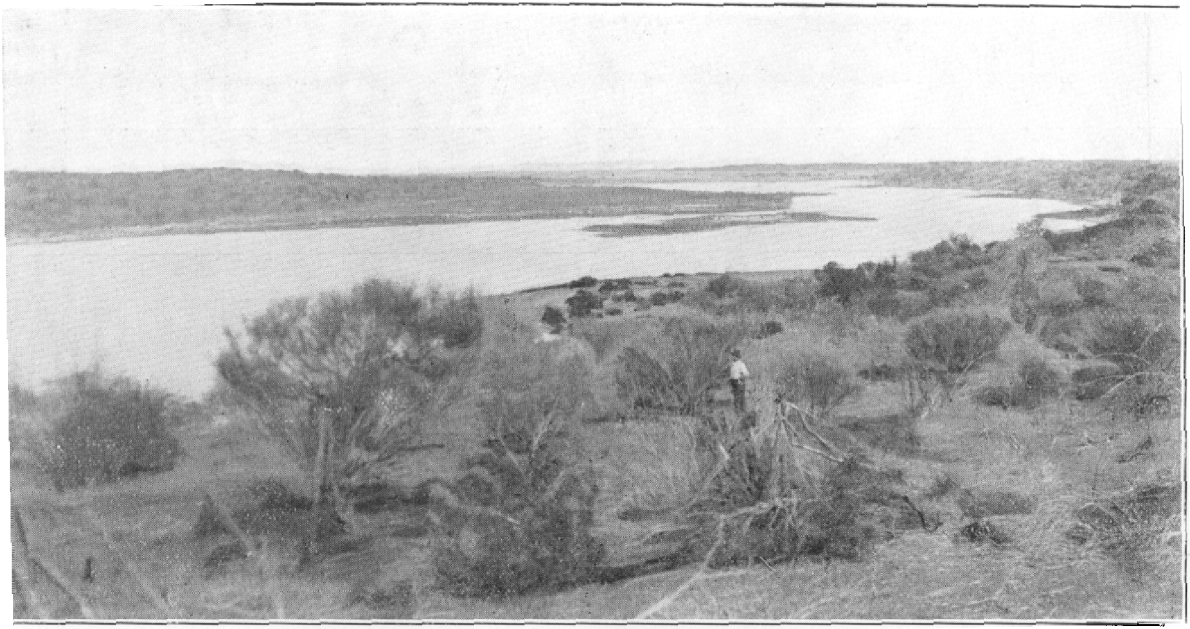


Fig. 54.—Mouth of the Brockman Creek, with Lake Carnegie in the background, Northern Salinaland. The portion of the creek shown really forms an arm of the lake.

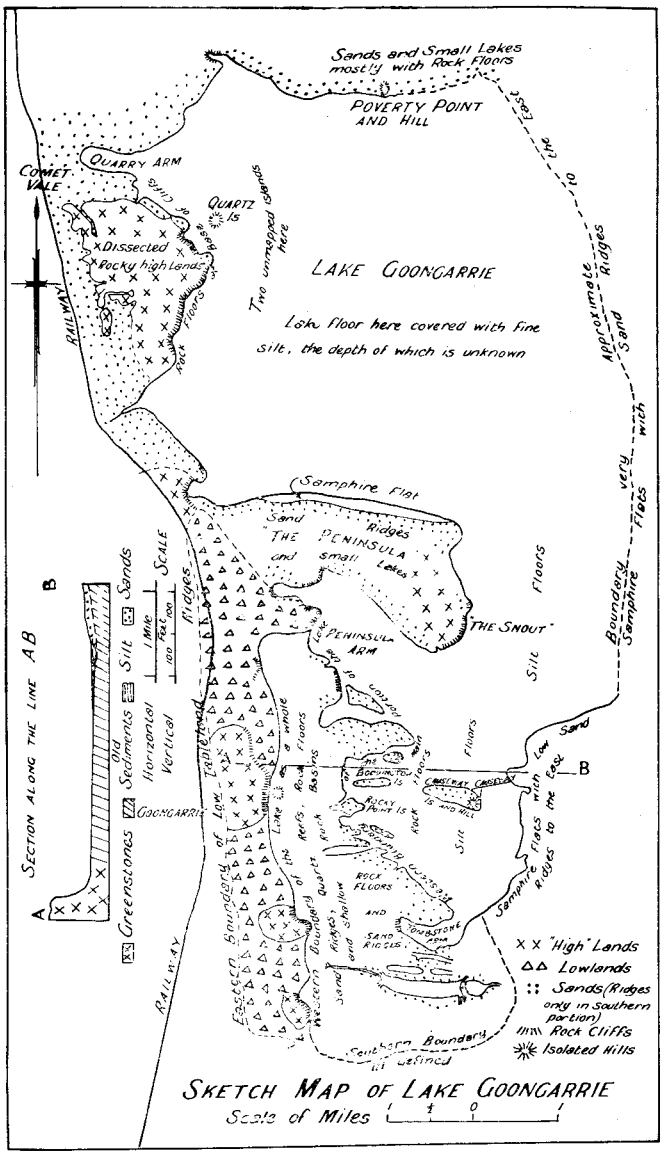


Fig. 55.—Physiographic Map of Lake Goongarrie, Salinaland. This "dry" lake illustrates very well the occurrence of rock cliffs and rock floors on the western side, and of sand ridges on the eastern, as well as the occurrence of "peninsulas," islands, silt floors and other sand ridges.

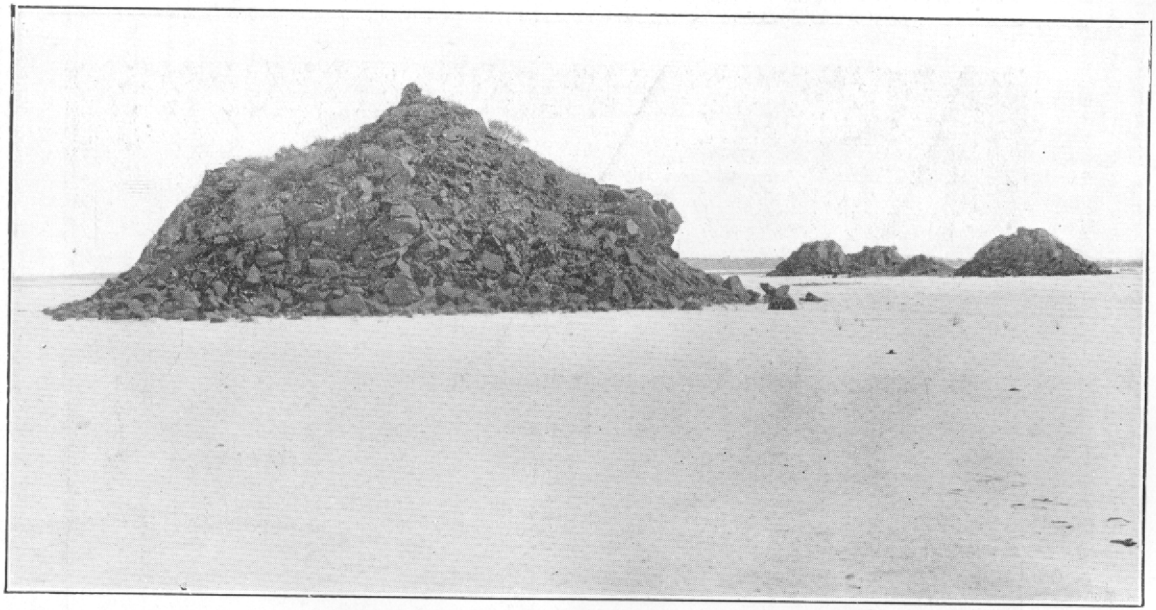


Fig. 56.—Surface of Lake Austin, near Day Dawn, Salinaland, showing islands of dolerite. The sharpness with which the islands rise from the "lake" is particularly well shown.

the whole of the division, the granites greatly predominating. The trend of the greenstone belts (see geological map, Pl. II.), the general strike of the sedimentary rocks, and the general direction of the foliation planes of the metamorphic rocks are about north-north-west, and consequently the topographical features largely follow the same direction. Associated with the rocks are many large projecting quartz "blows" which usually are barren of gold.

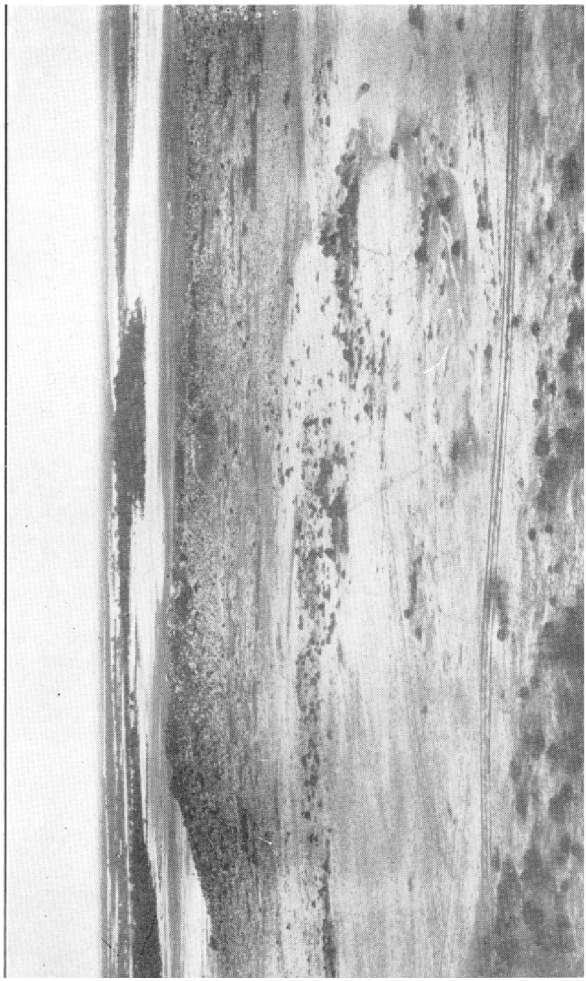


Fig. 57.—View across the southern end of Lake Goongarrie, Salinaland, looking east, showing on the dry floor of the lake, a quartz "blow" in the middle distance, and sand ridges, bearing vegetation, in the background.

(9) The great abundance of mineral wealth, consisting almost entirely of gold. The division as a whole is one of the richest goldfields in the world, the famous Kalgoorlie field being in this division.

(10) The high temperatures but low humidity in summer, and the mild, but bracing winters. The mean annual temperatures vary from 60° F., in the south to 75° F., in the north (see fig. 6).

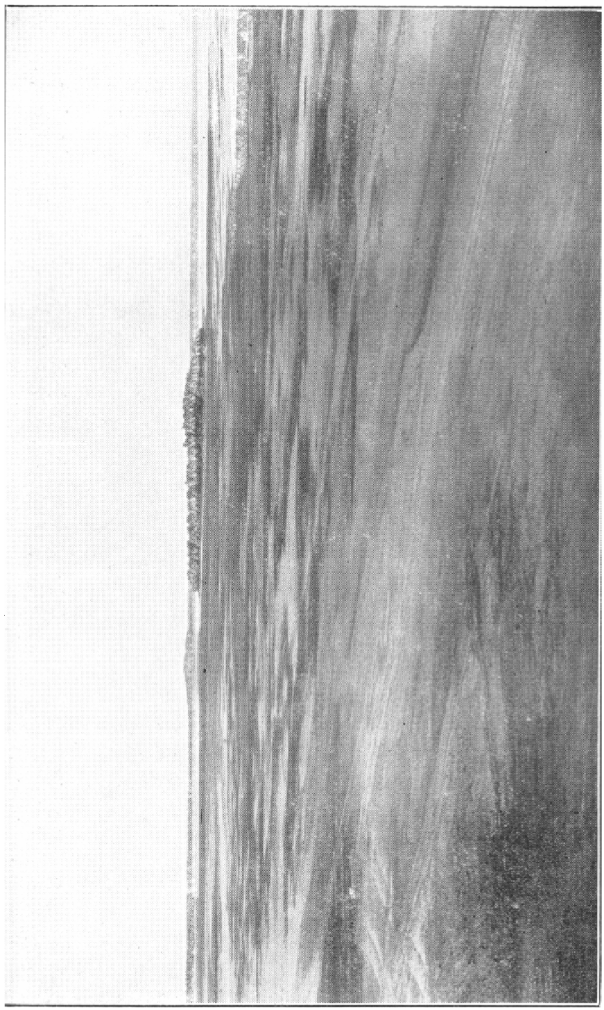


Fig. 58.—View across the northern end of Lake Goongarrie, Comet Vale, Salinaland, looking east, showing the dry, bare surface (rock-floored at the edge) in the foreground, an island composed of a quartz reef and blown sand in the middle distance, and water in the background. The water is blown about the lake by the wind.

(11) The abundance in places of rock detritus on the surface of the ground, as a result of the disintegration of the harder rocks, such as the fine-grained greenstones, quartz and ironstone. The detritus is so widespread on some hill slopes and plains that "stone fields" have been formed.

VEGETATION.

The xerophytic and frequently stunted and sparse character of the vegetation has been mentioned above. The vegetation is divided into two main groups, corresponding with differences of latitude, and the result therefore apparently chiefly of differences of temperature, although there is a somewhat greater rainfall in the south than in the north. These two groups occupy nearly equal areas. The dividing east and west line runs from Lake Moore in the west, easterly past Mt. Jackson, Broad Arrow, Pinjin and a little to the north of Queen Victoria Spring. The southern belt is bounded on the east by the Nullarbor Plains.

The southern (salmon gum) belt extends southwards from the east-west dividing line to the coast, and the northern (mulga) belt extends northwards to the northern boundary of Salinaland (see Pl. I.)

The salmon gum belt is characterised by the predominance of eucalypts of various kinds of which the salmon gum (*E. salmonophloia*) is the type and commonest species (see fig. 59). These eucalypt forests have been of great value to the gold mining industry for both mining timber and firewood; but the forests have been largely cut out, especially in the neighbourhood of Kalgoorlie.

The mulga belt, as its name denotes, is characterised by the great predominance of the "mulga" scrub, small trees up to about 15 feet in height of various kinds of acacias, with eucalypts strictly subordinate. The mulga timber has also been useful for firewood for the mines, and, to some extent, as mining timber.

The sandalwood (*Santalum spicatum*) grows throughout the division, and it has been much cut for export to China.

Most of the trees afford little shade, but there are some fine shady salmon gums on the goldfields. In small patches, the she-oak and the native pine occur, lending some variety to the landscape. Mention should also be made of the graceful and shady kurrajong tree, which usually grows singly.

Grass is generally absent except for a short period after moderate or heavy rain, so that the spaces between the shrubs and trees are bare. (The writer believes that he is well within the mark in stating that at least half of the ground—excluding the bare areas of the salt lakes—is quite naked during most of the year.) After heavy rains, numerous small annuals thrive for a time and carpet the country for miles.

The detailed character of the vegetation is often an important guide to the nature of the underlying rocks in areas, as in Salinaland, where outcrops are scarce. For general types of the vegetation, see figs. 52, 59, and 30.



Fig. 59.—Vegetation of Salinaland. Salmon gums (*Eucalyptus salmonophloia*) and salt-bush, Ora Banda, 40 miles north-west of Kalgoorlie.

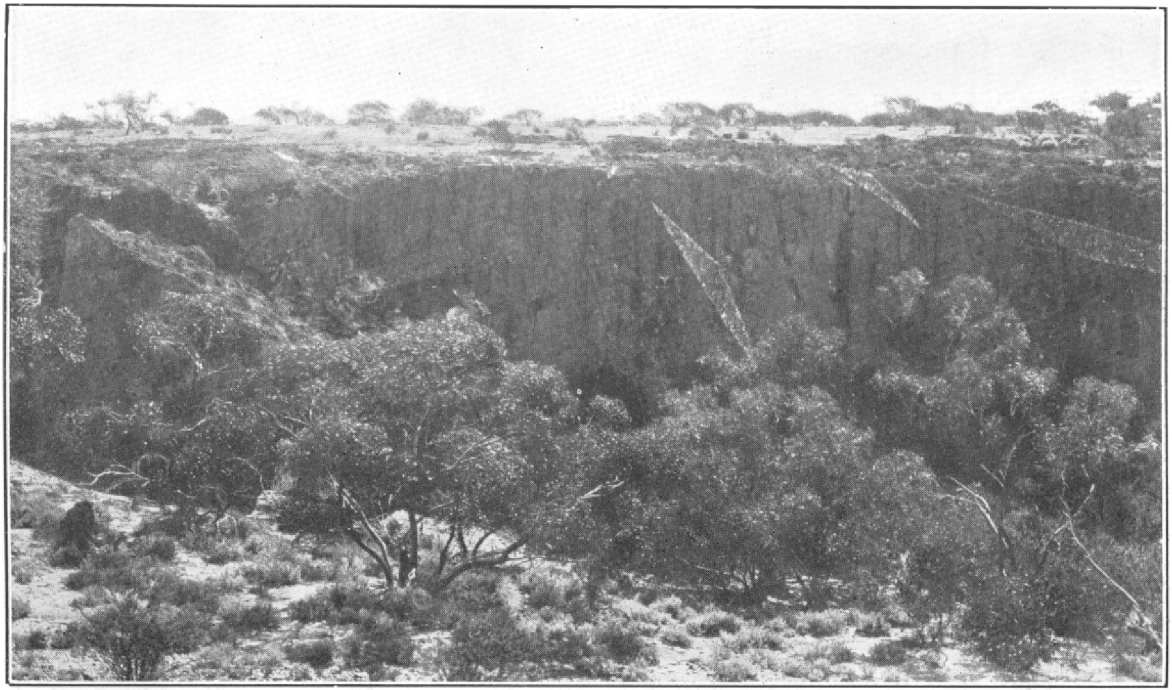


Fig. 60.—Vegetation of Salinaland at Niagara. Mulga (Acacia) on the barren tableland and small eucalypts with saltbush in the more sheltered lower country in the foreground.

CONTOUR.

The height of the new plateau in the division is difficult to determine. It possibly varies from about 700 feet to 2,000 feet. The railway heights are very instructive (figs. 61, 62, and 63). Thus,

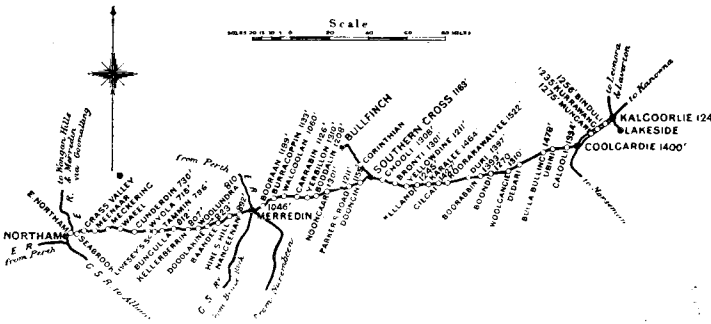


Fig. 61.—Map of portion of the Eastern Goldfields railway, showing the heights of the stations in Salinaland from Cunderdin to Kalgoorlie, illustrating the low average fall of the plateau from east to west.

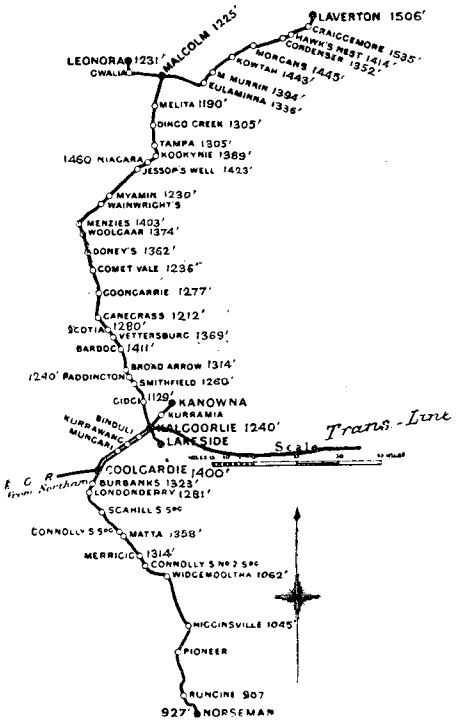


Fig. 62.—Map of portion of the Eastern Goldfields railway, showing the heights of the stations in Salinaland from Norseman to Laverton, illustrating the low average fall of the plateau from north to south.

taking the Kalgoorlie line from Cunderdin (730 feet above sea-level) near the western boundary of the division, to Koorarawalyee (1,522 feet), a distance of 175 miles, there is a rise of 792 feet, an average of 4½ feet per mile. From Koorarawalyee to Kalgoorlie the heights fluctuate, now rising, now falling, but Kalgoorlie (1,240 feet) is the lowest railway station, as Koorarawalyee is the highest. From Coolgardie (1,400 feet) south to Norseman (927 feet), a distance of 108 miles, there is a fall of 473 feet, giving an average of almost 4½ feet per mile. From Kalgoorlie northward to Malcolm railway station (1,225 feet), there is no continuous rise, the country fluctuating mainly between 1,200 and 1,400 feet, and reaching its highest point 114 miles from Kalgoorlie at Niagara (1,460 feet), which, however, is only 60 feet above Coolgardie. From the Malcolm railway station eastward to Laverton (1,506 feet) 64 miles, there is a rise of 281 feet,

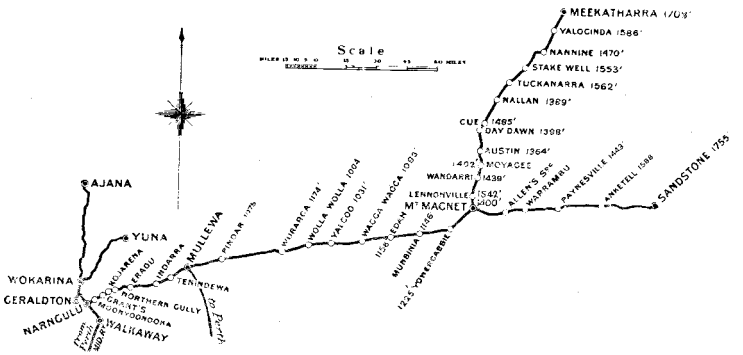


Fig. 63.—Map of the Mt. Magnet, Sand tone and Meekatharra railways, showing the heights of the stations in Salinaland from Pindar to Meekatharra and Sandstone, illustrating the low average fall of the plateau from north to south, and from east to west.

giving an average again of almost 4½ feet per mile, a remarkable coincidence with the other averages taken. Considering the railway much farther north, the Meekatharra line, and taking from Pindar (1,075 feet), east to Mt. Magnet (1,400 feet), a distance of 133 miles, there is a rise of 325 feet, an average of about 2½ feet per mile. From Mt. Magnet north to Meekatharra (1,708 feet), a distance of 118 miles, and a rise of 308 feet, there is an average of a little over 2½ feet per mile. From Mt. Magnet east to Sandstone, a distance of 93 miles, there is a rise of 355 feet, an average of about 3¾ feet per mile. These figures bring out very clearly that the country rises to the east and to the north, but very gradually.

The orographical map published by the Commonwealth Meteorological Bureau in 1918 shows that almost the whole of the division is between 1,000 and 2,000 feet above sea-level, thereby demonstrating the fact of its being a plateau. In the northern portion there is a narrow east-west belt shown on the same map as between the 2,000 and 3,000 feet contours. (See fig. 2.)

ECONOMIC ASPECTS.

Water in small quantities is obtainable from "gnamma holes" and "soaks" (see Part XV.), and it can also generally be found as well water, but the latter varies from fresh to brackish and salt. The character of the underground water in regard to its salinity has had an important influence in the use of the land for pastoral purposes, as it is on the underground water that stock have mainly to depend.

From a mining standpoint, the salt water has often caused much difficulty. The geological structure of the country, so far as known, forbids any possibility of artesian water.

The water supply difficulty has been largely overcome (1) by the magnificent water scheme provided by the Western Australian Government, by which millions of gallons of water are pumped through pipes from the Mundaring Reservoir, near Perth, to Kalgoorlie, a distance of about 350 miles, and a height of many hundreds of feet, the water also being distributed along the route by side-lines; and (2) by the comprehensive system of tanks, wells and dams in the more outlying parts, established by the Government.

The plateau character of the division, and the absence of close-set forests, render transportation easy by road or rail. The arid nature of the country, however, made the early exploration, prospecting and mining of the country difficult and full of hardship.

The undissected and arid nature of the plateau with its cover of laterite, travertine, clays and sands has had an important effect on gold mining, in that many of the lodes are quite hidden, and have often been discovered only by the merest chance; in that few lodes can be worked from tunnels or adits, as may often advantageously be done in more dissected countries; and in that the absence of streams has caused much difficulty and expense in obtaining the necessary water for mining purposes. Against these serious disadvantages, is the great advantage of easy transportation by road and rail. It may also be pointed out that over considerable areas there is not much accumulation of surface detritus; consequently the bedrock and its contained lodes in those areas are quite close to the surface, although unfortunately a thin cover of laterite or of other superficial deposits often conceals the lodes. This cover, however, is a small difficulty compared with that which would arise if great thickness of detritus existed to any extent. That such thick deposits do occur is shown by the records of the "deep lead" workings.

The division has produced an enormous quantity of gold, and is still producing a moderate amount.

In the western portion of the division wheat-growing is being extensively developed despite the low rainfall, and throughout the division sheep and cattle are grazed, the sheep now displacing cattle from areas formerly occupied by the latter alone. It must, however, be remem-

bered that, on account of the arid nature of the country, the number of sheep or cattle to a given area are few, compared with well watered countries.

COMPARISON AND CONTRAST WITH OTHER DIVISIONS.

The division in its contour, rainfall, and in the vegetation of its northern portion approaches Murchisonia in character, but it has no streams that can be called rivers, and in this respect it differs from Murchisonia, although in that division they are not well defined.

In its south-western portion, Salinaland in its vegetation is akin to that of the eastern portion of Swanland into which, as well as to the other adjacent physiographic divisions, Salinaland merges without any pronounced physical discontinuity. It is distinguished from Sandland by its more vigorous vegetation, by the absence of sand ridges over wide areas, by more drainage channels, and by the predominance of salt or "dry" lakes (salinas or playas), which are its peculiar characteristic, and from which it takes its name.

The physical differences between Salinaland and Sandland are due more to differences in the geology than to differences of climate.

CHAPTER IX.

THE SAND RIDGE DIVISION OR SANDLAND.

CONTENTS.

Boundaries. Literature. Rainfall. Temperature and Humidity. Vegetation. Geology. The Plateaux and Scarps. Contour. Sand Ridges. Sand Plains. Watercourses and Lakes. Economic Aspects.

BOUNDARIES.

This division is the largest of all the physiographic divisions of Western Australia (fig. 8). It is mainly confined to the eastern portion of the State, and, except in the extreme north and south of the State, it abuts South and Central Australia, into which areas the physical features of Sandland continue. It reaches the coast at the Eighty-Mile Beach between Fitzroyland and Pilbaraland. The division corresponds fairly closely with Clarke's three natural regions, Carnegie, Canning and Warburton combined. So far as existing knowledge indicates, there are not sufficient physical differences between the areas forming the Canning and Carnegie natural regions to make two physiographic divisions, so that for the present the one great division is maintained. The Warburton natural region would probably justify a separate division, but on account of its small area and the comparatively little information available concerning its physical features, it is at present included in Sandland.

Sandland as here defined is the most barren and least inhabited portion of Western Australia. It comprises part of the huge "Western Desert" described by Griffith Taylor (*b*, 2, fig. 1, and pp. 3 and 18) which extends into Central and South Australia, and also the Desert Outlet (Griffith Taylor *b*, 2, fig. 1, and pp. 17 and 18), which is the extreme north-western portion of the Western Desert.

LITERATURE.

Our knowledge of this division is due chiefly to the labours of the explorers now mentioned. Their lines of traverse are in most cases marked on the general topographical map of the State (Pl. II.).

1873. Colonel Warburton.
1874. John Forrest.
1875, and 1876. Ernest Giles.
1891-92. David Lindsay.
1896-97. D. W. Carnegie.
1896-97. L. A. Wells.
1904, 1906 and other years. Frank Hann.
1906-07. A. W. Canning and H. W. B. Talbot.
1912, 13 and 14. H. W. B. Talbot.
1916. H. W. B. Talbot and E. deC. Clarke.
1924. F. G. Clapp.

The publications most informative of the geology and geography are those by Carnegie, who travelled from Erlistoun to Hall's Creek and returned by a more easterly route; Talbot (*a*), who traversed with Canning what is now known as the Canning Stock Route; Talbot (*d*), who topographically and geologically mapped a vast area immediately to the north of Salinaland; and Talbot and Clarke (*a* and *b*), who mapped the country topographically and geologically between Laverton and the South Australian border by Mt. Gosse.

RAINFALL.

The rainfall (fig. 3) is low, the greater part of the division having an average annual fall of not more than 10 inches, except in a narrow northern belt, where it is between 10 and 15 inches, and also in the extreme north where it is from 15 to 20 inches. The latter area is so insignificant in size that it can be ignored.

Summer rains in the north, and winter rains in the south predominate.

The low rainfall, as would be expected, has had a very important effect on the configuration of the country, and on its vegetation, as will be shown below.

TEMPERATURE AND HUMIDITY.

The mean annual temperature ranges from about 65° F. in the south to 80° F. in the north (fig. 6), but away from the coastal area in the north, which is moist and muggy, the humidity is low, the great heat being thus tempered,

VEGETATION.

On C. A. Gardner's Vegetation map of Western Australia, 1928 (Bulletin 42 of the Forests Department), there are four main types shown in Sandland (see Pl. I.).

(1) A southern portion, north of the Nullarbor Plains, forms portion of the great mulga belt which sweeps away westwards and north-westwards to the coast north of Shark Bay.

(2) North of that belt and occupying most of the remainder of the division is the spinifex belt. (1) and (2) overlap each other, and it is probable that (2) predominates.

(3) In the extreme north of the division is the savannah belt, which extends westwards to the coast and passes into Pilbaraland and Fitzroyland. It is characteristic mainly of Pilbaraland.

(4) A small portion in the extreme south-west of the division belongs to the salmon gum belt. Details of these various belts are given in the Part treating of the vegetation of the State.

Carnegie, in his most interesting account of his explorations in the West Australian deserts, gives many graphic word pictures of the physical characteristics of portions of Sandland, including its vegetation. On pp. 178 and 179 is perhaps one of the best. He describes the country for 200 miles south-west of Mt. Worsnop, and shows that in addition to the spinifex, there may be, in different areas, desert gums, kangaroo grass, mulga thickets, various shrubs such as *Acacia salicina*, the quandong, the native poplar, an occasional grass-tree or "black boy" and little clumps of "mustard bush." The "hateful spinifex," however, predominates. (See fig. 64.)

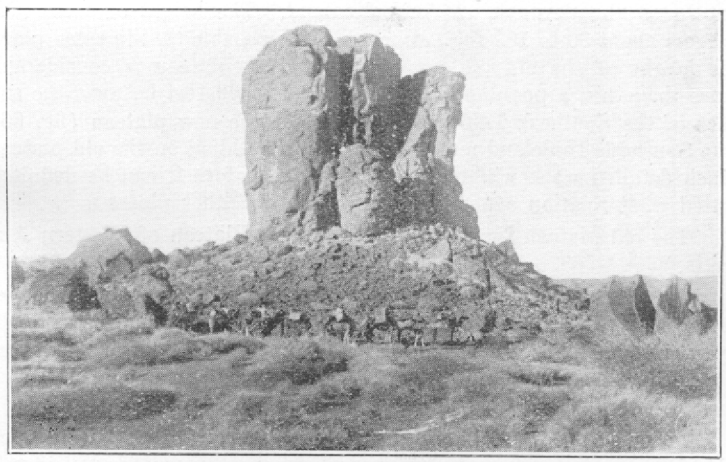


Fig. 64.—Vegetation of Sandland. Sandstone Butte, 33 miles east of the 692-mile post, rabbit-proof fence. A residual of erosion. Spinifex (*Triodia*), the typical vegetation of a great portion of the desert, is shown in the foreground.

The vegetation characteristic of the sand ridges, which constitute the most important physical features of the division, is referred to when describing those features.

GEOLOGY.

The rocks of the division are chiefly of sedimentary origin. They are either horizontal or but gently inclined, and largely consist of sandstones, the disintegration of which has furnished the enormous quantity of loose sand existing in the division in the form of sand ridges.

Reference to the geological map (Pl. II.) will show the distribution of these rocks. In the south-east there is a belt of Cretaceous, about which little is known. Jurassic rocks occur as a narrow fringe along the coast near Broome, and a great belt of Carboniferous rocks lies between the Fitzroy and the De Grey-Ridley Rivers and stretches away towards the eastern border of the State. South of this belt is a great band of rocks of the Nullagine Series, in which old lava flows are associated with sediments.

THE PLATEAUX AND SCARPS.

Sandland, like Salinaland, consists of a plateau, the "new plateau," on which stand the remnants, often in the form of mesas and buttes of an older higher plateau, the "old plateau." (See fig. 65.)

Much of the surface of the new plateau and some portions of the old plateau are masked by sand plains and particularly by sand ridges. The old plateau is in places capped by a band of laterite which rests upon somewhat soft rocks. The result is that the connection between the two plateaux is in many parts by fairly steep cliffs, which are known as "breakaways," as in Salinaland. The height of these cliffs is from about 30 to 100 feet, although it is probable that in some places the height of the old plateau above the new plateau is considerably more than this, a possible example being the 300 feet between the surface of the Southesk Tableland and that of the new plateau (fig. 66). The Southesk Tableland may, however, be a residual on the old plateau. Much detailed work will require to be done before it can be definitely stated what relation a particular hill bears to either plateau.

The old plateau forms part of the Great Plateau of Western Australia.

Talbot (*d*, 15) notes that to the east of the large rivers flowing towards the coast, there is an immense peneplain, broken occasionally by ridges and hills, extending eastwards beyond the South Australian border and northwards to Kimberley. The peneplain is evidently what the present writer terms the "new plateau."

No evidence of block-faulting in this division, except in one possible instance to be presently mentioned, has been recorded; but if such faulting has occurred, its presence would not be so readily observable as in Pilbaraland.

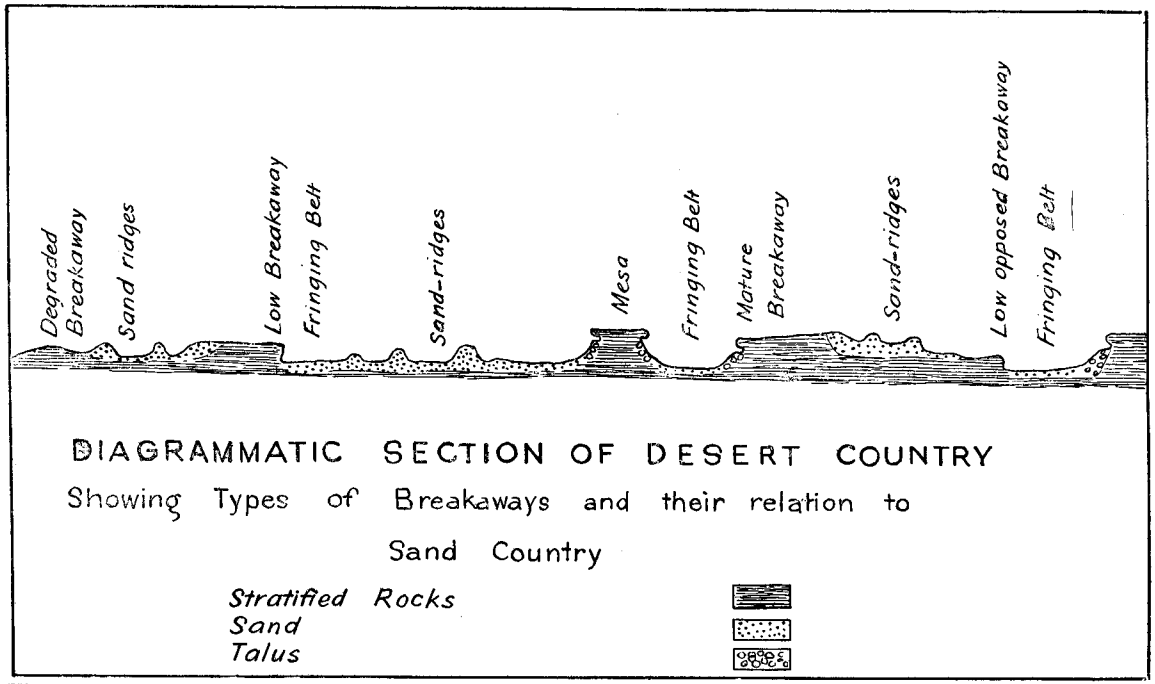


Fig. 65.—Diagrammatic section of Desert Country, showing types of "Breakaways" and their relation to Sand Country. It also illustrates the configuration of the country between Laverton and Townsend Range, Sandland. (After Talbot and Clarke, Bull. 75, G.S.W.A., fig. 12, p. 44.)

The possible example referred to is described by Clapp (*a*, 51, *et seq.*). It is an escarpment, termed by him the "North Escarpment of the Interior Plateau in the Desert Basin," and occurs in the extreme north-west of the division.

Clapp states that the escarpment constitutes a vast topographical feature 100 to 300 feet high in places, commencing 77 miles south-east of Broome, running south-eastwards for many miles, and then turning to the east. It faces the north-east and north, overlooking a broad

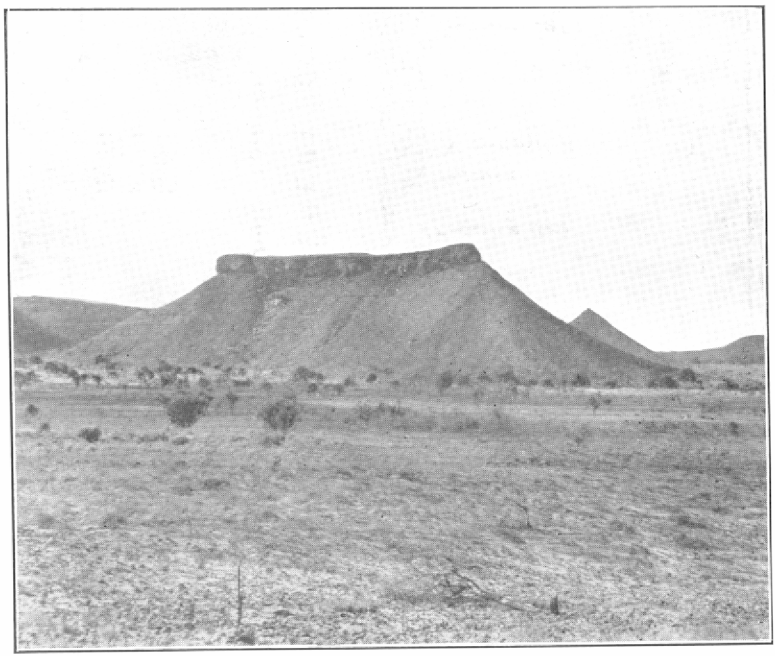


Fig. 66.—The Southesk Tableland, in the northern portion of Sandland. It rises about 300 feet above the level of the plain. The cap of hard ferruginous sandstone is well shown.

valley which forms part of the Fitzroy lowland. Throughout, it forms an irregular line of vertical cliffs, and in the vicinity of the 123rd meridian "breakaways" indent the plateau many miles back of the escarpment proper. The rocks composing the plateau are sediments dipping to the south-west at an angle of 1° to 2°. This escarpment may be given a briefer and therefore a more convenient name than Clapp's by terming it the "Great Desert Scarp."

Clapp does not discuss the origin of this striking feature, but the existence of the scarp over so great a distance immediately suggests that it is a fault scarp. On the northern side of the Fitzroy valley the fault scarp of the Napier Grant and other ranges (the Napier-Geikie Fault Scarp) occurs. Should the Great Desert Scarp be a fault scarp, then the Fitzroy Valley in its lower portion is a great sunkland (the latter term is preferable to rift valley in consequence of the great width between the scarps compared with the length of the portion of the valley referred to).

Further research as to the origin of this interesting scarp is highly desirable.

Monadnocks or residuals of erosion on the old plateau occur, of which Mts. Worsnop and Allott (close to latitude 26° and longitude 125°), Mts. Wilson and Elphinstone in the extreme north-east, and Mt. Webb (north of Lake Macdonald) are probably examples. The Southesk Tableland may also be, as above suggested, of similar origin.

In the extreme central east of the division in the Warburton region, the numerous hills may be regarded as monadnocks on the old plateau (see Talbot and Clarke, *a*, 59, who refer to the occurrence of a large peneplain on which the hills and ranges form monadnocks).

CONTOUR.

In regard to the height of the new plateau, the orographical map of Australia published in 1918 by the Commonwealth Weather Bureau (fig. 2), shows the greater portion of the division to be between 1,000 and 2,000 feet above sea-level, and falling (apparently gradually) to the southern and north-western coasts respectively. Judging by the heights recorded by Wells and by Talbot and Clarke (*a*, 40) the greater part of the new plateau would be about 1,500 feet above sea-level.

SAND RIDGES.

The most striking characteristic of this division, which in itself is one of the most remarkable in Australia, is the predominance of sand ridges; hence the alternative names which the writer has given to the area.

"One of the most remarkable characteristics of the interior of Western Australia is the enormous development of sand-ridges, which extend from the northern edge of the Great Southern Plain northwards to Kimberley, and eastwards to the South Australian border, from a line drawn from near Condon on the North-West coast through Erlistoun and thence southwards." (Talbot and Clarke, *a*, 41.)

This sand ridge country passes into Central and South Australia, the whole area being referred to by Griffith Taylor (*b*, 2, fig 1, and 3) as "the Western Desert." It occupies about 440,000 square miles, of which much the greater part is in Western Australia.

Some idea of the vast extent of the sand ridge country is gained from Carnegie's record (412) of a traverse of 420 miles on the outgoing (northern) journey, and of a traverse of 451 miles on the return (southern) journey in different country, *i.e.*, 871 miles of actual travelling, over a desert of sand, blown by the wind into parallel ridges.

The general trend of the sand ridges north of latitude 26° S., except in proximity to the ranges and hills, is west-north-west (Talbot and Clarke, *a*, 41, Keartland, 41, and Carnegie, 178). Clapp (*a*, 62), in the north-western portion of the division, records their direction as between S. 75° W. and N. 75° W. To the south of latitude 26° the sand ridges in different areas may run in different directions, although in each area they are approximately parallel (Talbot, *d*, 25). The irregularity in direction is ascribed to the variableness of the winds south of latitude 26°. North of that latitude, the ridges are parallel to one another and to the direction (E.S.E.) of the prevailing wind, the trend of the ridges being due to that wind. Where, however, in this northern area blown sand occurs in the vicinity of ranges and hills, the sand is heaped up into a jumble of hills and ridges which have no particular direction (Talbot, *d*, 25).

The remarkable parallelism of the sand ridges over wide areas, even, as shown above, where the directions are different in different areas, is noted by all the authors mentioned above.

The height of the sand ridges varies considerably. In the north-western portion they range from a few feet to 60 feet in height, measured from the base of the sharp ascent (Clapp, *a*, 62). Carnegie notes (178) that in one part they are from 30 to 50 feet high, that in other places (259) they have an average vertical height from trough to crest of 50 to 60 feet, and that though some are mere rises, others attain a height of considerably over 100 feet. Wells (19) also records sand ridges 100 feet high. Between Laverton and Townsend Ranges the sand ridges have an average height of about 30 feet (Talbot and Clarke, *a*, 43). The highest sand ridge noted by Talbot is Streich Mound, close to Queen Victoria Spring, which "rises to a height of about 150 feet above the surrounding sand hills and is, by aneroid, 330 feet above a depression 60 chains to the west. It is visible for a distance of 20 miles from any rise to the east or south-east, and forms a good landmark by which Queen Victoria Spring may be picked up" (Talbot, *c*, 5).

The length of the ridges also appears to vary much, but there is little recorded information on this point. In the north-western portion they are very persistent, and few of them have any ascertained termination (Clapp, *a*, 62).

The width of the ridges is also variable, so far as our scanty knowledge permits any statement to be made. In the north-western portion, they vary from 150 to 1,500 feet (Clapp, *a*, 62).

The distances apart of the ridges are very unequal. In the north-western portion, 85 sand ridges were crossed in a traverse south from the North Plateau escarpment (Clapp, *a*, 62). Presumably they were fairly close together. The depressions between them were only slightly encumbered with deep sand, so that an ordinary motor car, once arrived between any of the ridges, could travel for long distances between them (Clapp, *a*, 62). In the more northerly portion, the ridges were so close together that, in a day's march, Carnegie (249) crossed from 60 to 80 ridges. In places he states (250) the ridges were a quarter of a mile apart, but in other parts ridge succeeded ridge like the waves of the sea, and on one day he was crossing them at the rate of 10 in 40 minutes. Keartland (41) notes, in regard to the sand ridges farther west, that they were in places half a mile apart, but that occasionally they were so close together that the leading camels in the caravan were ascending a ridge before the last of the team had descended the previous one.

Between Laverton and the Townsend Range, the distance between the sand ridges is from about 200 yards to nearly a mile (Talbot and Clarke, *a*, 43); and along the Canning Stock Route the distance varies from a few chains to a mile or more (Talbot, *a*, 81).

North of latitude 26°, on the western or north-western side of ranges and hills, the ground is usually free of sand ridges; but on the eastern and south-eastern sides the sand ridges are piled up against the hills as a result of the prevailing east-south-east wind; the sand occasionally drifts over the western face and obliterates all traces of the rock beneath (Talbot, *d*, 25).

The vegetation of the sand ridges is distinctive. On those along the Canning Stock Route there is usually a fairly strong growth of vegetation consisting of desert gums, shrubs of various kinds, spinifex (*Triodia*) and sometimes grass (Talbot, *a*, 81). Carnegie (177) refers to the ridges as being overgrown by the "hateful spinifex" and timbered pretty thickly with desert gums (*Eucalyptus eudesmoides*) and low acacia bushes. In the sand ridge country between Laverton and the Townsend Range spinifex predominates. Desert gums grow on the ridges and the intervening flats, and mallee and mulga also grow on the flats but are not seen above the base of the ridges. Parakylia grows luxuriantly (Talbot and Clarke, *a*, 43).

Concerning the sparseness or abundance of vegetation, Carnegie notes (249) that portions of the country traversed by him are very barren and destitute of vegetation (except spinifex) and that (252) spinifex does not grow on the tops of the ridges; and Talbot (*d*, 26) records that there is often some loose, bare sand on the tops of the ridges. Clapp (*a*, 62) referring to the sand ridges in the north-western portion of the division observes that most of them are covered with a growth of hummocky spinifex, but that they have a greater proportion of sand than spinifex surface, and they support a few trees. Taken as a whole, the vegetation on the sand ridges may be said to be sparse.

So far as known, the sand ridges are composed practically entirely of quartz which has been derived partly from granite, but chiefly from the vast areas occupied by the sedimentary rocks of Nullagine, Permo-Carboniferous and Cretaceous age. A glance at the geological map (Pl. II.) will confirm this statement, and show that the great abundance of sand ridges in Sandland and their comparative scarcity in Salinaland are not due to any great differences of rainfall, but are due almost entirely to the differences in the lithological composition of the rocks of the respective divisions. Granite provides sand, but not in the same quantity as the sedimentary rocks. Talbot (*d*, 16) has noted that a large area of the country described by him to the immediate north of Salinaland is uninhabited, not by reason of the scarcity of water, but owing to the barren nature of the country. This barrenness is due to the preponderance of sandstones and quartzites.

Very little attention hitherto appears to have been given to the mineral composition of the sand ridges, and the size, shape and general characters of the component grains. Studies on these lines may be looked for in the future.

The interesting question as to whether the sand ridges are fixed or moving has been briefly touched upon by Carnegie, Talbot, and Clapp. North of latitude 26° the sand ridges appear to be moving westwards (Talbot, *d*, 25) as would be expected in view of the prevailing east-south-east winds. This feature, however, is only observable at the western ends of the belts. As one passes eastwards "the type of vegetation changes, the ridges grow in size and length, and in a few miles from where the first sand is encountered one finds himself amongst the established ridges with the usual growth of desert gums, spinifex and low scrub" (Talbot, *d*, 25). In the same publication Talbot (26 and 27) notes that the sand ridges appear to be practically stationary, that there is little manifestation of erosion of the sand ridges, that there is a movement in the grains of sand on the surface of the ridges, but that the sand appears to be deposited as fast as it is removed, and that the stability of the sand ridges is due entirely to the covering vegetation, amongst the types of which spinifex is the most important, in restraining movement of the sand. See also Talbot and Clarke (*a*, 41) to the same effect.

Carnegie records (252) that the spinifex serves to bind the sand and keep the ridges for the most part compact.

Clapp observes (*a*, 62) that sand ridges are still being deposited over large areas of the interior.

Some observations may be made as to the stability of the sand ridges. Talbot (*d*, 26) remarks that in windy weather a large amount of sand is driven forward by the wind, and also that it is only on the tops of the ridges, where there is often some loose bare sand, that the movement of sand is noticeable. He also observes (Talbot and Clarke,

a, 41, 42), that north of latitude 26° the prevailing south-easterly wind has blown in the daytime with sufficient velocity, for three weeks without a break, to fill the air with dust and fine sand. Griffith Taylor (*b*, 18) states that the constant south-east trade winds blow the sands of the sand ridge desert into the ocean [at the Desert Outlet] just as is the case to the west of the Sahara, and that from an aeroplane he had an excellent view of the streaks of yellow and red dust extending for miles over the waters of the pearling grounds. It is clear, therefore, that much fine sand and dust are being driven westwards by the wind, and Talbot (*d*, 25), as noted above, has shown that the sand ridges at the western end of the belt are moving westwards. These facts necessitate the consideration of the origin of the sand that is observed to be moving. Some of it must arise from the disintegration of siliceous rocks that are still outcropping, but these outcrops are probably very small in comparison with the vast surfaces of bare sand (allowing for a moderate amount of vegetation on the sandy country) that occur. Enormous quantities of sand are therefore available at any time to the action of the wind, and must be moved by the wind. If the latter were variable there might not be much change in the sand ridges, but as in the northern areas the prevailing wind is east-south-east, the direction of sand movement is west-north-west. This movement is readily observable on the tops of the ridges, but it may be much slower and not directly observable at the bases and sides.

It may therefore with some degree of confidence be maintained that, although the ridges away from the western margin are relatively stable, yet there is probably a steady, if slow, westward movement of the ridges. These remarks are intended to apply only to the ridges which occur north of latitude 26°.

SAND PLAINS.

Associated with the sand ridges are the sand plains, which are naturally less conspicuous than the sand ridges, but which nevertheless occupy considerable portions of the division. Their name indicates their essential characteristics. The sand may be derived either from granite or from sedimentary rocks, but in the belt of country between Laverton and the Townsend Ranges the sand plains overlie granite and the sand ridges rest upon the sedimentary rocks (Talbot and Clarke, *a*, 41). It is suggested by these authors (41) that the reason for this peculiarity is perhaps that the granite sand is coarser than that derived from the other rocks, and that it is too heavy to allow the wind to arrange it in the form of ridges. There is, no doubt (they state), a good deal of movement in the sand on the granite area, but it appears to lead to levelling-up rather than to dune-building.

The thickness of the sand deposits on these plains is probably inconsiderable (Talbot and Clarke, *a*, 41), but they are suffi-

cient to cover the bedrock over wide areas. Farther north, sand plains and sand ridges both occur on granite areas, but the former predominate (Talbot, *d*, 27).

Spinifex and desert gums constitute the chief vegetation of the sand plains as of the sand ridges; but on the plains there may be in addition thick clumps of mulga and occasionally a little wattle and quandong (Talbot and Clarke, *a*, 40 and 41).

Carnegie describes the country traversed by him as a great undulating desert of gravel, formed largely of pebbles of ferruginous sandstone. Apparently this refers to the plains or "flats" between the sand ridges.

WATERCOURSES AND LAKES.

The whole division is essentially riverless. By far the greater portion is occupied, as already noted, by sand ridges and sand plains. Mesas, bounded by breakaways, and various isolated hills and ranges of higher land, occur; and in them gullies and canyons are cut by the rain (see fig. 67). Ephemeral streams are formed which, on passing out on to the plains, become lost in the sand short distances from the higher lands, or empty themselves into salt lakes.

The best known watercourse is Sturt Creek in the extreme north. This runs into Gregory's Salt Sea.

In the extreme eastern portion of the division in the vicinity of latitude 20°, Elder and Lilian Creeks are well defined, but their courses are very short, and each soon loses its identity on the plains (Talbot and Clarke, *a*, 76). In the northern portion of the division, the gorges cut by water action in some of the hills are valuable in that they conserve water by means of natural rock-holes. This aspect is referred to below.

Salt or "dry" lakes appear to be few in Sandland, as would be expected from the wide distribution of sand, which must absorb immediately so much of the rainfall. Very little, however, appears to be known about those "lakes" that do exist.

On the general topographical map of the State (Pl. II.), Lakes Yeo (north-west of Laverton), Rason (south of Lake Yeo) and Macdonald (on the Tropic of Capricorn and near the Central Australian border) are shown. These appear to be lakes of moderate size, but no particulars concerning them are available. Gregory's Salt Sea, a group of lakes near the South Australian border in the vicinity of latitude 29°, and a few others are also shown on the map.

ECONOMIC ASPECTS.

From the nature of the country there is practically no permanent surface water. Such surface waters as do occur are in the form of rock-holes and gnamma holes. In addition to these small natural reservoirs the native wells and soaks in certain parts are of great value. These are, however, not always found even in country of similar geological structure to that in which they are known to occur. Thus Talbot

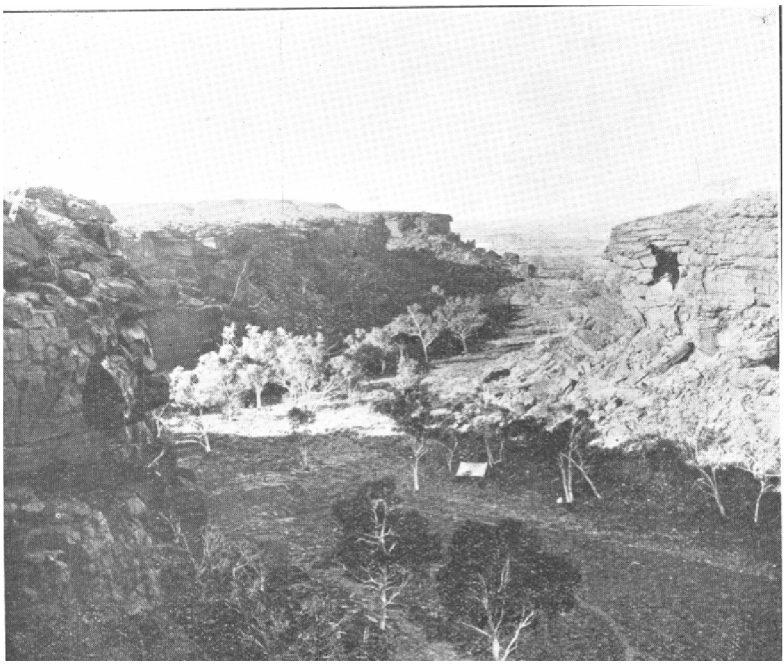


Fig. 67.—A sandstone gorge in Sandland, due to stream action. Near Killagurra Spring, about 250 miles north of Wiluna.

and Clarke (*a*, 22 and 23), referring to the country between Laverton and the Townsend Range area, state that there is an entire absence of native wells on the flats between the sand ridges, whereas in similar country along the Canning Stock Route native wells and soaks are found, many containing permanent supplies of water. In the Laverton-Townsend belt the only waters seen occurred on the top or at the base of the "breakaways" (*Idem, a*, 23).

Examples of the rock-holes found in the gorges of creeks are Breadon's Pool (fig. 68) and Godfrey's Tank, which are close together on the Canning Stock Route between latitudes 20° and 21°. The rocks are sandstones. (See Talbot, *a*, 53-55, and figs. 26 and 27.)

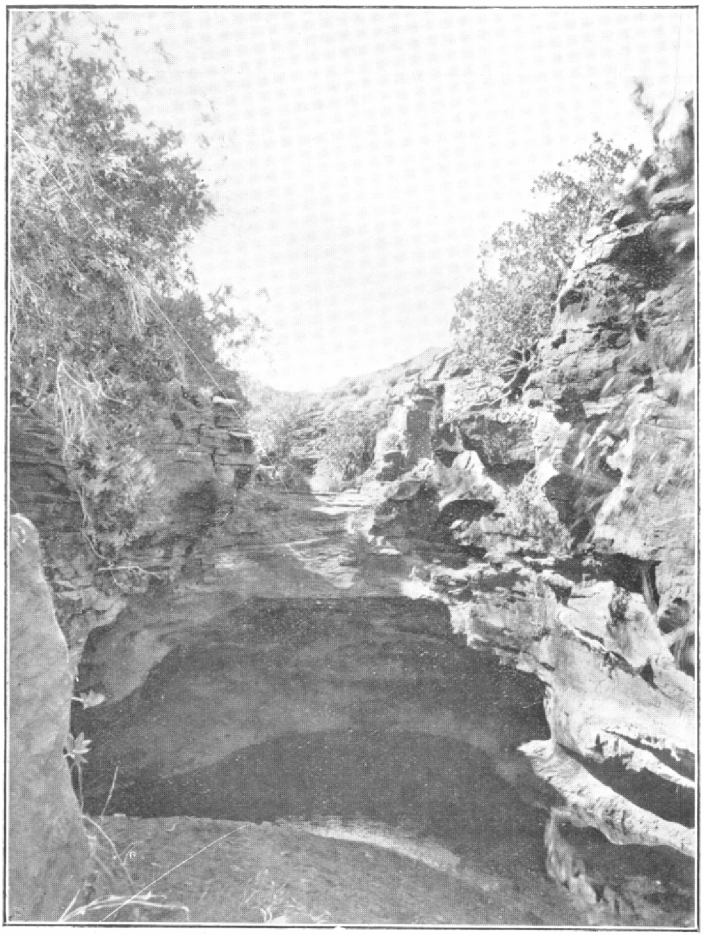


Fig. 68.—Breadon's Pool, a rock-hole in sandstone in a creek gorge. Near Canning Stock Route, Sandland.

No minerals of any value have been found in the division; and, except in limited areas, the country appears to be practically useless even for pastoral purposes, and over vast areas it is uninhabited.

Although there is so little surface water available, excellent ground water can be obtained at fairly shallow depths along the Canning Stock Route, and probably elsewhere in the division; but, at present, hardly any information is available as to the underground water outside of the Canning Stock Route. Artesian water has been proved to exist in the extreme north-western portion of the division. This artesian belt is known as the "Desert Basin" (fig. 19).

The Canning Stock Route between Wiluna and Hall's Creek, along which a number of wells were opened up for the purpose of bringing cattle from Kimberley to the southern portions of the State, had up to 1925 only once been used for stock in the fifteen years since it was opened, by two parties of drovers, and the members of the advance party were murdered by blacks (Griffith Taylor, *b*, 6 and 7).

Pearling is carried on at the north-west coast with Broome as headquarters.

Hitherto the camel has been the only reliable means of transport, but, as noted above, Clapp was able to make use of the motor car a good deal by using the flats between the sand ridges. The aeroplane will doubtless play an important part in the future in journeying over this division.

CHAPTER X.

EUCLONIA.

CONTENTS.

Boundaries. Rainfall. Temperature and Humidity. Vegetation. Characteristics of the Eucla Limestone Plateau. Drainage and Water Supply. "Blowholes" and "Dongas." Coast Line. Economic Aspects other than Water Supply.

BOUNDARIES.

The division is a comparatively small one (fig. 8). It is bounded on the south by portion of the Great Australian Bight, on the east by South Australia (into which the distinguishing physiographic features continue), on the west by Salinaland, and on the north by Sandland. Euclonia, as here defined, corresponds approximately with Clarke's "Nullarbor" (*b*) but, for reasons already stated, that term is not adopted.

RAINFALL.

The rainfall, except near the coast, is under 10 inches per annum (fig. 3). Along a very narrow coastal strip, it is between 10 and 15 inches per annum.

TEMPERATURE AND HUMIDITY.

The mean annual temperature for the greater part of the division is between 60° and 65° F. (fig. 6). The humidity, as a rule, is low.

VEGETATION.

Gibson (*d*, 18) describes the country as composed of vast, treeless, grass and saltbush plains with some timber nearer the coast. This description finds cartographic expression on C. A. Gardner's "Vegetation Map of Western Australia" of 1928 (Bulletin 42 of the Forests Department of Western Australia) where the 10-inch rainfall belt is coloured as treeless saltbush plains (D1 in the Part of this work on the vegetation of the State); and the narrow coastal strip, with a 10 to 15 inch rainfall, is shown as part of the Salmon Gum Belt. (See Pl. I. of this work.)

On Gibson's map, the country near the coast, from Twilight Cove to Balladonia, is marked in places as possessing mallee and myoporum, with some grass and saltbush, and patches of spinifex.

CHARACTERISTICS OF THE EUCLA LIMESTONE PLATEAU.

The division comprises the plateau known as the "Eucla Limestone Plateau," which is composed of limestone of Miocene age (Maitland, *k*, 44 and 88). The rocks lie either quite or nearly horizontal. Below the Miocene are sedimentary Cretaceous rocks of great thickness (Maitland, *k*, 39). It is the outcrop of the Eucla Limestone which constitutes the area as a distinct physiographic division.

The plateau extends into South Australia, and is described by Maitland (*k*, 44) as follows:—"The plateau at its southern extremity at the head of the Great Australian Bight is from 200 to 400 feet above sea-level; it is more or less abruptly truncated by cliffs which in part form the coastline and elsewhere occur at varying distances inland. The plateau rises steadily to the north, and where it is traversed by the Great Western Railway its altitude above sea-level varies from 450 to 650 feet; from the railway line it gradually passes northwards into the Central division of the State, where the average altitude is about 1,000 feet above sea-level. There are no rivers on the plateau, hence few if any natural sections of the strata are to be seen. The strata of which the Nullarbor Plains are built up consist of more or less cavernous limestone (the Eucla Limestone) associated with soft sandstones, clay shales,

and occasional conglomerates. It is now known from the bores put down in connection with the water supply of the Great Western Railway, that these sedimentary rocks attain a thickness of at least 2,000 feet. The limestone maintains a fairly uniform lithological character over its whole length, though it varies very much in thickness, being from 485 feet to 903 feet. All the available fossil evidence indicates that the age of the Eucla Limestones is Miocene Tertiary."

The treeless elevated plains forming the plateau are the famous Nullarbor Plains, which extend into South Australia, and constitute one of the geographical wonders of the world by reason of their vast extent, their treeless character, the absence of rivers and their remarkably level surface. The Trans-Australian (Great Western) railway line runs for 330 miles across these plains without a curve (Bolam, 47).

Notwithstanding the absence of streams, as there is a definite but very gentle fall of the country towards the coast, the rain and the wind must gradually lower the surface of the plateau, and in process of time, such surface may reach the base-level of a peneplain. Such a plain would be wrongly interpreted as a peneplain formed by normal erosion, that is to say, by rivers first reaching base-level and then the remainder of the area being reduced to that level approximately.

Residuals do not appear to exist on the plateau. If this be so, it is probably due to the uniformity of rock structure, which permits of even denudation.

The plateau is part of the Great Plateau of Western Australia, the origin and history of which are discussed in Part VIII. The surface, however, of the Eucla Limestone Plateau has no doubt been worn down considerably since its uplift.

DRAINAGE AND WATER SUPPLY.

There are no rivers on the plateau, as the porous rocks absorb practically the whole of the rain, some of which is discharged in the form of freshwater springs at the ocean (Maitland, *h*, 13).* As a result of the absorption of the rain, normal erosion is absent, and the plateau remains to all intent a level surface. It is described by Gibson (*d*, 18) and by Maitland (*h*) as practically dead level, or at most slightly undulating. It actually falls to the east at the average rate of nine inches per mile (Bolam, 47), and there is also a gentle fall to the coast. It is covered with a varying depth of light-coloured loam, from beneath which flaggy limestone can be seen outcropping in places. The only surface water that can be procured

* The area, therefore, is an example of "cryptoreism," that is, as defined by Fenner, having underground drainage. In the present work, however, it is placed in the area of no surface (areic) drainage.

is from a few small "gnamma holes" (fig. 69), which are quite insufficient for stock purposes. Artesian and sub-artesian stock water has, however, been obtained by boring (Maitland, *k*, 89), but it is too saline for use in large areas of the plateau (Griffith Taylor, *b*, 20). The division constitutes an artesian area which is known as the "Eucla Basin" (fig. 19, and see Maitland, *k*, 88, 89).

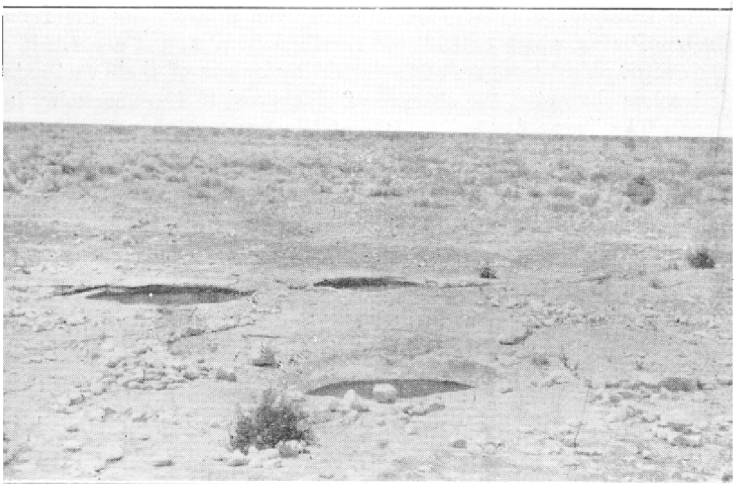


Fig. 69.—The Nullarbor Plain, showing the low-growing vegetation (saltbush, etc.), and also gnamma holes in the Tertiary limestone, which forms the rock of the plain.

"BLOWHOLES" AND "DONGAS."

Castilla (4) notes that the plains are dotted with "blowholes" into which, after heavy rains, considerable streams can be seen running.

Bolam in his delightful "Trans-Australian Wonderland" (Chapter 6) gives an excellent account of the "blowholes" and also of the "dongas." The "blowholes," he states (50) occur as far north as 100 miles from the coast. He describes them as "more or less circular pipe-like openings in the limestone crust, with a diameter of from one foot to eight feet. Through these openings the air often rushes with considerable force, and in some cases the outward draught is so powerful and constant as to keep a felt hat suspended in it. At other times there is a strong suction, and any light object held over the mouth of the blowhole is rapidly drawn in. Some of the blowholes are almost extinct, so far as their pneumatic action is concerned."

Bolam considers that the blowholes were undoubtedly gnamma holes, and that the water which collected in the holes gradually dissolved the limestone and ate through to the caverns beneath, which had been scooped out by underground water. Although the mouths of the blowholes are circular, the sides close in as they descend, and have ledges of rock. The bottom is usually a crevice in the solid rock (Bolam, 50).

To quote Bolam again, regarding the "dongas" (51 and 52):—"Every here and there on the Nullarbor Plain there exist shallow circular depressions in the surface, and these are called 'dongas.' The dongas vary in diameter from five chains to three miles, and the greatest have a depth of about 20 feet in the centre. They are undoubtedly formed by the caving in of subterranean chambers in the limestone. In the lowest part of the basin there is almost invariably a hole through which the water escapes. The dongas generally carry a good depth of soil, and grasses, buck-bush, etc., grow in great profusion in them. That beautiful flower, Sturt's Desert Pea, grows luxuriantly in all the dongas, giving a touch of vivid scarlet to the depressions."

The subterranean chambers or caves referred to by Bolam must be fairly common, and systematic search would doubtless result in many caves being located.

COAST LINE.

The coast line is remarkably smooth and unbroken. The western half is bounded by almost vertical cliffs (the Bunda Cliffs) from 200 to 400 feet in height, and the eastern half has mainly low sand-hills, backed by high cliffs at varying distances from the coast. The coast line is discussed in the first chapter of Part XIV., but here it may be said that these high cliffs are, no doubt, a fault scarp, as noted by Woodward (*a*, 15) and may be referred to as the Great Bight or Bunda Scarp (fig. 70).

ECONOMIC ASPECTS OTHER THAN WATER SUPPLY.

Roads and railways offer no engineering difficulties along the extraordinarily level country of the division. It is traversed by the Great Western Railway, which by reason of the absence of watercourses was laid with great ease and rapidity.

Except in a limited pastoral way, the plateau is of no economic use at present. Its water supply has been referred to above.

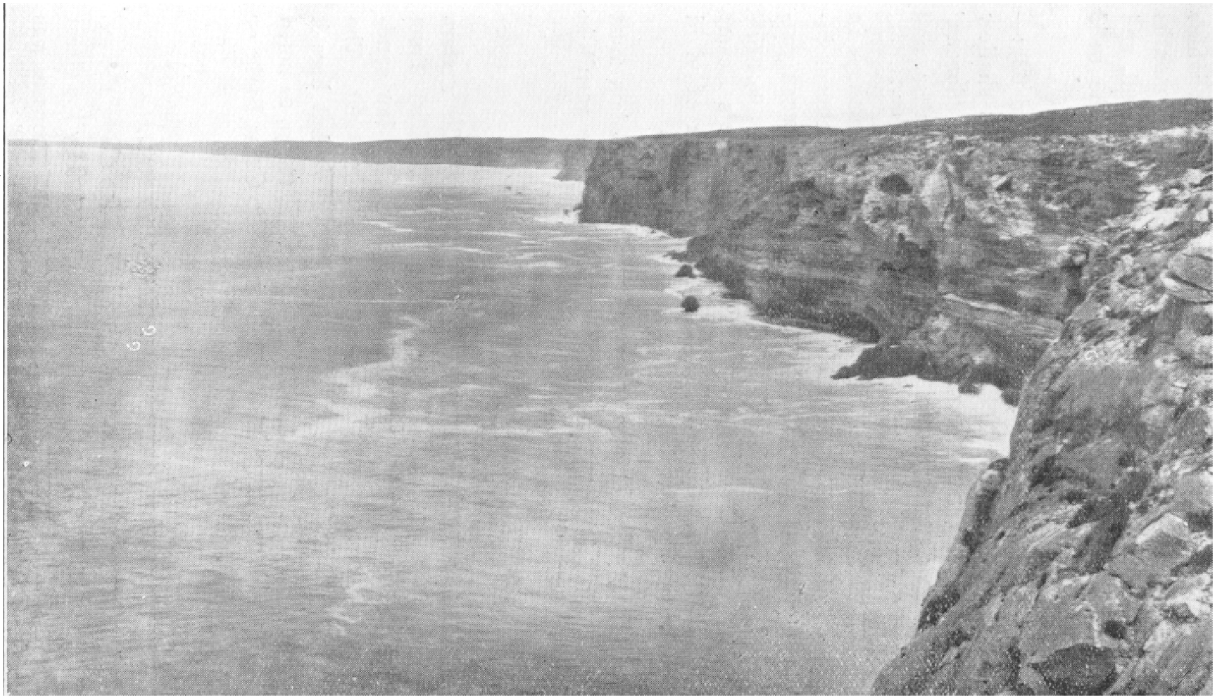


Fig. 70.—Limestone cliffs, near Twilight Cove, Eyre, on the Eucla coast. The cliffs form part of the scarp (possibly a fault scarp) known as the Great Bight or Bunda Scarp. They are now being subjected to marine abrasion.

PART VII.—THE DRAINAGE SYSTEMS AND THE PROBLEMS OF THEIR DEVELOPMENT.

CHAPTER I.

THE RIVERS OF NORTH KIMBERLEY.

CONTENTS.

Literature. General Characteristics. Remarks on Individual Rivers. Isdell, Lennard, Charnley, Calder, Sale and Glenelg Rivers. Prince Regent River. Moran and Roe Rivers. Mitchell and Lawley Rivers. King Edward River. Carson River. Drysdale River. Durack and Chamberlain-Pentecost Rivers. Hann and Adcock Rivers.

LITERATURE.

The chief publications bearing on the rivers of North Kimberley are those by Easton and by Brockman and Crossland. Blatchford (*h*, 10, *et seq.*, and Pl. III.) has also noted some features of the streams in the eastern portion of the division.

GENERAL CHARACTERISTICS.

It may be noted that some tributaries of the Fitzroy and Ord Rivers pass from the southern and eastern fringes of North Kimberley into Fitzroyland and Ordland respectively. Reference may be made to the chapters dealing with the rivers of those divisions for any particulars concerning such tributaries as are considered to be of sufficient importance to warrant any notice.

The rivers of North Kimberley are radial in character, as most of them run from Mount Hann to almost all points of the compass. (See figs. 9 and 13, and Pls. II. and V.) The chief exceptions to this rule are the Chamberlain-Pentecost and Durack Rivers in the eastern portion of the division. They run northerly, and their sources are far from Mount Hann. This radial character of the streams is in marked contrast with those of Fitzroyland and Ordland. It may also be noticed that in each of the latter divisions one great stream is dominant. That is not so in North Kimberley.

The principal rivers of North Kimberley are the Isdell, the Charnley, the Prince Regent, the King Edward, the Drysdale and the Chamberlain-Pentecost.

So far as known there are only two main types of rocks in the area. They are old lava flows (the basalt of Easton) and massive sandstones, which are horizontal or but gently folded; hence the strike and dip have not much influence on the character of the streams.

The country as a whole may be said to be an extensive tableland dissected by rivers, the valleys of which in their upper and middle portions form deep gorges which are in places inaccessible; above the gorges the streams in some cases run practically on the top of the tableland in very shallow valleys.

The sandstones are more resistant to erosion than the basalts. Consequently in sandstone areas the fact that the country was originally a plateau, although now seamed by rivers, is quite apparent; whereas in the basaltic portions, on account of the greater amount of weathering the basalt has sustained, the valleys are more open. The remains, however, of the plateau are still easily recognisable.

The valleys frequently follow the junction between the basalt and the sandstone, examples of which, according to Easton's map, are portions of the Charnley, Calder, Sale, Glenelg, Roe, Moran and Carson Rivers. (See Pl. V.)

Water gaps are not common in North Kimberley, in this respect the country being notably different from the rivers of Fitzroyland. Examples, however, of water gaps occur in the gorge of the Isdell River through the Artesian Range (Brockman and Crossland, 13) and in the gorge of the Hann River through the Phillips Range (Fitzgerald, 8). The deep gorge of the Charnley (Brockman and Crossland, 13) just before entering Walcott Inlet is apparently not a water gap.

No valleys within valleys have been recorded, nor do any of the photographs seen by the writer indicate such features.

The country forms an uplifted peneplain, and from its contour (a conoplain) and the radial distribution of the streams, the latter appear to be consequent upon the uplift and not to be revived streams. On uplift the rivers may have retained the courses they had on the completion of the peneplain, but those courses may have been modified since to bring about a harmony between the directions of the streams and the contour of the country after uplift. Of these possibilities, however, no evidence has yet been produced. The rivers cutting through the Darling Fault Scarp in Swanland are apparently consequent on the uplift, so that there is no inherent improbability of the streams of North Kimberley being consequent in the wide sense of the term.

Between the rivers there are ridges (comprising the so-called ranges, such as the Synnott Range, the Princess May Range and the Durack Range). In places the ridges are wide enough to be called plateaux, and both ridges and plateaux are clearly residuals of erosion formed during the present cycle, and distinct from the monadnocks on the peneplain, which are the remains of a previous cycle of erosion.

The rectangular character of some of the streams is a marked feature. Examples are the Durack, noted by Crossland (Brockman and Crossland, 15 and 16); also (within a small area) the Hann, the

Harris, the Macnamara and other associated streams (see Blatchford's geological map of East and West Kimberley, *g*, Pl. I.); and also the Glenelg, the Moran, the King Edward, and the Carson Rivers. The rectangular courses of the streams named are probably due to master joints.

Possible fault line valleys are indicated by the very straight courses of the Prince Regent and Chamberlain-Pentecost Rivers, particularly the former.

By a recent submergence of the land the lower portions of the North Kimberley streams have been drowned, and since the country at the time of submergence had been deeply dissected, the coast has been deeply indented and a number of rias or sounds, some of which are of much scenic beauty, have been formed, examples of which are the gulf at the mouth of the Prince Regent River and Prince Frederick Harbour. (See figs. 15, 16, and 17.)

The submergence of the lower ends of the valleys has resulted in the betrunking of many of the rivers, details of which are given in the descriptions of the individual rivers; and in the aggradation and widening of the floors of the valleys.

The apparently original and continued radial distribution of the rivers suggest not only that they were consequent on the uplift, but that the geological structure of the country is such that there will be no great development of subsequent streams. In Fitzroyland and Ordland there has been an adjustment of streams to structures by reason of the ocurrence of well-defined more or less parallel bands of rocks of different degrees of "hardness," and the working out of the geology has been facilitated by this adjustment. The rivers of North Kimberley have probably had quite as long a period for their development as those of Fitzroyland and Ordland, and therefore if there were much variation in the geology a more advanced stage in the development of the North Kimberley rivers would be expected than actually exists. Hence the inference, based on the physiography of the area and the known facts of its geology, may be drawn that future investigation will not yield much more geological knowledge on a broad scale than what is already known.

REMARKS ON INDIVIDUAL RIVERS.

The Isdell, Lennard, Charnley, Calder, Sale, and Glenelg Rivers.

The Isdell River in its upper course flows south-westerly, but as it approaches the King Leopold Range, it turns sharply to the north-west and runs parallel to, but north of, the range. It enters Walcott Inlet, and in its north-western course to that inlet it passes through the Artesian Range in a gorge, thus forming a water gap.

The upper Lennard runs north-westerly close to and north of the King Leopold Range, but it breaks through the range at the Bell Gorge,

and thence flows south-westerly as the middle Lennard, cutting through the Napier Range at the Devil's Pass. It then turns to the west as the lower Lennard. The upper Isdell and the middle Lennard both flow

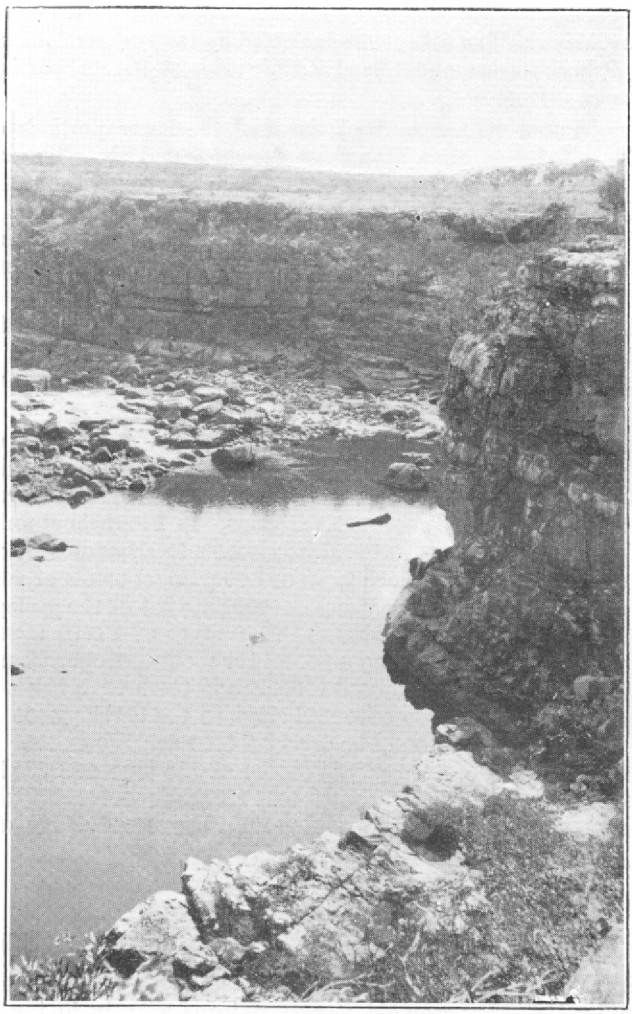


Fig. 71.—The Charnley River Gorge, Charnley River, North Kimberley.

south-westerly, and are in the same line. These facts suggest that the upper Isdell and middle Lennard were originally one south-west flowing transverse stream, unconnected with the present lower Isdell,

but that the latter river, by reason of its shorter course to the sea than the old Isdell-Lennard River, has beheaded the upper portion (now the upper Isdell) of this old stream, and so reduced the latter in length and volume. (See figs. 13 and 73.)

The Charnley and the Calder Rivers flow generally in a south-westerly direction, more or less parallel to each other, and they enter Walcott Inlet close together. Easton has noted that the Charnley River near Walcott Inlet runs through a magnificent gorge (the "Charnley Gorge") about 25 miles long and in one place 500 feet deep with perpendicular sides. Crossland (Brockman and Crossland, 13) also refers to the same gorge. (See fig. 71.)

The Isdell, the Charnley, and the Calder were originally united, and flowed as one big river along the site of the present Walcott Inlet and so into Collier Bay, which was formerly a wide plain. By the submergence already referred to, these three rivers were betrunked. (Se Pl. V.)

The Sale and Glenelg Rivers are short streams which enter a small bay at the head of Collier Bay. They must at one time have been united, but have been betrunked by the recent submergence. As a united stream they may also have been joined to the old Isdell-Charnley-Calder River before the formation of Collier Bay. If the formation of Collier Bay took place before that of Walcott Inlet then the main Sale-Glenelg-Isdell-Charnley-Calder was betrunked, resulting in the formation of two separate streams (the Sale-Glenelg and the Isdell-Charnley-Calder); and on the formation of Walcott Inlet each of these was betrunked and five separate rivers were formed.

The Prince Regent River.

The Prince Regent River has a remarkably straight course in a north-westerly direction, and is therefore suggestive of occupying a line of faulting. The short, straight, southern tributaries of the river near its mouth suggest that cross-faulting has also taken place. The river has also suffered great submergence, as shown by its wide and long estuary at the head of Brunswick Bay, and by the numerous islands. There are inner bays—Rothsay Water (fig. 16), which is a long narrow indentation, and a larger unnamed bay to the east—each of which, according to the maps, has no valley of any size entering it; hence some surprise is felt at the occurrence of these bays.

The Moran and Roe Rivers.

These rivers run in a north-westerly direction, but the Moran suddenly swings to the west to join the Roe River. The combined stream then enters Prince Frederick Harbour, which is a fine example of a ria, the length of which shows how great has been the recent submergence of the land, although insufficient to betrunk the rivers mentioned,

The Mitchell and Lawley Rivers.

These rivers flow in a general northerly direction, the Mitchell River entering Admiralty Gulf, and the Lawley River entering Port Warrender at the head of the same gulf. Port Warrender is the drowned lower portion of the Lawley River. The rivers were originally united, and passed over what is now Admiralty Gulf, which, before submergence, was evidently a wide plain. The formation of Admiralty Gulf has resulted in the betrunking of the two streams.

The King Edward River.

This river in its lower course flows northerly from near Mt. Hann, but as it reaches the vicinity of Port Warrender, it swings suddenly round to the east at almost a right angle and joins the Carson River. The united stream then runs into the spacious Napier Broome Bay, which, prior to submergence, was probably a wide plain. The natural course of the King Edward River would appear to be either due north into Vansittart Bay, or west past Mt. Connor into Port Warrender. The unusual course taken by the river suggests that possibly an east-flowing tributary of the Carson River has captured the upper portion of the King Edward River; but in view of the comparatively short courses to the sea at Port Warrender and Vansittart Bay, such capture is hardly likely to have occurred. Detailed investigation, however, on the ground is required to determine the history of the streams.

The Carson River.

As already noted, when describing the King Edward River, the latter and the Carson unite and flow into Napier Broome Bay. Before such union, the Carson has a pronounced rectangular bend to the west, and at the turn the river is very close to the adjacent Drysdale River, so that the possibility of an original connection between the Carson and Drysdale Rivers, with a subsequent capture of the upper Carson by a short west-flowing tributary of the King Edward River, must be borne in mind.

The Drysdale River.

This north-flowing stream enters a narrow arm of Napier Broome Bay at the eastern head of the bay, and by reason of its proximity to the Carson River, as already noted, it is possible that the two rivers were at one time connected. There is a drowned valley at its mouth.

The Durack and Chamberlain-Pentecost Rivers.

The Durack River is roughly parallel to and between the Drysdale and the Chamberlain-Pentecost Rivers, and runs in a general northerly direction for some distance; it then swings round sharply to the east to join the Chamberlain-Pentecost River. The rectangular bends of the Durack have been noted by Crossland (Brockman and Cross-

land, 15, 16), who describes the valley as consisting (in one place) of "rough gorges through which the river passed, making almost rectangular bends every few miles."

The Chamberlain-Pentecost River flows in a north-north-easterly direction in a very straight course, which is strongly suggestive of being a fault line. It is flanked on the east by the Durack Range (which may have a fault scarp) and enters Cambridge Gulf close to the mouth of the Ord River. The latter and the Chamberlain-Pentecost River were originally united, but became betrunked by the formation of Cambridge Gulf, owing to the recent submergence of the land beneath the sea.

The Hann and Adcock Rivers.

These streams rise near Mt. Hann and are south-east-flowing tributaries of the Fitzroy River. They have some pronounced rectangular bends which have been referred to under the heading "General Characteristics." The Hann River has a water gap formed by the gorge which passes through the Phillips Range.

CHAPTER II.

THE RIVERS OF FITZROYLAND.

CONTENTS.

Literature. General Characteristics. Examples. Origin of the Water Gaps. Possible History of the Rivers. Objections to Suggested History. Evidence in favour of Suggested History. Effect on the Rivers of Recent Changes of Level.

LITERATURE.

The principal publications bearing on the physical geography of this division are those by Hardman (*a* and *b*), Woodward (*c*), Blatchford (*g*) and Wade.

GENERAL CHARACTERISTICS.

The principal river is the Fitzroy, which with its tributaries drains almost the whole area. The lower Fitzroy and its tributary Christmas Creek really form one river, the whole of which runs in the same north-westerly direction. The middle and upper Fitzroy, which mainly has a south-westerly course, is really a tributary of the lower Fitzroy-Christmas River. Apart from Christmas Creek, the most important tributary of the Fitzroy is the Margaret River, which runs at first south-westerly and then turns sharply to the west-north-west, running approximately parallel to Christmas Creek. On the southern side of the lower Fitzroy River and Christmas Creek the tributaries appear

to be few and short, judging by the maps. The other important stream of the area is the Lennard, which, as it approaches Stokes Bay at the north-eastern corner of King Sound, branches into two streams which are known as the Meda and May.

The lower portions of the Fitzroy and of the Meda and May Rivers meander (with lagoons and billabongs) through extensive alluvial flood plains which are well grassed. The lower Fitzroy valley is subject to widespread floods, as the river in the wet season overflows its banks annually, and inundates the adjacent country, often many miles (up to 20) in width (Blatchford, *g*, 11 and 12). The fall of the Fitzroy for the last 200 miles (in a direct line) of its course is 200 feet, being at the rate of one foot per mile (Blatchford, *g*, 11). The extensive floods of the Fitzroy have also been noted by Hobler (5), who states that the material of the flood plains consists principally of light and red sandy loam and chocolate soil. Behind the flood plains are the low ridges known as Pindan country (Hobler, 5).

The Margaret River and the adjacent Louisa River also have extensive alluvial plains which are well grassed (Hobler, 5).

The belt of country between the Napier-Geikie-Oscar Range and the King Leopold Range is higher and more broken than the remainder of the division, and this feature is reflected in the character of the river valleys which are less mature than those in the lower land, as of course would be expected.

From a study of the maps and literature of this division, the following points may be emphasized (see figs. 9, 13, 72, and 73).

(1) The fine examples throughout the division of the "adjustment of streams to structures," illustrated by the parallelism between the strikes of the rocks, trends of the ridges (which are determined by the strikes of the rocks) and courses of the main streams, either as a whole or in their lower portions. Such rivers are the longitudinal and probably (in part) subsequent streams (see fig. 9) and trend north-westerly.

(2) The general south-westerly trend of the upper portions of some of the chief streams and of some of the most important affluents of the latter, together with junctions or sudden bends at almost right angles. Such rivers are the transverse and probably (in part) consequent streams (see figs. 9 and 13).

(3) The number of water gaps in the valleys of the transverse streams (see figs. 13, 72, and 73).

(4) The maturity and old age of the streams, notably the Fitzroy, the older condition being indicated by the wide alluvial plains in the lower portions of some of the rivers. The gorges which form the water gaps in the Lower Carboniferous ridges have of course immature characters.

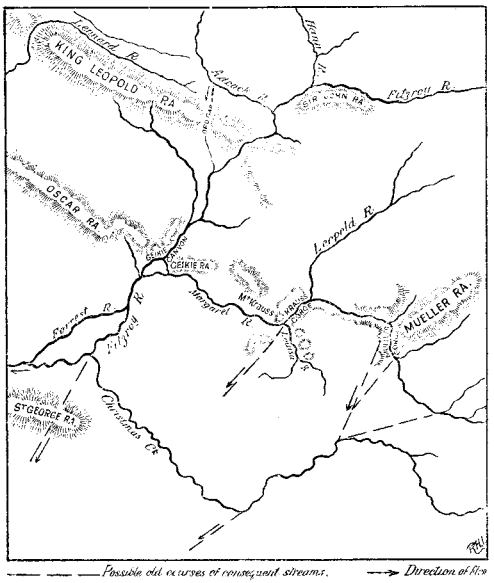


Fig. 72.—Enlarged plan (of part of fig. 13), showing the water gaps of the Fitzroy River (Geikie Canyon) and of the Margaret River (Krauss and Mueller Gorges), and also the possible old courses of the consequent streams.

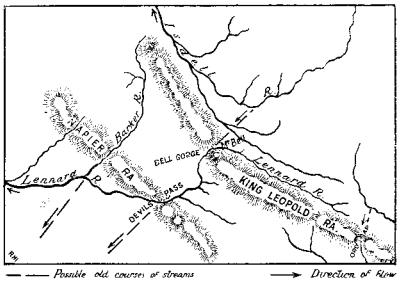


Fig. 73.—Sketch map showing the water gaps of the Lennard River (Bell Gorge and Devil's Pass), the water gap of the Barker River (Napier Gorge), and the possible old courses of the consequent streams.

Examples.

In illustration of (1) the strikes of the rocks of the Grant, St. George, Poole, Oscar, Geikie and Napier Ranges and others are about north-west; and many rivers, or portions of them, including the lower Margaret, Christmas Creek, the lower Fitzroy, the lower Lennard and others run approximately parallel to the ridges. The rocks of the ridges are mainly sandstones, conglomerates, grits, quartzites and limestones dipping at a moderate angle, and of Lower and Upper Carboniferous age.

Examples of (2) are the upper Margaret, Leopold, middle Fitzroy, middle Lennard and Barker Rivers (fig. 13).

Examples of (3) are the Mueller and Krauss Gorges of the Margaret River; Geikie Canyon (fig. 74) and a gorge farther north, of the Fitzroy River; the Devil's Pass* of the Lennard; the Napier Gorge of the Barker River and other unnamed ones (figs. 72 and 73).

Examples of (4) are the lower Fitzroy River and Christmas Creek.

ORIGIN OF THE WATER GAPS.

Gorges of this character may be formed in any of the following ways: (1) By antecedent rivers, (2) by superimposed rivers, (3) by revived streams on slow uplift of the country as a whole, (4) by headward erosion, and (5) by consequents having sufficient fall to maintain their initial courses across the hard rocks, until broken by capture by longitudinal (in part subsequent) streams.

Method (1) is considered here with regard to most of the ridges as untenable. Antecedent streams imply slow uplift of ridges or belts of country and corrasion by the stream as fast as uplift. In Fitzroyland the ridges are fairly numerous, and follow the strike of the rocks, which are hard. The ridges mostly appear to be residuals of the present cycle of erosion, and not local uplifts.

It is possible, however, that the water gaps in the Napier and Geikie Ranges indicate antecedent streams, as Blatchford (*g*, 22) states that the southern face of these and other ranges is a fault scarp, which the present writer has named the "Napier-Geikie Fault Scarp," and that on the northern side of these ranges the country falls away gradually. The rivers may have cut down into the rocks as fast as the uplift took place.

(2) Superimposed streams take their courses irrespective of the structure of the underlying rocks, and retain their directions on meeting such rocks. An overlying cover is required for these streams, and this cover frequently consists of marine deposits. So far as the writer is aware there is no evidence of any extensive belt of such deposits ever

* The Devil's Pass appears to be identical with what Woodward (*i*, 11) calls the Wingrah Pass. Hardman (*a*) states that the Devil's Pass is two miles long.

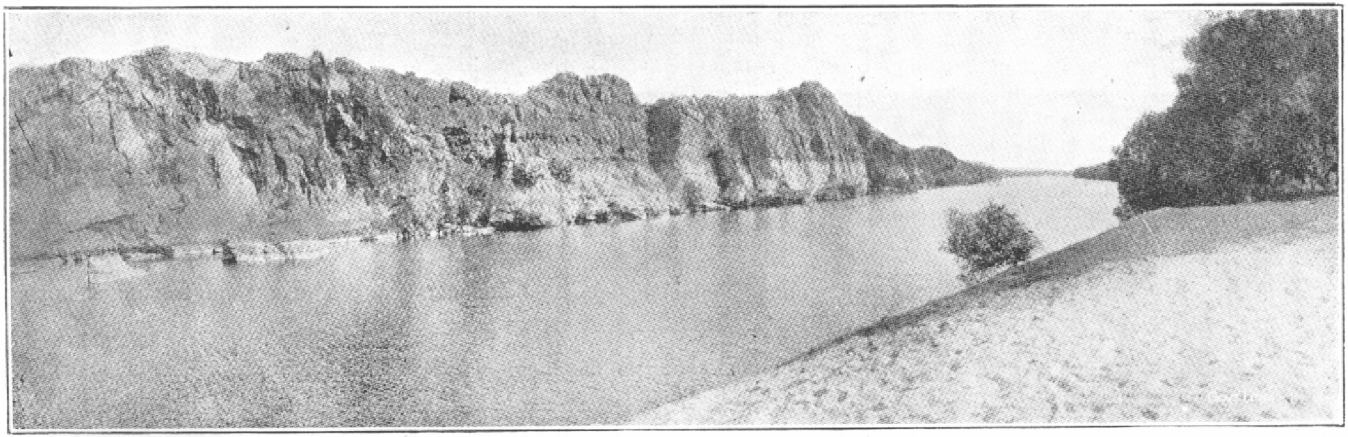


Fig. 74.—Geikie Canyon, Fitzroy River, Fitzroyland. The cliffs are formed of Carboniferous limestones.

having existed, or of any other covering deposits on the peneplain, so that in the absence of such proof, superimposed streams cannot be definitely accepted.

(3) By slow uplift it is possible that streams belonging to the previous cycle of erosion may retain their courses across belts of hard rocks; but it is doubtful, if a river system lasted sufficiently long to form a peneplain, that some of the chief rivers would be crossing the hard rock bands. There would probably be an almost complete adjustment of streams to structure, and therefore nearly all the main rivers would be longitudinal and not, as with several in the area under discussion, transverse. It cannot be definitely stated that the streams are not revived, but the known facts require careful consideration before acceptance of the theory of revival.

(4) Headward erosion may cut through a band of resistant rock, form a gorge and perhaps behead longitudinal streams, but whether this acts in a number of cases is perhaps doubtful. A possible example of this nature is the middle Lennard, which, followed upstream, cuts through the King Leopold Range near Mt. Bell (forming the Bell Gorge, fig. 73), and then sharply turns to the east. It is possible that this upper eastern portion originally belonged to the Isdell system, and has been captured by the middle Lennard working backward through the King Leopold Range. But as (5) is another method of interpretation in this particular case, and is adopted in the section treating of the possible river history, the solution by (4) cannot be definitely accepted. Without field knowledge it is impossible to state to what extent method (4) is valid in Fitzroyland; but it no doubt applies in some cases, *e.g.*, the small river between the Alexander and the Barker Rivers, which cuts through the Napier Range.

(5) This method appears to meet the known facts best, so it has been adopted as the most satisfactory tentative solution in the following outline of the possible history of the rivers. This suggested history states the case for method (5), so there is no need to further enlarge upon that method here.

POSSIBLE HISTORY OF THE RIVERS.

In the following statement, certain rivers outside Fitzroyland have been referred to, as their history is bound up with those of Fitzroyland.

Assuming that there is a distinct fall along the surface of the now dissected plateau south-westerly from the neighbourhood of Mt. Hann across the King Leopold Range to the Napier-Geikie scarp, and thence across the lower ground to the south-west, the following scheme is offered for consideration as the broad history of river development in Fitzroyland. On uplift, new streams may have been initiated, and if so they would mainly flow to the south-west, running across the bands of hard rocks and cutting therein the deep gorges already noted (figs.

72 and 73). Such would be the present upper Isdell and middle Lennard as one stream; the middle Fitzroy; the Leopold River; and the upper Margaret River. These would be consequent streams. Most of these streams would have no outlet to the sea, but would lose themselves in the interior as in the case of the present Sturt Creek. The Meda and Fitzroy would be short streams, having the same general directions as now, but with probably only short courses from their present mouths. The present lower Isdell, a subsequent of the Calder, would work backward (eastward), and behead the old upper Isdell-middle Lennard, the latter retaining its subsequent, the present upper Lennard, now no doubt greatly further developed. The old Meda would act in a similar way and eventually collect the waters of the Barker and of the middle Lennard. Similarly the Fitzroy would work eastward and receive the present middle Fitzroy. The Fitzroy's natural continuation eastward is Christmas Creek, which may represent an old subsequent of the middle Fitzroy, now greatly extended.

The present upper Fitzroy is a subsequent of the middle Fitzroy. The lower Margaret, originally a small subsequent of the middle Fitzroy working eastward, would divert the waters of the Leopold River and the upper Margaret.

Sturt Creek, a stream to the east of Fitzroyland, may be the sole important stream in the Kimberley district the drainage of which has not been diverted to the ocean to the west or to the north.

On the history outlined there has been a considerable adjustment of streams to the structure of the ground, the longitudinal (and in part subsequent) streams working along the strike of the softer ground, and capturing and diverting the transverse and consequent streams, the development of which was hindered by the belts of hard rock they had to cross. The adjustments will tend to increase so long as the erosion process continues without interruption. The conclusions are of course tentative only, but in thus sketching an outline of possible history, the problem is stated for future workers.

OBJECTIONS TO SUGGESTED HISTORY.

One of the most important objections which occurs to the writer to the scheme as outlined is the absence of evidence of the former continuation to the south-west of the diverted or captured streams. These old continuations should now be represented by reversed-flowing streams or obsequents, and scarcely any of these are shown on the maps. It may be that since beheading they have so shrunk in size that in the rough mapping of the country they have not been traced, and that some were diverted almost at their ends (but the latter is not likely to happen to the majority). Another feature is the absence of wind gaps, but these may exist, although not recognisable on the available maps. A striking feature

is the almost total absence (according to the maps) of tributaries of the lower Fitzroy from its southern slopes, a fact which renders somewhat explicable the absence of obsequents, as noticed above. The area along the course of the lower Fitzroy is within the 20 to 30 inch rain belt, so that it is difficult to understand why side-streams have been but little developed. It may be that this country is within the area where the rain soaks almost wholly into the ground. If so, it is difficult to say how the lower Fitzroy, as an independent river, could be formed. On the other hand, if the upper and lower Fitzroy were originally connected as one stream, the lower Fitzroy could be developed and maintained by the head waters of the upper stream without the formation of tributaries. This point is of great importance, as if sound, it would tend to invalidate some of the conclusions drawn. The necessity for accurate topographical maps and field work is thus convincingly shown.

EVIDENCE IN FAVOUR OF SUGGESTED HISTORY.

On the other hand the points in favour of the scheme are the adjustment to structure as already noted; the parallelism of the transverse streams; the parallelism and the direction at right angles to the transverse streams of the longitudinal streams; the fact that there is no *a priori* objection that such streams as the middle Fitzroy, Leopold, and upper Margaret, could exist originally without an outlet to the sea, as in the case of Sturt Creek (which runs in the same direction as the rivers named); the fact that longitudinal streams working from the coast could in time divert streams even in desert country, and that this will possibly happen to Sturt Creek; the undoubted fact that the valleys have been recently drowned at their mouths; that the coast line must therefore have extended somewhat farther west; and that the consequent streams must, therefore, have been farther inland (but probably not many miles) than at present.

EFFECT ON THE RIVERS OF RECENT CHANGES OF LEVEL.

A comparatively recent depression (positive displacement of the strand line) of the coastal land surface has resulted (1) in the drowning of the lower courses of the streams, which now form deep sounds; (2) in the betrunking of some of the rivers, *e.g.*, the Meda and May and the Fitzroy, the Meda and May being formerly united and then uniting with the Fitzroy towards the mouth of King Sound; and (3) in the aggradation along their lower courses by the deposit of much alluvium.

A later movement of slight uplift (negative displacement) has exposed older sea beaches, according to Hardman (*a*, 7) and enabled the streams to degrade again by cutting partly through the alluvium of aggradation, a point also noticed by Hardman (*a*, 13).

CHAPTER III.

THE RIVERS OF ORDLAND.

CONTENTS.

Literature. General Characteristics of the Ord River System. Water Gaps in the Ord Basin. Suggested History of the Ord River System. The Divide between the Fitzroy and Ord River Systems. The Sturt Creek System.

LITERATURE.

The chief publications relating to the Ordland rivers are those by Hardman (*b*), Carnegie, Woodward (*c*), Blatchford (*g*), and Wade.

GENERAL CHARACTERISTICS OF THE ORD RIVER SYSTEM.

The Ord River and its tributaries are the chief streams of this area. Amongst the tributaries are the Elvire, the Panton, the Johnston, the Nicholson, the Bow, the Denham, the Negri and the Benn. A portion of the drainage of the North Kimberley Plateau finds its way into the Ord by means of some of the east-flowing tributaries. A general account of the rocks of Ordland is given in the description of that division, to which reference may be made.

The Ord River flows in a general northerly direction. In its upper portion it follows an extensive fault line which runs parallel with the strike of the Cambrian strata (Blatchford, *g*, 11). In its upper portion generally, as far north as Argyle Downs Station near the Benn River, the Ord and its tributaries are in deep well-defined valleys with gorges and water gaps in places.

The interesting structural feature known as the Ord River basin extends north-north-east from the Albert Edward Range to Mt. John and the Osmond Range. Wade (26) describes it as an elliptical area almost 80 miles long and 40 miles wide, with its long axis running approximately north-east and south-west. The basin is completely surrounded and underlain by basalt, associated with which is a massive limestone, which projects above the surface in the form of walls many miles long. The Ord River follows the long axis of the basin and divides the latter longitudinally into two portions (Wade, 26 and 29). This is apparently the fault line of Blatchford (*g*, 11).

In its lower portion the Ord apparently cuts across the strike of the rocks. North of Argyle Downs Station extensive black soil plains occur and extend north and east for many miles (Blatchford, *h*, 14, and fig. 20). Through these extensive alluvial plains the lower Ord and its tributaries meander as old rivers. The lower Ord is subject to widespread floods.

The Ord towards its mouth bends to the west and enters Cambridge Gulf to the east of the Chamberlain-Pentecost River, with which the

Ord was formerly united; but, by the formation of Cambridge Gulf, the valley of the united stream was drowned and the individual rivers were betrunked.

Information as to the characters and history of most of the tributaries of the Ord is very scanty. (For maps, see Pl. II. and figs. 9 and 75).

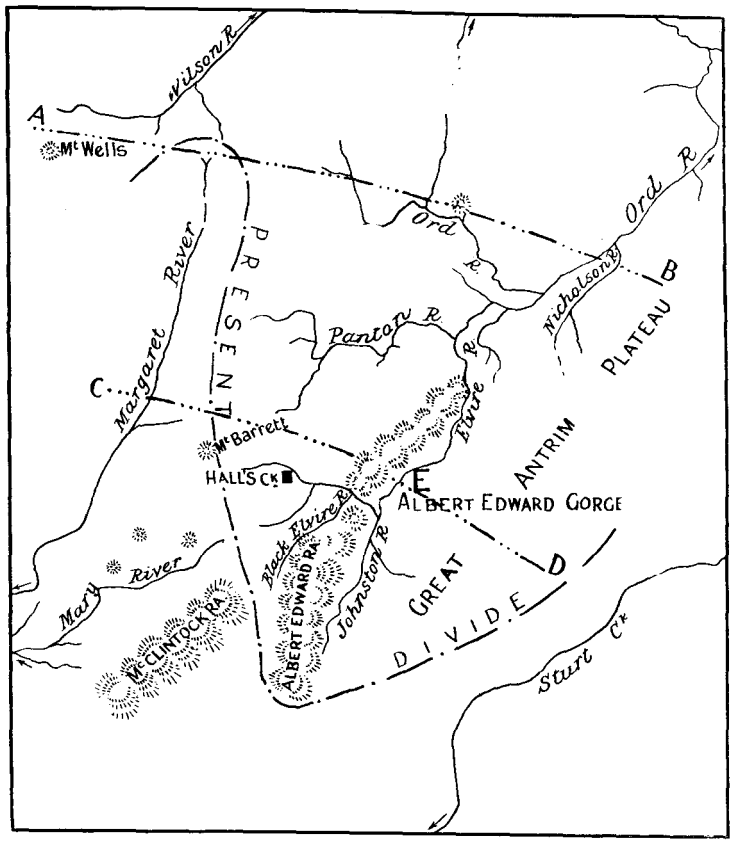


Fig. 75.—Headwaters of the Margaret River and of the Ord River system, Fitzroyland and Ordland. Diagram showing the present divide and the possible old divide, either along AB or CD. If AB were the old divide, then the main streams to the south of it would be originally south-flowing streams, parallel to the Margaret River and Sturt Creek. If CD were the old divide, the portion north of CD of the Margaret River would be originally north-flowing and the Johnston River south-flowing.

WATER GAPS IN THE ORD BASIN.

The Elvire River has cut a gorge (the Albert Edward Gorge) through the Albert Edward Range (Woodward, *c*, 7, and Hardman, *b*, 31). This gorge is a water gap, and its true nature was recognized by Hardman (*b*, 31) by his statement that the formation of the gorge must have been commenced before the country possessed its present configuration, and when the ground to the westward was much higher than the edge of the range now is. (See fig. 75.)

Wade (25) refers to a sheer wall of quartzite in the western portion of Ordland, about 400 feet high, running almost due north and south and traceable for close on 200 miles. He states it would form an impassable barrier if it were not for the gorge-like gaps cut through it by the Elvire and other streams. The Elvire runs north on the western side of the wall, where it is known as the "Black Elvire," turns to the east through the gap, and again to the north on the eastern side of the wall. The gap is along the line of a dip-fault which has thrown the wall to the west for several hundred yards on the northern side of the gap (Wade, 25). This gap is evidently the gorge in the Albert Edward Range referred to by Woodward and by Hardman. Wade, in discussing the origin of the gaps, notes that the softer beds have been removed by erosion, and that the quartzite wall has been left standing, but that the stream must have cut through the gaps when the softer beds were at the level of the harder ones. Wade (29) notes a gorge in the Osmond Range as a fine example of a beheaded valley.

The water gaps are not antecedent and are due to differential erosion.

SUGGESTED HISTORY OF THE ORD RIVER SYSTEM.

As suggested in the account of the Fitzroyland rivers, if new rivers in southern Ordland were initiated on uplift, they would flow mainly to the south-west, judging by the present courses of the upper Margaret River and Sturt Creek. Such rivers would include the Johnston (now a north-flowing tributary of the Ord) and perhaps part of the Elvire (see fig. 75.) Sturt Creek is described below but it may here be pointed out that its course is south-westerly and roughly parallel to the Johnston River. As in the case of the present Sturt Creek, the Johnston and the Elvire, if originally south-west flowing, would die out in the arid area in that direction. The development of the Ord River system may, however, have resulted in the capture and reversal of flow of the Johnston and the Elvire.

The above remarks are by way of suggestion only, and the life history of the streams must be determined in the field.

THE DIVIDE BETWEEN THE FITZROY AND ORD RIVER SYSTEMS.

Another point of interest is the divide between the Fitzroy and Ord river systems (see fig. 75). The present divide runs easterly from between the heads of the Fitzroy and Wilson Rivers, past the head of the Margaret, thence southerly for a long distance to the south of the Albert Edward Range, and thence north-east to the north-west of Sturt Creek. This very irregular line may safely be predicted not to be the original divide. The latter, in the absence of sufficient topographical data, is difficult to determine. Judging from known heights its most likely position seems to be about Hall's Creek in a line running west-north-west along the line D.C. of fig. 75. If this be so, then the flow of some of the north-south rivers has been reversed. An alternative line of the divide is suggested by A B of the same figure. Wherever the old divide existed there seems little doubt that changes must have taken place in the courses of the streams.

The courses of the upper Ord and Panton are somewhat indicative of boat-hook bends, and this suggests that perhaps the original divide stretched eastward along the line A.B. of fig. 75 as already suggested. If so, then a considerable amount of originally south-flowing and interior drainage has been diverted to north-flowing and exterior drainage.

THE STURT CREEK SYSTEM.

Sturt Creek from near its source to its junction with its chief tributary, Wolf Creek, is included in Ordland. The best general description of Sturt Creek is that by Carnegie (361, 362), from which the following account is taken. It rises in North Australia, runs for nearly 300 miles in a south-westerly direction, and ends in Gregory's Salt Sea in Sandland. In the dry season it ceases to flow and largely dries up. In the wet season, it spreads into swamps and marshes for a width of from five to six miles. Permanent pools are numerous, and occur wherever a ridge of sandstone cuts across the creek bed. Above the junction with Wolf Creek there are well-grassed plains, but as Sturt Creek is traced below Wolf Creek a change from the grasslands to the desert country takes place.

The possible original similarity of development of Sturt Creek and of the upper tributaries of the Ord River has been referred to above in the description of the Ord River system.

CHAPTER IV.

THE RIVERS OF PILBARALAND.

CONTENTS.

Literature. General Characteristics. Water Gaps and Non-antecedent Streams. Consequent or other Characters of the Rivers. Remarks on Individual Streams. Ashburton River. Tributaries of the Ashburton River (Henry, Hardey and Angelo Rivers, and Seven-Mile, Turee and Monkey Creeks). Fortescue River. Harding, George, Sherlock, Peeawah and Yule Rivers. De Grey-Ridley River and its Tributaries. Possible Drowning of Valleys.

LITERATURE.

The principal publications affording geographical details of this division are those by Gibb Maitland (*f* and *g*), Woodward (*f* and *n*), Montgomery (*d*), and Talbot (*d* and *e*).

GENERAL CHARACTERISTICS.

(1) The generally well-defined course of the main streams as contrasted with the ill-defined courses of the chief rivers of Murchisonia. The valleys, as a rule, are fairly normal, the upper portions being early mature, and the lower portions flowing over wide alluvial plains.

(2) The intermittent character of the rivers, most of which dry up in the summer except for chains of waterholes or large pools (due to depressions in the stream beds) which may last for considerable periods. These pools are fairly common along the beds of the upper Ashburton and its tributaries. They are, in some cases, due to the occurrence of permanent springs along the river courses. Many of the rivers after heavy rains become rushing streams, overflow their banks, and inundate the country for miles.

(3) The parallel west-north-west courses of the three main streams of the district, the Ashburton, the Fortescue, and the De Grey-Ridley.* The two first-named rivers follow the strike of the rocks (which in the upper part of the Ashburton Valley belong to the Nullagine and Ashburton Series, and in the Fortescue valley to the Nullagine Series), but the Fortescue valley has been determined by faults, the direction of which coincides with the strike of the rocks. The Ashburton and Fortescue Rivers may therefore be termed longitudinal streams.

The lower De Grey-Ridley River flows over chiefly granitic rocks, the foliation planes of which, where they occur, are approximately north and south (Talbot, *d*, 137). The river is therefore, in these areas, a transverse stream.

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* David (13) points out that as the Pilbara region is approached, all the trend lines become north-west and south-east, and that this trend is well shown in the directions of the Ashburton, Fortescue and De Grey Rivers as well as in the trend of the Hamersley and Throssell Ranges.

(4) The transverse nature of certain tributaries of the Ashburton, viz., the Henry River from the south, and the Angelo River, Seven-Mile Creek and the Turee Creek from the north (Talbot, *e*, 10). The very short tributaries of the Fortescue are also transverse streams.

(5) The longitudinal and apparently consequent character of the north-flowing tributaries of the De Grey-Ridley River, such as the Shaw, the Coongan, the Nullagine and the Oakover Rivers. Between the De Grey-Ridley and Fortescue Rivers there are comparatively short longitudinal and apparently consequent streams, such as the George, the Sherlock, the Yule and the Turner, which flow in a northerly direction to the sea.

(6) The occurrence of canyons in the valleys of the tributaries of the three main rivers where such tributaries traverse the rocks of the Nullagine Series; and the more or less old character of those tributaries where they pass over the sedimentary rocks of the Ashburton Beds, or over the wide granite areas, or over the sediments surrounding "The Marsh." The plains, however, over which these old streams run may be studded with more or less isolated hills and ridges.

(7) The occurrence of water gaps, mainly north of the Fortescue River. These water gaps are found chiefly in the dolerite or gabbro ridges (which are frequently dykes) which are common in the northern portion of the area. Water gaps also occur in quartz "blows" and in banded cherts. Examples of the water gaps are the Doolena Gap of the Coongan River; various gorges in the valley of the Shaw River; and the gorges of the Peeawah, Maitland and Harding Rivers.

In addition to the rocks mentioned as forming the ridges containing the water gaps, there are also ridges of quartzites, conglomerates, grits, sandstones, volcanic and metamorphic rocks. The granite, which is widespread, has, on account of its comparative softness, been reduced largely to a low-lying plain, surrounding, in some instances, the ridges which contain the gaps.

The occurrence of water gaps as a marked topographical feature in the Pilbara district has been noted by Maitland (*f*, 9).

(8) The remarkably straight course of the Fortescue River, the valley of which is apparently a rift valley in its upper portion; the possible occurrence of a sunkland (the "Marsh Sunkland") in the floor of the rift valley; lower down the same river the occurrence of the deep and long canyon known as "Gregory's Gorge"; and the narrow drainage basin of the whole river, its tributaries being so short compared with the great length of the trunk river that the latter may be said to be a through stream, practically without tributaries.

(9) The influence of block-faulting on the courses of the north-flowing tributaries of the De Grey-Ridley River, and (such as they

are) of the Fortescue River. Those courses appear to be the direct result of block-faulted areas being slightly tilted to the north; the streams are therefore consequent.

(10) The probability that the lower portions of some of the rivers running to the northern coast have been drowned.

In connection with the above and the succeeding remarks, reference may be made to figs. 21, 23, 24, 25, 27, 28, and 76.

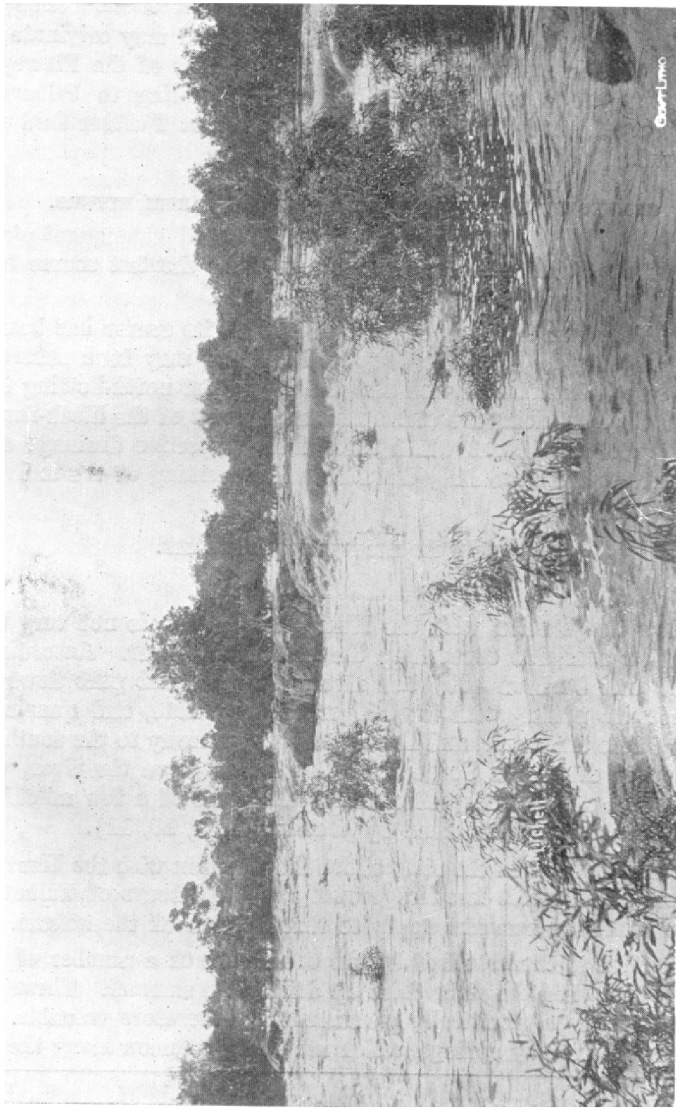


Fig. 76.—The Harding River, Pilbaraland, in flood.

WATER GAPS AND NON-ANTECEDENT STREAMS.

In Pilbaraland the water gaps are in ridges composed of dolerite, gabbro, quartz "blows" and banded cherts. The courses of those ridges have been traced on the geological maps of the area. It is impossible to regard such ridges as so many separate uplifts. The one explanation is differential erosion, by means of which the rocks less resistant to erosion (principally granite) have been worn down to plains, leaving the more resistant rocks projecting as ridges. The rivers which pass through the gaps are not therefore antecedent.* The ways in which similar water gaps to those just described may originate have been discussed in endeavouring to trace the history of the Fitzroyland rivers. The maps and geological literature relating to Pilbaraland do not give sufficient data to determine the matter. Further field study is required.

CONSEQUENT OR OTHER CHARACTERS OF THE RIVERS.

The Ashburton appears to be a longitudinal consequent stream. It follows the strike of the rocks and takes the shortest course to the sea.

The Fortescue River is consequent in that its course has been determined by faults. The De Grey-Ridley River may be a subsequent stream, but its tributaries, and also the very short north-flowing tributaries of the Fortescue, are consequent as a result of the block-faulting and tilting of the blocks which form their respective drainage areas. These matters are more fully discussed when treating of the individual streams.

REMARKS ON INDIVIDUAL STREAMS.

The Ashburton River.

Below its junction with the Henry River there is not very much information available concerning the Ashburton River. According to Maitland and Jackson (20) this river "for the most part flows over large alluvial plains, with low ridges of clay, slate, and quartz outcropping here and there, and flat-topped ranges away to the south; but in one place called the Gorge the hills close in upon the river, which then flows in a deep rocky channel for the space of a few miles." It has also been briefly described by Woodward (*b*, 10, 11).

Of that portion of the river above the junction with the Henry, we have now considerable knowledge owing to the labours of Talbot (*e*), and the following remarks apply to that portion of the stream.

The river is characterised by the occurrence of a number of pools along its bed when the river dries up during the summer. These pools are in places large, practically permanent and therefore valuable. They are frequently fed by springs, which are fairly common along the Ash-

* A possible antecedent stream is the Strelley in its upper course. This is suggested by Maitland's figures and descriptions (*f*, 14-16).

burton and its tributaries. Above the junction of the Ashburton with the Hardey River, the following pools are noted as occurring on the Ashburton on one of Talbot's maps (*e*, Pl. III.):—20 Mile, Kooline, Waggoon and Moori Pools. Claypans which dry up only in times of drought occur along the Ashburton River (Talbot, *e*, 70).

The general course of the river is about west-north-west, which is the direction of strike of the Ashburton Beds and of the overlying Nullagine Series. It is therefore a longitudinal stream. The river has carved out a broad valley, and in doing so has removed the Nullagine rocks and exposed the Ashburton Beds, which are highly inclined sedimentary rocks, over which the river flows for about 150 miles (Talbot, *e*, 10). The Nullagine rocks now form an extensive plateau to the south of the river, and the edge of that plateau is in one place 20 miles from the river.

In the valley in places are many low table-topped hills, which are capped with limestone (Talbot, *e*, 35).

Talbot considers that the course of the river is along the denuded axis of a long anticlinal fold (*e*, 30); he also notes (*d*, 84) that at the head of the Ashburton, plains of any size are rare, and that the predominating features are dissected plateaux or isolated mesas and buttes.

At flood time the Ashburton continues as a muddy fresh-water stream for miles in the sea off Onslow (Despeissis, 16).

Tributaries of the Ashburton River.

The Henry River.

The Henry River is a transverse stream flowing in a broad valley of the Ashburton Beds, from above which the Nullagine Series has apparently been removed, as in the case of the Ashburton River itself. To the east of the valley the Nullagine Beds form a plateau, and to the west there is an extensive outcrop of granite. Woodward (*f*, 13) records that in its upper course it flows over a large plain with occasional exposures of granite and other crystalline rocks, but thirty miles above its junction with the Ashburton it flows through a deep gorge in crystalline limestone. Below this it has large alluvial plains.

If the western branch of the Henry River is working headwards rapidly, it may yet capture the upper Lyons River, which, as suggested when discussing the rivers of Murchisonia, may have already been severed from the Minilya River by the present middle Lyons.

The short eastern branch of the Henry has a peculiar course. It is roughly S-shaped. It flows north-west, then south through a gap forming a gorge eight miles long (Talbot, *e*, 50) in the Barlee Range, which is formed of the Nullagine Series of rocks; it then swings round to the north-west and joins the main Henry River. It is probable that this eastern branch may at one time have continued south from the Barlee Gorge as a tributary of the upper Lyons along the

line of the present Alma River, and that the main (western) branch of the Henry River beheaded it and changed its course from south-flowing to north-west-flowing.

Pools along the Henry are noted on Talbot's geological maps.

The Wannery Creek is the chief tributary of the Henry River. It has several pools marked on the map (Talbot, *e*, Pl. III.), one of which is Talga Pool. Above this pool is a gorge three miles long, and below the pool the stream enters a wide level valley in the Nullagine rocks, with steep escarpments of plateaux some miles to the east and west. At one locality the top of the eastern escarpment is 750 feet above the creek (Talbot, *e*, 51).

Only a few short creeks flow into the Henry from the west.

The Hardey River.

The Hardey River is a longitudinal stream more or less parallel to the Ashburton and flowing over the Ashburton Beds. It calls for no special remarks except that it possesses an unnamed northern tributary which joins the Hardey below the Turner Creek, and which issues from a gorge south of Mount Wall (see Talbot, *e*, Pl. III) to the east of which is a valley cut through the Nullagine rocks into the Ashburton Beds, and bounded by Nullagine rock escarpments to the north and south. The valley is from one to three miles wide. A short stream flows east to the Turner Creek, and the main stream flows west to the Hardey River, passing on its way through the gorge mentioned above. The configuration of the country suggests that an air gap exists between the heads of the two streams in the valley.

The Angelo River and the Seven-Mile and Turee Creeks.

These streams join the Ashburton from the north. They are transverse streams, and there is a remarkable parallelism where they cross the strike of the Ashburton Beds (Talbot, *e*, 10). The Seven-Mile and Turee Creeks have early mature valleys in the Turee Plateau of Nullagine rocks, with some prominent gorges, examples of which are the Seven-Mile Creek Gorge south of the junction of the Bellary and Seven-Mile Creeks (see Talbot, *e*, Pl. IV.); and the Turee Gorge, about 16 miles north of Mt. Channer.

Where they meet the Ashburton Beds, the valleys tend to become more open and alluvial plains are formed (Talbot, *e*, 13). The Angelo River, however, traverses the Turee Plateau in a broad valley bounded by hills two and one-half to six miles away (Talbot, *e*, 19).

Along these various streams are excellent pools, the Horrigan Pool on the Angelo being one of the finest in the State (Talbot, *e*, 70). It is fed by permanent running springs (Talbot, *e*, 19). A point of interest is that the Angelo River follows a fault line for about six miles near the Horrigan Pool. No springs are found above or below that stretch of the river (Talbot, *e*, 20).

Monkey Creek.

Monkey Creek is a southern creek which has cut through the Lofty Plateau and captured the headwaters of the Yanneri Creek, a stream which flows eastwards into the area of interior drainage (Talbot, *d*, 53).

The Fortescue River.

The Fortescue River, as noted above, is remarkable for its very straight course, its very narrow drainage basin, and the long deep canyon known as "Gregory's Gorge" in the middle part of its course. Woodward (*n*, 9) states that the canyon is 500 to 600 feet deep and about 70 miles long, and that it has been cut through solid volcanic rocks. Near its mouth the Fortescue runs through its own flood-plain, and in its upper portion, above the great canyon, its elevated course is ill-defined, both above and below "The Marsh" (Talbot, *d*, 54). The connection between the upper portion and Gregory's Gorge is, the writer understands, by a fairly gradual slope, nothing approaching a waterfall existing, but at times of heavy rains, low cascades or rapids may develop. In the outline of its thalweg and the general features of its valley the Fortescue is therefore a fairly normal river.

Numerous pools occur along the Lower Fortescue as shown on Woodward's geological map (*n*, Pl. I.).

In the first edition of this work it was suggested that the scarp of the Hamersley Range was a fault scarp, and that the river had been eroded along or very close to a fault. Talbot's recent work (*d*) in regard to the upper portion of the Fortescue valley, has confirmed these suggestions, although it is only by his geological sections that such confirmation is indicated (see Pls. II., X., and XIII.), there being no indication on his maps or in his text to the fault or fault scarp except in the text by reference to a sunkland, which is mentioned below. The Hamersley Scarp is therefore a fault scarp, although perhaps considerably dissected, and may be known (in its eastern portion at least) as the "Hamersley Fault Scarp."

Talbot has also shown in the same publication that on the north side of the river there is an escarpment of the Nullagine Beds which is due to a fault, the downthrow side being to the south.

It is therefore evident that a portion of the Fortescue valley at and above the Coodiadarri Hills is a rift valley, on the floor of which—now covered in part by alluvium (*d*, 97)—the Fortescue flows as a sluggish stream, and reaches a huge swampy area known as "The Marsh," over which the river spreads in times of flood (*d*, 105). "The Marsh" Talbot regards as the remnant of an extensive lake and as evidence of a sunkland which may be called "The Marsh Sunkland" (*d*, 54, 97, 99, 105 and 141). Bores sunk to a depth of 104 feet in this sunkland have not struck bedrock (Talbot, *d*, 141).

Thus there may be the extremely interesting phenomenon of a rift valley on the floor of which is a sunkland, although from Talbot's de-

scription it is not clear whether both features occur, or whether the rift valley is identical with the sunkland, but if the rift valley can be traced beyond the sunkland, then the two features occur, although probably formed at the same time.

To the south of the Fortescue in the area under description is the Hamersley-Ophthalmia Plateau. The plateau is pierced by the Fortescue River in its north-flowing course by a transverse valley, which is known as the "Ethel Gorge," but which is not a gorge in the usual sense as there are no steep cliffs on either side (Talbot, *d,* 54). On the southern side of the plateau the stream has captured some of the old south-flowing tributaries of the Upper Ashburton, an example of which is the upper portion of the Goldfields Creek, as noted by Talbot (*d,* 53). Another unnamed creek west of the north-flowing Fortescue above the Ethel Gorge now flows into that portion of the Fortescue, but it formerly joined the Ashburton, and its capture is indicated by a boat-hook bend. (See Talbot, *d,* Pl. X.)

The comparatively short southern tributaries flow from the southern side of the Hamersley-Ophthalmia Plateau to the Fortescue, the direction of flow having been determined by the tilt to the north of the fault-block forming this plateau.

Two remarkable similar features deserve mention. There are practically no tributaries flowing south to the Fortescue and cutting through the southern edge (the Nullagine Fault Scarp) of the Nullagine Plateau; and there are few tributaries flowing south to the Ashburton River, and cutting through the southern edge (the Ophthalmia Fault Scarp) of the Hamersley-Ophthalmia Plateau. Both of these plateaux have a northerly tilt, and hence the headwaters of the streams flowing northwards across them tend to work towards the southern edges of the plateaux, but it is none the less strange that the southern scarps have been so little dissected by south-flowing streams, and that capture of some of the north-flowing streams has not taken place.

The area just referred to is at the extreme eastern end of the river, but the absence of tributaries of any length is noticeable along the whole course of the stream. The Hamersley Scarp extends westwards from the headwaters of the river to Mt. Flora (according to the maps), a distance of not less than 200 miles, and almost all the rivers north of the Fortescue flow to the north. It is therefore suggested that the causes which have operated at the eastern end of the river, in bringing about the features described, have also operated practically throughout the whole course of the river.

It may also be mentioned that the absence of long tributaries may have contributed to the maintenance of the deep narrow canyon of the Fortescue in that the plateau bordering the main stream would not be broken up by corrasion into numerous blocks, which would then present many faces on which the ordinary atmospheric agents would destructively work.

The Harding, George, Sherlock, Peeawah, and Yule Rivers.

North of the Fortescue several streams flow approximately northwards to the sea. They include the Harding, the George, the Sherlock, the Peeawah, and the Yule Rivers (fig. 25). They are all short streams except the Yule, which, however, is of no great length. Their northerly course is determined apparently by the tilting to the north of that portion of the Pilbara Plateau which they traverse. These streams are therefore "consequent" in the wide sense of the term. They are all shown on Woodward's geological map (*n*, Pl. I.), and have eroded early mature valleys in the rocks of the Nullagine Series, which form the plateau.

In their lower courses they run across granite and greenstone plains and then pass through extensive beds of alluvium fringing the coast-line. A special feature of these rivers is the number of water gaps along their courses, the gaps being cut through long narrow ridges of gabbro and banded chert. The alluvium mentioned above appears to be unique, and an investigation as to its nature and history is much to be desired.

The De Grey-Ridley River and its Tributaries.

Farther east than the Yule, the Turner enters the sea, but the Strelley, the Shaw, the Coongan, the Nullagine, the Oakover, and the upper De Grey join the lower De Grey-Ridley River, which runs west-north-west, cutting somewhat diagonally across the streams which are tributaries to it (fig. 25). These tributaries (see Talbot, *d*, 54 and 55) in their upper courses, traverse the Nullagine Plateau in young valleys in which there are many deep gorges and ravines. On leaving the Nullagine rocks they flow across wide plains, largely composed of granite, and therefore have the appearance of old rivers. On the plains are long and narrow ridges of hard rocks (gabbros, cherts, etc.) in which water gaps have been cut by the streams.

The northerly course of the tributaries is due apparently to the tilting to the northward of the Nullagine Plateau, but the course of the De Grey-Ridley River is difficult to explain. It is parallel to the Fortescue and to the Ashburton, but the Fortescue, as shown above, is parallel to the strike of the rocks and to faults along the strike; the Ashburton is also parallel to the strike of the rocks. The De Grey-Ridley, however, cuts across the strike of the rocks, so that the agreement in direction of the De Grey-Ridley with the Fortescue and the Ashburton is probably a coincidence only. It may be that the De Grey-Ridley River occupies a line of faulting or depression, and so constitutes a trough into which the north-flowing streams would naturally enter and so be diverted. Another possible explanation is that these northerly rivers originally continued their courses northwards towards the sea, but in consequence of the possible greater aridity of the

country, or its extremely porous rocks, in the vicinity of the Eighty-Mile Beach, some of these streams never reached the sea, but became lost in the sands or disappeared by underground percolation. The De Grey-Ridley, originally perhaps a tributary of the Shaw, or one of the more western streams, may have extended itself eastward by headward erosion, and possessing a direct passage to the sea, captured and diverted the waters of the north-flowing streams in turn. If this be so, some remnants of the beheaded streams should be found to the north, but the maps do not show any. They may be so insignificant as to have escaped mapping, and some of the streams may not have reached much farther north than where they now enter the De Grey-Ridley. On this explanation some of the rivers that perhaps did not reach, although they came close to, the sea, have since become changed from what might be termed interior drainage (although as examples of the latter they are not good) to exterior drainage. Be that as it may, there is probably little doubt (although no direct evidence is yet available), that a considerable portion of the original interior drainage has been converted into exterior.

It will be noticed that the alternative explanation of "interior" drainage offered for the somewhat discordant courses of the De Grey-Ridley and its tributaries is similar to that propounded for the lower Fitzroy and the streams that run in a southerly direction towards it. The course of the lower Fitzroy is also roughly parallel to that of the De Grey-Ridley. The courses of the streams of the De Grey-Ridley system also suggest that perhaps a slice of the coast has recently foundered.

The writer is indebted to Dr. W. G. Woolnough for drawing attention to the peculiar course of the De Grey-Ridley River.

POSSIBLE DROWNING OF VALLEYS.

The maps of the northern coast of the division, showing its numerous islands and indentations, immediately suggest that the lower ends of the valleys have been drowned. This is corroborated to some extent by Montgomery's description of the Cooglegong, Shaw, and Moolyella "deep leads," in the Pilbara district, which have not been proved to be more than 30 feet deep. Montgomery points out that these leads belong to a time when watercourses had cut into the bedrock, and that since then considerable filling of the older channels has taken place (Montgomery, *d*, 65). He also remarks as to one lead that possibly it did not follow the existing creek (76-78).

The occurrence of these "leads" is just what would be expected if there were a slight subsidence by which some of the lower portions of the valleys were drowned. Aggradation of the higher parts would then take place, burying the old bottoms. The sinking or later movements might dismember some of the old drainage lines, so that the present stream-courses would not always follow the older ones.

CHAPTER V.

THE RIVERS OF MURCHISONIA.

CONTENTS.

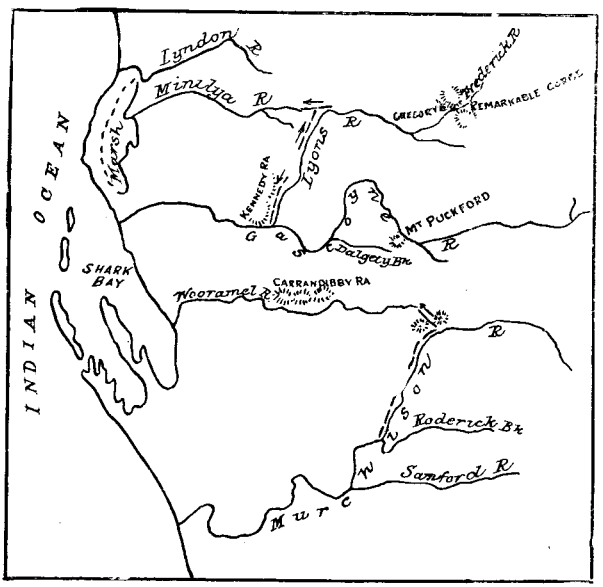
Literature. General Characteristics. Non-Trenched Valleys and their Significance. Water Gaps and Non-Antecedent Streams. Consequent Character of the Streams. Remarks on Individual Streams. Murchison and Wooramel Rivers. Gascoyne, Lyons and Minilya Rivers.

LITERATURE.

The principal publications affording geographical details of this area are those by Maitland (*g*), Woodward (*f*), and Talbot (*d* and *e*).

GENERAL CHARACTERISTICS.

(1) The occurrence of somewhat abnormal rivers in that they flow on elevated plains with little trenching, and of extensive alluvial deposits which form part of the plains. The marked absence of trenching by the creeks at the heads of the Murchison and Gascoyne has been noted by Talbot (*d*, 52).



— — — Possible old courses of streams. ——⇒ Direction of flow.

Fig. 77.—Outline Map of the principal Rivers of Murchisonia, showing the possible old courses of and the resulting changes in the streams.

(2) The occurrence of water gaps (figs. 77 and 78). They are however, not numerous in this division. The following are examples:—

(a) The pass or gorge of the Kennedy Range (fig. 78) through which the Gascoyne flows. According to Woodward (*f*, 15) this gorge is 20 miles long. It appears, however, doubtful whether this gorge is a true water gap, as from the description by Clapp (*a*, 53) the country to the west of the Kennedy Scarp may be a gigantic cuesta as suggested by the writer in the description of Murchisonia; that is to say, that there appears to be no sudden drop in the country to the west of the scarp so as to form a distinct ridge or "range." Field work is required to determine the point.

(b) The gorges of the Arthur and Wyndham Rivers in the Arthur Range (fig. 78).

(c) The gorge of the Frederick River, "Gregory's remarkable gorge" (fig. 77).

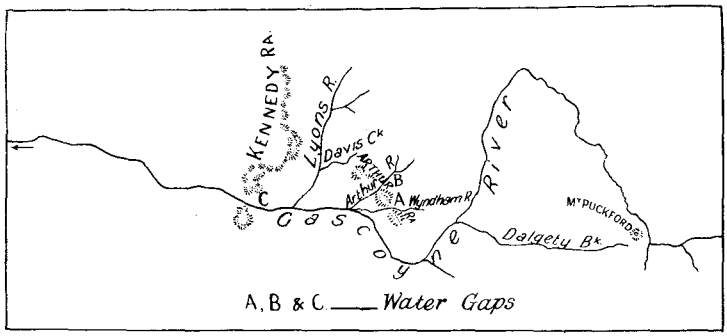


Fig. 78.—Outline Map showing the two water gaps through the Arthur Range, the gorge in the Kennedy Range, and the great triangular bend of the Gascoyne River.

A.—The Wyndham Water Gap.

B.—The Arthur Water Gap.

C.—The Kennedy Gorge which cuts through the great Gascoyne Cuesta.

(3) The fact that a number of streams flow westwards, and that although some are parallel to one another, others are in the same straight line. Examples of these various features are the Sanford and lower Murchison, the upper Murchison and Wooramel, the Gascoyne, and the upper Lyons and Minilya (fig. 77). Those streams, with the possible exceptions of the Sanford and the lower Murchison, approximate in their general direction to the strike of the old rocks.

(4) The prominent south-south-west-flowing rivers, the lower Lyons, the Frederick and the middle Murchinson (fig. 77).

(5) The striking and gigantic triangular bend of the Gascoyne, between Mt. Puckford and the junction with the Dalgety Brook (fig. 78).

(6) The intermittent character of many of the streams, the latter frequently being only chains of waterholes or large pools in the summer; but in times of heavy rain they are often rushing, overflowing streams. The pools occur in depressions, and may be fed by springs.

In speaking generally of the rivers of Pilbaraland and Murchisonia, Talbot (*d*, 52) states that they are not rivers in the generally accepted meaning of the term, as they run only at intervals.

(7) The probability that the main west-flowing streams are consequent on uplift.

NON-TRENCHED VALLEYS AND THEIR SIGNIFICANCE.

A remarkable feature about the Murchison and the Gascoyne (and probably also most of the smaller streams of the division) is that, unlike normal rivers, they have cut practically no trench for themselves (other than the water gaps), even near their mouths, although the country which they traverse forms an elevated plain. They have wide alluvial flood plains on this high country. The explanation appears to be that, although there has been considerable vertical corrasion by the rivers, it has been so slow (probably on account of the comparatively light rainfall, the very great evaporation, and the probable deposit in the beds of the rivers of so much detritus that little energy has been left for corrasion of the solid rocks), that lateral erosion—part of which is, no doubt, due to the wind—has kept pace with the vertical.* The slow cutting through of hard ridges would also facilitate lateral erosion in the softer rocks. The result has, therefore, apparently been that the uplifted peneplain has been reduced in height to a lower-lying, but still high, plain on which stand the isolated hills and ridges as residuals of the peneplain. Vertical corrasion by the river will, no doubt, still proceed, but lateral erosion will probably keep pace with it. The result will be that if the present conditions continue, the country will be reduced to a lowland little above sea-level (a peneplain), but during such reduction and on its completion, the surface will be very similar to the existing one, except that the residuals may be relatively, as well as actually, reduced in height.

The high plain that is now being formed below the old uplifted peneplain would thus appear to be more akin to a plain of arid than to one of normal erosion, and it shows that, though near the sea-board, such plains can be formed at any height, and may be easily misinterpreted as uplifted peneplains.

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* Nicolay (*b*, 83) quotes F. T. Gregory to the effect that the upper portions of the rivers (Murchison, Gascoyne, etc.) have an average fall of six feet to the mile.

WATER GAPS AND NON-ANTECEDENT STREAMS.

The water gaps in the division are of importance in determining its past history. At first sight it may be thought that the streams are antecedent, and consequently that the ridges which they traverse have been uplifted above the general level of the country. Detailed information as to the nature of the rocks in the ridges and in the adjacent country is not available, but the Kennedy and Arthur Ranges (figs. 77 and 78) are known to consist of hard rocks, such as conglomerates and grits, dipping slightly to the west. Softer rocks alternate with these more resistant ones, and as both, by having a slight dip, would come to the surface, by selection the former would be eroded and the latter remain. Moreover, it is not likely that the ridges, if elevated by the force of deformation above the rest of the country, would consist only of hard rocks. From the consideration of the nature of the ridges themselves, they are believed to be merely residuals of the old high peneplain, and consequently the rivers are not antecedent. This view is strengthened by geological descriptions of the country, in which it is shown that there are many isolated ridges and hills capped or composed of resistant rocks, which nevertheless have approximately the same height or are in one continuous line with one another, and with less dissected portions of the old peneplain. Thus the hills and ridges are believed to be residuals.

CONSEQUENT CHARACTER OF THE STREAMS.

As shown below, there have apparently been considerable changes in the directions of the streams owing to river piracy. Before such changes took place the main rivers appeared to flow westwards to the sea, and, as the natural fall of the country is in that direction, it is suggested that the westerly courses were determined as a result of the contour of the country following uplift.

This does not necessarily imply that such uplift was rapid, but it does imply that if the rate of uplift were slow, the western fall of the country was determined practically from the beginning of the uplift and so continued, otherwise there should be records of early changes in the stream channels.

REMARKS ON INDIVIDUAL STREAMS.

Some interesting changes may be indicated as having probably taken place since the inception of the present drainage system, however that originated. The various rivers will therefore be discussed in regard to those modifications.

Murchison and Wooramel Rivers.

The Murchison may be divided into three portions—the lower, the middle, and the upper. The original stream would appear to have consisted of the present lower Murchison and its tributary, the San-

ford, with the lower portion of the present middle Murchison as a tributary. The present upper Murchison and the Wooramel (fig. 77) may have been another stream distinct from the Murchison-Sanford. The growth headward (northwards) of the middle Murchison tributary, perhaps favoured by geological structure* has apparently beheaded the old upper Murchison-Wooramel, diverting the upper waters into the present lower Murchison, and leaving the Wooramel a diminished stream. The Murchison is *par excellence* the typical old-looking stream, winding about on a high plain with wide alluvial flats, and hardly possessing anything in the way of a trench in the plateau. The Wooramel, on the other hand, according to Woodward (*f*, 16), runs over the plain of the crystalline rocks but on meeting the Carboniferous sediments it has developed a trench in which it apparently continues to the sea. The reason for this divergence of type is not apparent. As regards the Wooramel itself, its trench may be due to the fact that the Carboniferous and younger sedimentary rocks are softer than the older crystalline rocks, but this does not explain why the rivers farther north, such as the Gascoyne, Minilya, and Lyndon, have not likewise cut trenches. The rocks have not been sufficiently mapped in detail to answer this question. The rainfall may also vary considerably, and so affect stream corrasion. This corrasion of the lower course of the Wooramel is typical of a young stream incising a plateau, and suggests revival by possible local uplift.

Maitland (*d*, 9) notes that the Murchison 20 miles from its mouth enters a narrow gorge, flanked by vertical walls of sandstone and grit. The point of entry is apparently at the junction of the Jurassic sediments with the old crystalline rocks which is marked by a fault (Maitland, *j*, 40). The reason for the gorge, however, is not apparent.

Gascoyne, Lyons and Minilya Rivers.

These form another interesting group (figs. 21, 77 and 78). The Gascoyne appears to have been a great west-flowing stream with a tributary, the lower Lyons, which was probably not originally connected with the present upper Lyons. Another distinct stream, the present upper Lyons and the Minilya, ran almost due west to the sea. The Lyons tributary of the Gascoyne, working backward (northwards) by headward erosion, has apparently beheaded the old upper Lyons-Minilya stream, and diverted the upper waters into the Gascoyne, leaving the present Minilya a diminished stream.

Since the above was written in the first edition of this work, another map has been published by Talbot (*e*, Pl. II.). That map shows that at the headwaters of the Minilya there is a gap in the north and south trending Black Range, and that to the east of the range, Gregory

* Both the middle and lower Murchison are close to the junction of the Carboniferous and younger sediments, with the older crystalline rocks.

Creek flows eastwards into the Lyons in the same line as the Minilya. Gregory Creek may be an obsequent stream and the gap in the Black Range may be a wind gap. The map, therefore, strengthens the suggestion as to the beheading of the old upper Minilya (now the upper Lyons).

The present lower Lyons is apparently a subsequent stream eroded in comparatively soft sedimentary rocks, which have a general north and south strike in the locality mentioned. It thus has a great advantage over streams which cross both soft and hard rocks, and it is this feature which has probably given the advantage to the lower Lyons.* This, if correct, is another illustration of the adjustment of streams to structures. The erosion by the Lyons along soft rocks would also account for the great east-facing scarp of the Kennedy Range. The rocks of the latter have a slight dip to the west, and the tendency of a stream following the strike of a band of soft rocks, with such a dip, would be to erode in the direction of the dip, and so produce a steep escarpment on the western side of the stream. This explanation will not hold good if the Kennedy Scarp be a fault scarp as suggested by the writer in the chapter on Murchisonia, that suggestion being due to Clapp's observations on the Kennedy and other scarps.

The Frederick River is a tributary of the upper Lyons, and is rapidly working backward (northwards), having cut a water gap in a ridge, such gap being referred to on the maps as "Gregory's remarkable gorge."

The great triangular bend of the Gascoyne, from Mt. Puckford to the junction with the Dalgety Brook, is a most striking feature (fig. 78). In the absence of field examination, a satisfactory explanation cannot be given. One point, however, appears to be certain, and that is that the Dalgety Brook, with its straight course to the sea (along the lower Gascoyne) will ultimately capture that portion of the upper Gascoyne above Mt. Puckford, and perhaps leave the other two sides of the triangle as a huge ox-bow lake.

Despeissis (16) notes that outside Carnarvon (at the mouth of the Gascoyne) in flood time there is a muddy freshwater stream stretching for miles into the ocean. That is the result of the river detritus carried into the sea by the Gascoyne.

* The upper portion of the lower south-flowing Lyons appears, however, to be in crystalline rocks.

CHAPTER VI.

THE RIVERS OF THE SOUTH-WEST DIVISION OR SWANLAND.

CONTENTS.

Literature. General Characteristics. Remarks on Individual Rivers. Swan-Avon and Moore Rivers and their Tributaries. Murray-Williams, Hotham, Harris, Collie and Adjacent Rivers. Blackwood-Arthur River. Warren-Tone and Frankland-Gordon Rivers. Frankland-Gordon, Kalgan and King Rivers. Pallinup River and Adjacent Streams. Coastal Limestone Streams between Capes Naturaliste and Leeuwin. Greenough River. Chapman River. Bowes River, Irwin River. Sub-surface Drainage. Exterior and Interior Drainage. Drowning of Valleys. Stanniferous Deep Leads at Greenbushes.

LITERATURE.

The chief publications containing geographical data for the area in connection with river development are by Woodward (*f*), Nicolay (*b*), Campbell (*c*), Woolnough (*b* and *d*) and Clarke and Williams.

The present writer (*a*) has also outlined the probable history of the Swan-Avon and other rivers of the division.

GENERAL CHARACTERISTICS.

(1) The most prominent characteristic is the rectangular courses of the streams, the bends in many cases being almost at right angles Pl. IV. and fig. 30). This is not observable in most of the rivers of the northern portion of the area, such as the Greenough, the Chapman, and the Irwin; but it is strikingly shown in the Moore. It may also be noticed in the Swan-Avon, the Hotham, the Murray-Williams, the Warren-Tone, the Frankland-Gordon and the Kalgan. These courses suggest changes by capture

Griffith Taylor (*a*, 60 and 61) has suggested that the rivers originally flowed to the south-west, that later tilting to the north-west "strengthened the westward flowing streams," and that possibly major joints at right angles have influenced the directions of the streams.

(2) The deflection of the streams near their mouths to the north or to the south, this change of direction apparently being due to the building up of sand dunes along the coast. Examples are the Serpentine, Wellesley, Greenough, Hutt and Harvey. Some connect directly with the ocean, *e.g.*, the Greenough, and some enter it by lagoons, *e.g.*, the Harvey (Pl. IV.). The formation of these lagoons may have been aided by an "uplift" of the land (Aurousseau and Budge, 34).

(3) The Blackwood-Arthur is the great stream of the South-West. It drains a large area, and it appears to be a river that has firmly established itself (fig. 30). The Swan-Avon basin also occupies a wide extent of country.

(4) The rivers vary in the Darling Peneplain from young or early mature to mature (fig. 79). On the Swan Coastal Plain and the narrow coastal plain in the south, they meander through their flood plains and have the features of old rivers.

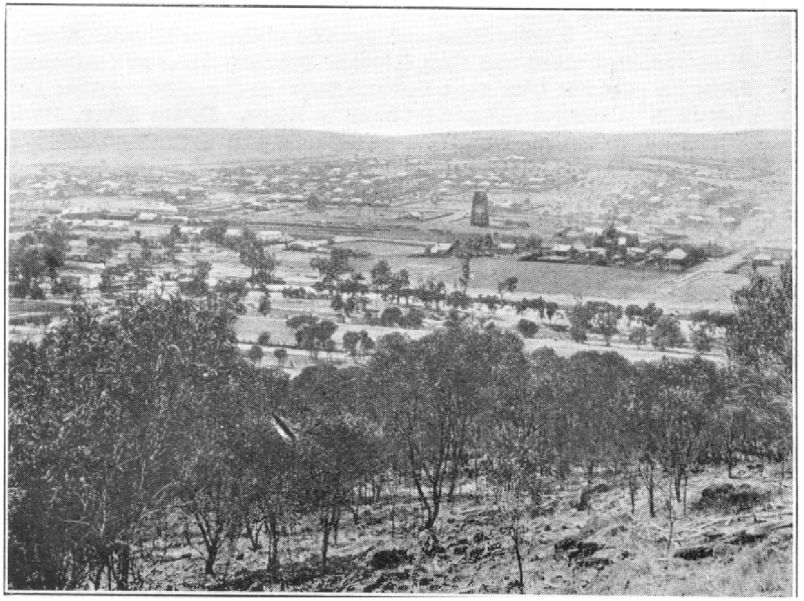


Fig. 79.—The Avon River at Northam, showing its mature valley.

(5) A north and south rift valley occurs to the east of the Naturaliste-Leeuwin Ridge, and between the Augusta-Dunsborough and the Darling Fault Scarps. The northern extension of this valley has sagged beneath the sea. The final course of the Blackwood-Arthur River has probably been determined by the rift valley. (See Pl. IV. and fig. 38.)

REMARKS ON INDIVIDUAL RIVERS.

Swan-Avon and Moore Rivers, and their Tributaries.

In 1912 (*a*, 152, *et seq.*) the writer dealt with the Swan-Avon and adjacent streams. The north-west and south-east courses of many of the streams, which at least in the case of the upper Avon, flow in a mature valley parallel to the strike of the rocks where such

strike existed; and the approximately east and west courses of others, which, in the case of the middle Swan-Avon and Helena Rivers, flowed through young (or early mature) valleys across the strike of the rocks where such strike existed, were pointed out.

Three possible explanations for the present courses of the streams were stated in the writer's paper (*a*) just mentioned, and in the first edition of this work (*b*, 127, *et seq.*) substantially as follows:—

1. Their courses are those which were initiated on uplift, the more mature upper valleys being formed by being in softer or more easily eroded rocks (by virtue partly of the streams in these mature valleys being parallel to the strike of the rocks), whereas the gorges are in less yielding rocks. The principal gorges are in consequent west-running valleys, and the mature north-west and south-east valleys are subsequent, which by "adjustment of streams to structure" have most rapidly developed.

2. The present streams are old rivers revived on the uplift of the Darling Peneplain, but owing to greater gradual elevation on the western than on the eastern side of the plateau, aided by more easily eroded rocks on the eastern side, the eastern valleys have more rapidly developed than the western. If this be the correct history, then the principal adjustments took place in the cycle of erosion preceding the present one, such adjustments being the great development of the subsequent streams compared with the consequent streams, which development has since been maintained.

3. The eastern and western streams were originally distinct, but the eastern were captured by the western and the waters of the former were diverted. The eastern would at first be the principal streams.

In the first two cases the drainage would be radial and so remain. In the third case the drainage would be at first marginal, but later radial.

The third statement was tentatively adopted as a working hypothesis, and the following outline of probable history was set forth:—

As a result of long continued sub-aerial erosion, a low lying peneplain was developed in pre-Pleistocene times. This peneplain would naturally slope to the coasts in different directions and the drainage would be radial. Uplift occurred by which the present Darling Plateau reached its existing position. The elevation was greater in the western portion of the plateau, so that the surface of the latter became almost level, but with slight slopes to the east and to the south, giving the plateau a slight general fall to the south-east, with possibly also at its extreme western portion a slight fall to the west. This arrangement would be sufficient to make the principal drainage marginal, instead of radial. A series of south-east flowing streams would be formed, the longest and most important of which would be that running from north of Moora through Toodyay, York, Beverley, and down the line of the present Avon River and Wardering Brook (a tributary of the Hotham

River). From there its course may have been to the Southern Ocean, but what position the river occupied cannot at present be stated. Perhaps it ran in the direction now occupied by some lakes to the east of the Great Southern Railway, and thence either to the east or to the west of the Stirling Ranges. This old river is now represented by the north and south portion of the eastern branch of the Moore River, its tributary, Yanawindah Brook, Toodyay Brook, the small streams between Toodyay and Clackline (following the railway between these two places), probably a valley between Clackline and York (whose course cannot now be identified from the maps), the Avon above York, Wardering Brook, and either the upper portion of the Gordon and the Young and Kalgan Rivers, or the Pallinup River. A tributary would join this great river at York, now represented by the Mortlock River (northern branch) and the Avon from Northam to York.

Another stream would be the western (north and south) branch of the Moore River, the Brockman River* and the present Swan below its junction with this river.

The upper portions of the Helena and Canning Rivers may have been independent streams flowing south-easterly into an old main river running south or south-easterly to the southern coast.

While these south-east consequent streams were engraving their channels in the land, other consequent rivers were working back from the western coast. A very short course to the sea and a greater rainfall than the south-east streams possessed would enable the coastal rivers to rapidly cut down their channels, and headward (eastward) erosion would rapidly progress until they met the south-east streams, capturing portions, reversing the flow of other parts, and breaking such streams up into segments. Thus the lower Moore River, working eastward, captured portion of the old north and south river, and separated it from the Brockman River. Continuing to work eastward along its present eastern branch, the Moore River captured portion of the old north and south river, reversed the flow of part of the southern portion (now the Yanawindah Brook) and disconnected the latter from the present Toodyay Brook.

The Swan, working eastward from the junction with the Brockman River, captured portion of the old main north and south stream (now the Toodyay Brook) and reversed the flow of portion of the southern part (now the brook heading up to Hoddy's Well) separating the latter from the stream which runs south to Clackline. Eroding its channel still eastward, it met and beheaded the other branch of the old main north and south stream (now the northern branch of the Mortlock River) at Northam, and from the latter town gradually changed the course of the present Avon from south-easterly to north-westerly, ultimately disconnecting the present Avon from the rivers to the south.

In the case of the Helena, this probably consisted originally of several distinct streams. The present lower portion (below the Mundaring Weir) ran north-westerly to the Swan, whilst the upper portion, together with other streams which are now tributaries parallel to the main stream, ran south-easterly, probably joining a great river to the south. The lower Helena, with the same advantages as the lower Moore and lower Swan, gradually worked backwards (south-easterly), reversing the course of the stream. Its eastern branch was probably a tributary running south-westerly. This tributary cut backwards and ultimately beheaded the two streams that flow south-easterly into this old tributary, but originally flowed further south-east. The Gingin Brook is an example of a river that is eroding headward towards a north and south stream, but has not yet succeeded in beheading the latter.

* Suggested by Blatchford (*c*, 57).

Such, in brief outline, is the probable history of the Swan-Avon system. If correct, it shows how this chief river has added to its drainage territory and how great a quantity of water must have been diverted from the Southern Ocean to the Indian Ocean. The sedimentation, too, at the mouth of the Swan must have been enormously increased, and if most of the deposits proved by the bores are ultimately found to be of comparatively recent origin, then the sinking of the sea-bed in the Perth area is explained by the weight of the great sediments there deposited.

That the river systems farther south have had a somewhat similar history is also probable.

The evidence for such outline is set out in the paper mentioned (Jutson, *a*, 157, *et seq.*) and should be referred to by those desirous of pursuing the matter further. (See also figs. 80 and 81.)

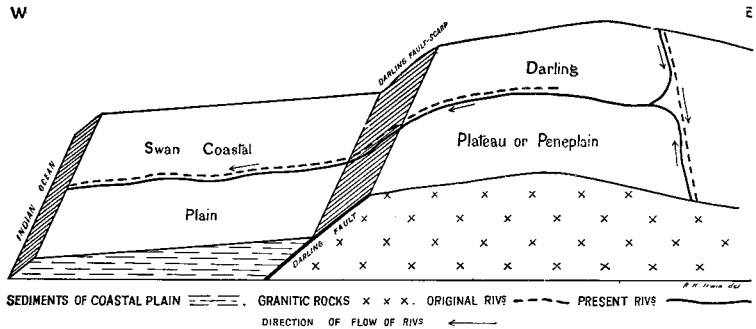


Fig. 80.—Block Diagram, showing the possible original courses of the streams on the Darling Peneplain and the Swan Coastal Plain, and the changes to their present directions.

As stated above, the outline given was adopted as a working hypothesis and to stimulate physiographic study in Western Australia.

Since the life history of the Swan-Avon system was outlined as above, consideration to the subject has been given by Griffith Taylor (*a*), Woolnough (*b*), and Clarke and Williams. Taylor's suggestion (which was not based on field study) as to the physiographic history of the streams has been given above (p. 167).

Woolnough (*b*, 389-391), in reference to the mature north and south valleys described by the writer, points out that (1) they form a series of sub-parallel troughs parallel with the general "grain" of the country; (2) they are very wide in proportion to their depth, that is, are highly mature; and (3) they are carved out of the laterite-covered plateau and their bottoms lie at least 200 feet below its level. He regards these longitudinal valleys as having been formed after a slight uplift which occurred subsequently to the formation of the Darling Peneplain, and before its elevation to its present altitude; and he has named the level to which these longitudinal valleys are now cut (as stated in the general

account of Swanland) the "Mature Valley or Meckering Level." Some of these streams flowed to the north and others to the south. Then came the great uplift of the plateau to its present height, and, as a result of the formation of the Darling Fault Scarp, new active consequent rivers, flowing from east to west, were formed. They rapidly extended their valleys headwards, gradually dismembered the older

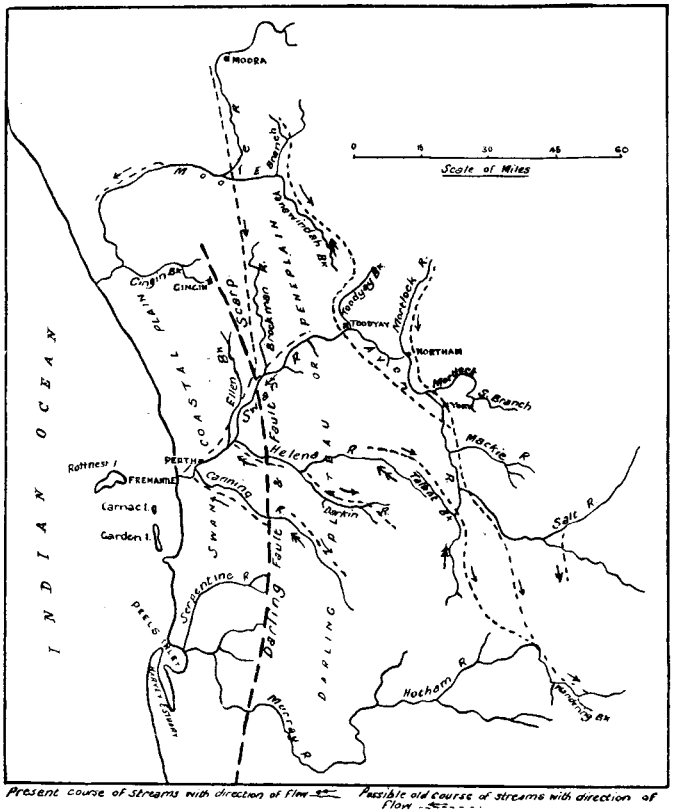


Fig. 81.—Map of the Swan-Avon and Moore River systems, showing the possible changes in the courses of the streams.

streams, and produced the present arrangement of the drainage. Thus the present writer's conception of the history of the drainage system is corroborated, with the addition, however, of an intermediate uplift to account for the mature character of the north-south streams, and with the reservation as to difference in the conclusions as to matters of detail (*b*, 391). At Northam and York the Avon River (fig. 79) has not yet been affected by the piracy carried out by the Swan, but at

Toodyay, the Swan is actively incising its valley (its bed lying far below the original valley bottom), and is in a comparatively youthful stage of development (Woolnough, *b*, 391).

Clarke and Williams (164 and 165) state that the Canning River valley, east of the Darling Fault Scarp, has several right-angled bends, "the north-south arms of which are probably portions of the old dismembered drainage system," and that "the tributaries which generally have a more or less north-south direction flow, for the greater part of their course, through shallow wide valleys, but their lower parts flow through narrow deep valleys."

The same authors (165, *et seq.*) also discuss the physiography of the Darlington area (which is also east of the Darling Fault Scarp and within the basin of the Helena River). The Helena valley is described and three types of tributaries of the river are noted. They are: (a) Wholly immature insequent tributaries. (b) Rejuvenated tributaries, comprising Smith's Mill and Cohen Brooks, and a stream which enters the Helena opposite the mouth of Smith's Mill Brook, all of which in their upper parts flow through wide shallow valleys in the Darling Peneplain, but on reaching the slopes of the Helena Valley they are immature. Piesse Brook in its upper portion is mature. (c) Beheaded tributaries, of which Greenmount and Hosking Brooks are examples probably.

As already noted when describing the Darling Peneplain, there are two high level terraces in the Helena valley, one at about 450 feet and the other at about 250 feet above sea-level, which indicate old base levels of erosion and two long pauses in the uplift of the peneplain. Similar terraces probably also occur in the Canning River valley, and along the Darling Fault Scarp. (Clarke and Williams, 167.) These movements have not yet been correlated with the step-faulting postulated by Woolnough at the Ridge Hill Shelf. (Woolnough, *c*, 16.)

Since the comparatively recent drowning of the lower Swan River, minor earth movements have occurred. These, with their associated phenomena, have been described by Somerville and by Aurousseau and Budge.

Somerville has claimed that in the lower Swan River valley an elevation to at least 23 feet has occurred, the evidence for which is the occurrence of shell beds with associated beach conglomerates or breccias, of uplifted spits, of beach platforms and of wave-cut platforms. (See fig. 43.)

Aurousseau and Budge hold that the Swan and Helena River valleys in their lower portions have a succession of river terraces one below the other and a few feet apart, which indicate a series of small "uplifts" and still-stands. The total height of the "uplifts" is 22 feet, which corresponds approximately with the height of the "uplift" of the lower Swan River valley, below its junction with the Helena River, as determined by Somerville on other and independent evidence.

It appears to the writer that great caution should be used in accepting such insignificant terraces as evidence of repeated "uplifts," unless the supposed elevatory movements of the river valleys can be correlated with changes in sea-level at the coast, which Aurousseau and Budge claim to be the case in regard to the phenomena described by them.

Murray-Williams, Hotham, Harris,* Collie, and adjacent Rivers.

The Murray-Williams, the Hotham, the Harris, and others (fig. 30), have the rectangular courses as already noticed, and cases of capture will no doubt be brought to light on investigation. So little is known of these streams, and the maps are so indefinite, that no useful discussion can now take place. It may, however, be pointed out that the acceptance of the drainage of the Swan-Avon-Moore area as originally to the south-east with a subsequent diversion to the west, need not imply that the history of all or most of the south-western rivers has been the same. It is quite feasible that some of the rivers, originally flowing westward, have been beheaded by north and south streams. A possible example is that of the Harris, which first flows west and then south to join the Collie. The head of the Brunswick River is close to the upper Harris, and the dispositions of the streams suggest that the upper Harris may have at one time been continuous with the Brunswick, but that the middle Harris working backward (northward) beheaded the Brunswick and diverted the upper waters to the Collie, although, from the shorter course of the Brunswick to the sea, this would hardly be expected. It may be that the Brunswick River is eroding headwards and may capture the upper Harris. The Bingham River is similar in all respects to the Harris.

The possibility of major right-angled joints being responsible for some of the rectangular courses of the streams, as suggested by Taylor (*a*, 60 and 61), is worthy of consideration, but at present our knowledge is too limited to discuss the matter.

Blackwood-Arthur River.

The Blackwood-Arthur (fig. 30) with its many tributaries has no doubt a most interesting history to unfold, but nothing can be stated here except that it is apparently a stream which has established itself firmly in the country by numerous acts of piracy, and that Somerville (13) notes that its mouth is a drowned valley with evidence of later uplift.

Warren-Tone and Frankland-Gordon Rivers.

The sharp turn of the Tone to the Warren River (fig. 30) and the occurrence of Lake Muir between this turn and the Frankland,

* The Harris is the northern branch of the Collie, and in the district the latter name is more used than "Harris."

suggest that the Tone was perhaps at one time a tributary of the Frankland or of the Deep River, but that it has been captured by the Warren.

Frankland-Gordon, Kalgan and King Rivers.

The Gordon (fig. 30 and Pl. IV.) has some sharp turns, and it may be that its upper more or less south-flowing portion was originally connected with the Kalgan, but has since been captured by the present west-flowing Gordon. Woolnough (*d*, 107) believes that the cause of the sharp turn of the Gordon River to the west is the uplift of the country along the line of the Stirling Range.

The south-easterly course of the upper Kalgan (or Young) River is also, according to Woolnough (*d*, 109) one of the results of the formation by uplift of the Stirling Range. The lower Kalgan flows in a south-south-westerly direction. A small stream, the Waychinicup, flows into the ocean in the same line as the upper Kalgan, and this fact and the course of the lower Kalgan suggest that the latter has beheaded what was originally one south-east flowing stream, leaving the Waychinicup a shrunken remnant.

The Kalgan and King Rivers enter Oyster Harbour at the head of King George's Sound. They were originally united below their present mouths, but owing to the drowning of the country they have been betrunked (Jutson and Simpson, 52, *et. seq.*).

Pallinup River and Adjacent Streams.

The Pallinup and associated streams have been studied by Woolnough (*d*, 106 and 107), who has shown that the major tributaries of the Pallinup enter the left bank, and only a few minor creeks enter the right bank. The major tributaries, he regards as originally the main streams which, at one time flowed southerly across the site of the present Stirling Range, which was not then in existence. The Pallinup River originated as a result of the faulting which formed the Stirling Range (for details see the chapter treating of the mountains of the State), as by such faulting the drainage was diverted to the south-east. The Pallinup has, therefore, beheaded and captured the earlier south-flowing streams.

Coastal Limestone Streams between Capes Naturaliste and Leeuwin.

Glauert (11 and 12) states that "the numerous winter streams that rise in the hills proceed uninterruptedly till the limestone belt is reached, when they mostly disappear, either in the mouths of caves or in 'swallow holes' . . . . . These subterranean water courses are usually a succession of clefts and caverns, increasing considerably in width and height when conditions are favourable. As a general rule

the upper contour of the underlying granite forms the bed of the stream, but a very hard band of the limestone will answer the same purpose, though not in so satisfactory a manner."

Greenough River.

Turning to the northern part of the area the Arrowsmith and Hill Rivers call for no special comment, but the course of the Greenough, near its mouth, has apparently been recently changed (fig. 82). According to Campbell's geological map it passes through a gap in the Tertiary limestone, and then flows north-westerly for some distance parallel and close to the coast before entering the sea. Near its mouth it is joined by Rudd's Gully, which Campbell (*c*, 80) describes as interesting on account of its large proportions, stating that evidently at one time it was an important drainage outlet from the Turner Flat, near the Bootenal Road. From this and the contour of the country it would appear that the Greenough originally ran north-west on the *eastern* side of the Tertiary limestone, following the course of the Northampton railway line, and joining the Chapman at the north-westerly turn of the latter.* Later a short stream (in Rudd's Gully) was formed which, having a shorter course to the sea, perhaps beheaded the early lower Greenough, and diverted its drainage from the Chapman to the sea, through the present Rudd's Gully. Later still a very short stream cut a gap through the Tertiary limestone, near the Walkaway Station, and captured the river, thus giving it a short course to the sea. The old stream then shrank to Rudd's Gully. The original course was apparently due to the building up of sand dunes (now the Tertiary limestone), which diverted the river to the north-west. After its second change of course, sand dunes again formed and again diverted the stream to the north-west, but on the *western* side of the Tertiary limestone, the river ultimately joining its old mouth at Rudd's Gully. This, if true, is indeed a curious example of "history repeating itself." In most of its lower course the Greenough cuts through the plateau of nearly horizontal Jurassic sediments, the dissection giving rise to escarpments.

Chapman River.

The Chapman River in its lower portion executes almost a semicircle before entering the sea. It does not take the shortest course to the ocean by cutting through the Moresby Flat-Topped Range, but flows southward to the eastward of the range and then turns westward at the end of the latter, thence flows north-westerly to the sea (fig. 82). This range appears, therefore, to have directly influenced the course of the river, and was probably either a monadnock on the old peneplain, or its upper rocks were so hard that it was easier for the stream to skirt them. The Chapman mainly flows through the plateau of Jurassic sedimentary rocks, which give rise to escarpments.

* Woodward (*b*, 7) has suggested this general course, the Greenough discharging itself "somewhere about the mouth of the Chapman River."

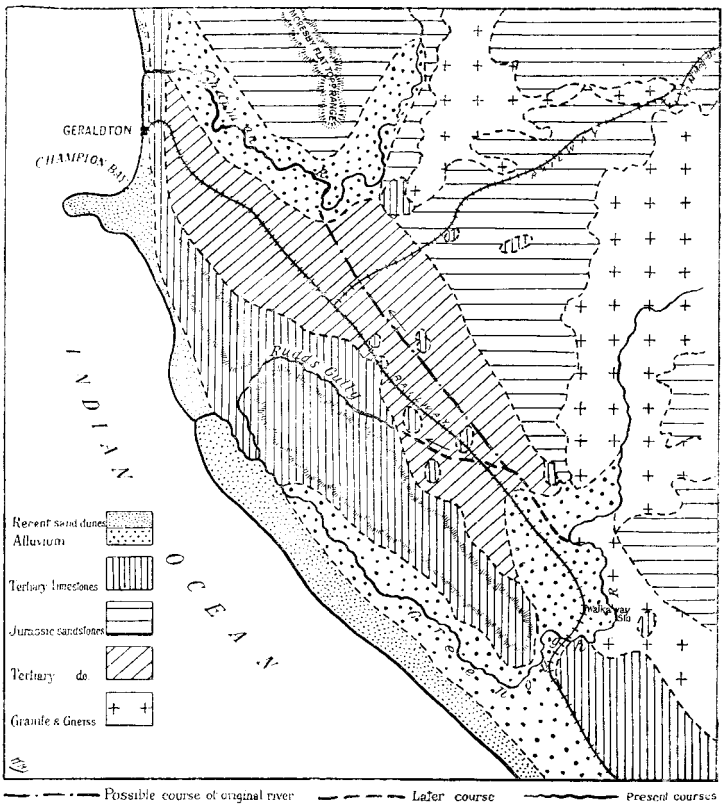


Fig. 82.—Map of the Greenough River district, Swanland, showing the possible old courses of the Greenough River, and the former possible connection with Rudd's Gully and the Chapman River. (Topography and geology from Campbell's map, Bulletin 38, Pl. 1.)

Bowes River.

The Bowes River appears to have had an interesting history, which may be gleaned from Campbell's geological map of the Northampton area (fig. 83). It runs south-westerly for some distance (this portion

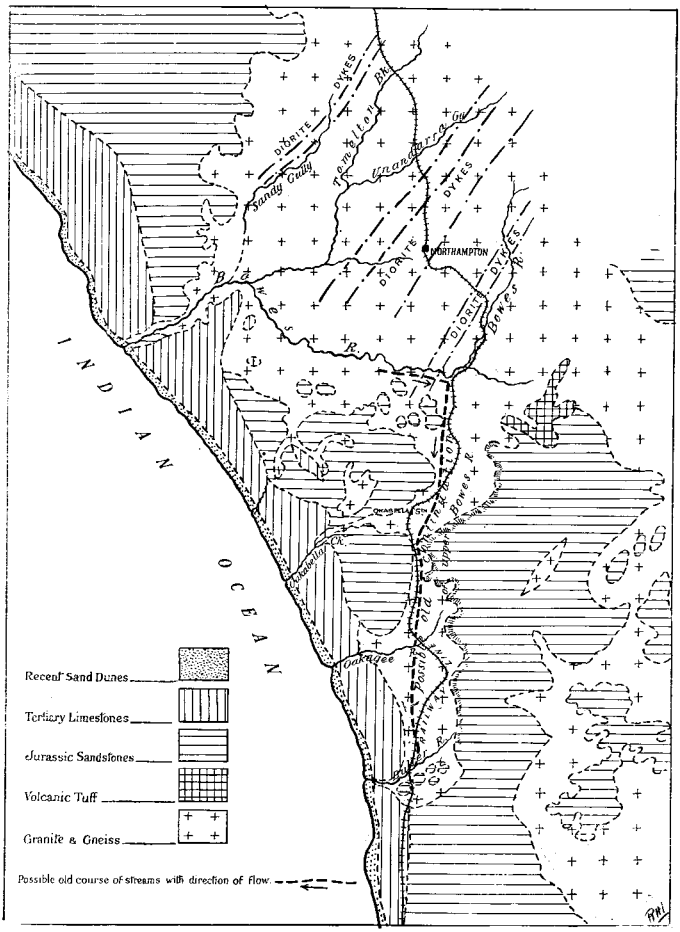


Fig. 83.—Map showing the possible old course of the Bowes River and its beheadal by the present lower Bowes, and also the tapping of the old valley drainage by the Oakabella Creek and the Oakagee River. Some details are omitted. (Geology and topography from Campbell's map, Bulletin 38, Pl. I.)

may be called the upper Bowes), and then turns sharply to the west-north-west, but turning to the west-south-west before it reaches the sea; from its turn from the south-west we may call the river the lower

Bowes. The principal tributary of the Bowes is the Tomelton Brook, which runs parallel to, but to the west of the upper Bowes. To the east the Chapman is also parallel to the upper Bowes. The natural fall of the country appears to be to the south-west or south. Continuing in the latter direction from where the upper Bowes, by its sharp bend, changes into the lower Bowes, is a narrow valley cut through the Jurassic rocks and exposing the underlying granite. The Northampton railway runs through this valley. The upper Bowes appears originally to have continued down this valley and to have joined the ocean, where the Buller River (a remnant of this old river) now enters. This was a long course to the sea. The lower Bowes, originally a distinct river, had a short course. By headward growth it eventually captured the upper Bowes. The old discarded valley is being drained by the Oakabella, Oakajee, and Buller Rivers. The railway traverses the old valley, and rises from Stone's Siding, near the Buller River, until Oakabella is reached, from where it again descends to the Bowes River. The drainage is, therefore, apparently to the north from Oakabella, being reversed as would be expected. The above appears to be the broad recent history of the Bowes River.

A point of interest is in connection with the mouth of the old river, which has been suggested above as that of the present Buller. The latter river, however, in its lower western portion cuts through the limestone-capped granite as a narrow gorge, while higher up it is in a broad valley. (See the geological map of Campbell (*c*) and Woodward (*m*, 17).) One of two explanations is available. Either the present lower Buller is a gorge within a broader (the old) valley, or the coastal limestone has been formed since the capture of the old stream, and hence only a narrow outlet for the shrunken remnant is required.

Irwin River.

This river, with its tributary the Lockier, mainly traverses nearly horizontal sedimentary Jurassic rocks. It does not call for special remark except the portion in the neighbourhood of Mingenew, where it and the Lockier are associated with a remarkable valley which has been described by Woolnough and Somerville (68, *et. seq.*). This valley is flat-floored, is about 30 miles long from north to south, by 9 miles wide from east to west, and is completely surrounded by steep escarpments. The Irwin River enters this valley from the east, flows south-westerly across the valley until it reaches Yarragadee, where it turns to the west and passes through the plateau (part of the Darling Plateau) in a deep narrow gorge. The Lockier has similar features, although the plateau gorge is less pronounced than that of the Irwin River at Yarragadee. The origin of this valley is not discussed by the authors named, although there are parallel north-north-west faults on either side of the valley, but in the case of the more easterly fault (the Main Fault) the fault is to the east of the eastern escarp-

ment of the valley, and in the case of the westerly fault, the throw is to the west of the fault, both of which facts apparently prohibit a tectonic origin for the valley. It appears to be suggested (100) that the valley is entirely due to erosion, which is so remarkable as to call for an explanation. Further investigation is desirable.

SUB-SURFACE DRAINAGE.

An interesting form of sub-surface drainage has been described by Aurousseau at Greenmount near Perth, and at Roelands 102 miles farther south, both within the Darling Peneplain area. "During the hot, dry summer, fissures form in the sub-soil, but do not extend to the soil, owing to its binding of vegetation. During the heavy, winter rains, much of the water sinks straight into the dry ground, which soon becomes saturated. Relief is afforded by flow along the sub-soil fissures, which soon become widened into definite underground channels. Pressure causes the surface soil to burst at the weakest spots, with the formation of pot-holes. As the channel is deepened and widened, the roof tends to collapse more or less along the whole length of the original fissure." (827.)

Aurousseau believes (827) that the formation of these lines of sub-surface drainage is to be attributed not to any peculiarity of the soil, which is derived from granite and laterite, but to the climate of the region which is characterized by marked seasonal rainfall.

EXTERIOR AND INTERIOR DRAINAGE.

As in Murchisonia, Pilbaraland, Fitzroyland and Ordland the rivers of Swanland have no doubt converted, and are still converting a portion of the interior drainage into exterior, an apparent example of which is at Wagin on the Great Southern railway, where the Beaufort River receives at times the drainage from an interior valley. (Woodward, *h*, 14.)

DROWNING OF VALLEYS.

The lower portion of the Swan-Avon River valley has been drowned (Jutson, *a*, and figs. 37, 43 and 44). Somerville (13) has also noted that the Blackwood-Arthur valley has been drowned in its lower portion, and the same remark applies to some of the rivers on the southern coast, notably in the neighbourhood of Albany (Jutson and Simpson). (See fig. 42.)

THE STANNIFEROUS DEEP LEADS AT GREENBUSHES.

At Greenbushes, in the southern portion of the division, stanniferous deep leads occur, the channels of which are not everywhere identical in direction with those of the present streams. From the nature of the detritus in these old deep lead channels and from the abundance of laterite in the neighbourhood, Woodward (30-33) considers that there have been changes in the climate of the district. This interesting point, however, cannot now be discussed.

It may be remarked in connection with the deep leads that if a movement of subsidence occurred after the formation of their channels, the latter might be broken by such movement and perhaps temporarily aggraded, but aggradation does not seem very likely in view of the height of the country at Greenbushes, from about 800 to 1,000 feet above sea-level. Subsidence has occurred as indicated by the drowned valley of the lower Swan, and by some of those on the southern coast, but whether it affected the Greenbushes district cannot be stated on present knowledge.

CHAPTER VII.

THE DRAINAGE OF SALINALAND, SANDLAND, AND EUCLONIA.

CONTENTS.

General Description. Conversion of Interior into Exterior Drainage.

GENERAL DESCRIPTION.

In Salinaland and Sandland there are short creeks (usually dry, but which may attain at times flood dimensions as shown by fig. 84),



Fig. 84.—West Creek, about 30 miles W.N.W. of Wiluna, in the north of Salinaland. In flood. Except for a short period after rain, there is no water in the channel.

but nothing that can be called a river, and the drainage is almost all to the interior. In Euclonia, on account of the nature of the rocks, mainly limestones, the rain almost immediately percolates beneath the surface, leaving none for the formation of streams. The land, therefore, is not dissected, and remains practically level. Portion, at least,

of the water issues at the base of the cliffs at the southern coast, as noted by Maitland (*h,* 13) and Gibson (*d,* 25-26). Probably in the north-west in Warburton's Great Sandy Desert, the water also finds its way to the coast.

Except in the areas mentioned, and except occasionally at times of heavy rain, when the salt lakes may overflow into coastal streams, no portion of the drainage reaches the sea. Part of the rain percolates through the rocks; part is lost by evaporation; and the remainder flows into the salt or "dry" lakes (figs. 51 and 54) where it quickly disappears by evaporation. In many instances, however, the streams die out by soakage and evaporation before reaching the lakes. The latter are treated in Part X., so that they are not further discussed here.

The valleys of Salinaland are described in Part XI., Chapter I.

CONVERSION OF INTERIOR INTO EXTERIOR DRAINAGE.

A word might be added on this question. The possibility that this action has occurred has been indicated when treating of the rivers of Fitzroyland. A similar suggestion has also been made with regard to the eastern tributaries of the De Grey-Ridley River in Pilbaraland. In other portions of that division, and in Swanland, there can be little doubt that the coastal streams are encroaching and diverting the drainage of the interior to the sea, although known instances are few. An example is the Beaufort River, which at times receives the water from an interior valley at Wagin (p. 180), as remarked when describing the rivers of Swanland; another instance is the apparent capture by the Avon River of the Salt River (see figs. 30 and 81).

PART VIII.—THE GREAT PLATEAU OF WESTERN AUSTRALIA.

CHAPTER I.

PREVIOUS OPINIONS AS TO ITS ORIGIN AND AGE.

1861. *F. T. Gregory.*

This writer points out that the principal portion of Western Australia consists of an undulating tableland which has a long western escarpment [the Darling Fault Scarp], which he recognises as due to a fault. His most interesting observation is that since Tertiary time, the country has been both elevated and depressed, more than once perhaps, but bodily and equably and without tilting. This is a distinct recognition of the possibility of the great Western Australian earth-block being relatively uplifted or depressed vertically with practically no folding, warping, or tilting.

1873. *H. Y. L. Brown.*

A brief reference is made to the belt of country dealt with (the South-West Division), that in general it may be considered a plateau having an average elevation of some 1,000 feet or thereabouts above sea-level, occupied in places by ranges and hills of greater elevation than itself, but yet not of any great height, and bounded on the west by an escarpment. No reference is made to the origin of the plateau.

1881 (*continued to* 1896). *C. G. Nicolay* (*b*).

The only point of interest in this publication, from the aspect under discussion, is that Nicolay states that F. T. Gregory describes the entire North-West as rising in successive terraces from the sea, but more or less broken up by volcanic hills towards the coast.

1884. *E. T. Hardman* (*a*).

In referring to the south-western portion of the Kimberley district, Hardman states that in the ranges near Point Usborne, the plateau-like outline is extremely well marked, indicating an old plain of marine denudation subsequently carved out into hills and valleys by the action of subaerial denudation, the harder rocks now forming the ridges and the softer the valleys (4).

1890. *H. P. Woodward* (*a*).

The plateau character of portions of the Kimberley district and of Warburton's Great Sandy Desert are recognized. In the North-West, tablelands of different heights are noted and the Darling Plateau and its continuation towards the interior are referred to. Woodward remarks that from Cape Arid to the eastern boundary of the State a great mass of limestone rises, presenting an almost vertical face from 300 to 400 feet in height to the Great Australian Bight; that this was probably formed by a great upheaval from the southward in recent times, the strain causing one great fault, the line of which now forms the cliffs, and that this great tableland extends some 200 miles into the interior.

1891. *H. P. Woodward* (*b*).

North of Geraldton across the valley of the Chapman and the back flats of the Greenough (this writer observes) is a broken tableland of Mesozoic age, presenting a series of bold flat-topped hills, most of which are marquee-shaped, but isolated peaks are also seen (7).

1893. *H. P. Woodward* (*d*).

In this report on the Murchison Goldfield Woodward remarks that the field is the ruined remains of a vast high, sandy tableland, which is probably a portion of the great plain of the interior of Australia, the age of which has been determined as Mesozoic (9 and 10).

1893. *Ralph Tate.*

This author points out that Australia in Cretaceous time was a vast archipelago and that at the close of that epoch the various insular masses became welded together, so that the antiquity of Australia as a whole is only post-Cretaceous. Tate also maintained that in the Diprotodon Period the rainfall of what is now the arid region of Australia was much greater than at present and that the isolation of West from East Australia, which existed while Central Australia was a marine area, was continued into late Tertiary times, not by geological but by climatic conditions, by conversion of the depressed area into a vast freshwater lake, to be followed in our own time by utter desiccation. In a summary of discoveries and original researches Tate concludes that the whole area of Australia seems to have been in a state of comparative quiescence since the period of those earth movements which resulted in the plication of the Archæan and in the crumpling of the Lower Palæozoic. Since then it seems to have undergone (he states) oscillation of level within very narrow limits, and the depressions which have taken place never brought more than the margins of insular areas beneath the level of the sea.

1894. *S. Göczel (a).*

This writer considered that the elevation of the goldfields took place probably at the end of the Palæozoic period.

1894. *S. Göczel (b).*

Göczel remarks that the ocean was formerly over the land, and that as the former receded south-eastwards areas became separated and were transformed into inland lakes (31).

1894. *H. P. Woodward (e).*

In referring to a high sandy tableland in the south, near the Phillips and Fitzgerald Rivers, this writer states that the tableland extends to the south where it is cut up by deep river valleys, forming cliffs of horizontally bedded white and coloured sandstones, some of which contain casts of recent marine shells.

1895. *A. C. Gregory.*

Gregory holds that at the end of the Palæozoic or the commencement of the Mesozoic period Australia was at least 1,000 feet higher than at present; that there was a wide depression in Cretaceous times, which included the interior of Western Australia and that early in the Tertiary period a new elevation commenced without any great disturbance of the strata, the uplifting being nearly equal in all parts of Australia. The height was at least 5,000 feet greater than at present and Australia assumed nearly its present limits. Since this elevation there has (Gregory asserts) been vast denudation of the continent and the rainfall in the interior is now much less than formerly. Gregory

also remarks that in a subsequent depression some of the valleys were drowned and examples in Western Australia are Cambridge Gulf and the Pallinup River.

1899. *T. A. Rickard.*

This writer, in referring to the great interior tableland, states that it is probably the oldest land surface on the globe and represents the basal wreck of a much larger continent; that the sea retired from the interior of Western Australia in the very dawn of geological time, and the movement of elevation which raised the land above the waters continued with but little interruption until the beginning of the Tertiary period; that since then slow subsidence has robbed the Australian continent of part of its extent; that the main drainage of the interior is to the south; that the last retreat of the sea was accompanied by the formation of broad valleys, which have lost their former outlines and now appear as long depressions largely filled up with the products of erosion.

1903. *J. P. Thomson.*

In the opinion of this author, Australia as a whole is probably one of the oldest of all the land masses on the face of the globe.

1903. *A. Montgomery* (*a*).

This author, treating of the origin of the various deep leads of the State, discusses the question of the movements of the southern portion of the Great Plateau and the changes of climate consequent thereon. His conclusions are that along the western and southern coasts there is proof that at the time the coastal sandstone formation (? the coastal limestone) began to be laid down the general level of the country must have been close on 2,000 feet higher than at present, as estuarine and other shallow marine deposits below Perth are found to nearly that depth; that from other evidence (notably the discovery of fossil shells on the shores of Lake Cowan at an altitude of 800 feet above sea level) there was a long continued slow subsidence of the country until it was quite 800 feet and probably more below its present general level, which would bring the sea far inland from the south coast along the low-lying country now occupied by Lakes Cowan, Dundas, and Lefroy; that very possibly the whole of the Eastern Goldfields were thus submerged; and that there would be thus two periods (one when the country was higher and one when lower than at present) during which the climate of the goldfields would be much wetter than now.

1906. *A. Montgomery* (*c*).

Montgomery remarks that throughout the Murchison district the occurrence of numerous flat-topped hills and "breakaways" points to the general prevalence at one time of an extensive marine plain at a higher horizon than the present general level of the country.

1906. *Eduard Suess.*

Suess briefly describes the Great Plateau and the Darling Scarp, which he suggests may be a fault scarp with the Carboniferous and Mesozoic beds, which lie in front of it on the west as downthrown zones. He describes the Bunda plateau (Nullarbor Plains, which include the Eucla Plateau) as an exposed sea-floor.

1907. *A. Montgomery* (*d*).

The granite plains near the coast of the Pilbara and West Pilbara Goldfields are referred to as plains of marine denudation.

1907. *J. W. Gregory* (*a*).

This author regards the Stirling Range and the Darling Range as faces of the Great Plateau. In the interior (he states) the plateau has been worn by winds, while the rainfall has been inadequate to carry away the waste material or to cut deep gorges. Gregory points out that the plateau of Western Australia owes its surface features to denudation by rain, the long, slow decay by the atmosphere, and the distribution of loose material by the wind; that since Middle Palæozoic times the old mountain area of Australia has been continuously worn down; that no great earth-folds have since disturbed the structure of the Australian mass and all the later earth movements on the continent appear to have been the vertical sinkings of wide earth blocks; that the much smaller size of the Greenough River compared with the Murchison indicates the arid nature of the country behind it; that the monotonous features of the plateau are the natural outcome of the low rainfall and high temperatures; that owing to the absence of rivers no deep valleys have been cut backward into the plateau; that the valleys are gradually filled up with the material carried by the winds and rain from the higher ground and the lower slopes of the hills buried under piles of rock debris, while wind erosion rounds off the summits; and that below the thick sheets of wind-blown drift are, as at Kanowna, beds of gravel, which indicate more powerful river action in former times; that it may be doubted whether marine rocks exist in the interior, and it, therefore, appears probable that Westralia consists of a great Archæan block or coign, which has never been below the level of the sea, although time after time the sea has washed its borders.

1908. *H. P. Woodward* (*l*).

This writer suggests long erosion of the land, in the course of which it is highly probable that wave action in a shallow sea has played an important part; but that portions of the area have undoubtedly been land surface for a very considerable period, and it may (he remarks) be safely concluded from the evidence that the western portion of the Australian continent has existed either as dry land or a group of islands in a shallow sea since the time at which an elevation took place in mid-Mesozoic times.

1908. *J. W. Gregory* (*b*).

Gregory points out that the interior of the Great Plateau is kept level by desert erosion, here mainly wind action.

1908. *James Park.*

Park believes that "the great desert plains of Australia are one-time upland areas that have been truncated by the wasting action of subaerial erosion that has been continuous through many geological epochs."

1908. *A. Montgomery* (*e*).

Reference is again made to a series of Tertiary to Recent movements of depression and elevation.

1908. *A. Gibb Maitland* (*f*).

This author, in describing the Pilbara Goldfield, refers to Lalla Rookh as lying at what may be called the southern margin of the great coastal plain, which presents many of the features which characterize a plain of marine denudation

1909. *A. Montgomery* (*j*).

Montgomery again states his belief that in geologically recent times a general depression of the State occurred (to at least about 1,000 feet below its present average altitude).

1911. *T. W. E. David.*

The Great Plateau is not discussed by David, but in the text and in one of his figures the plateau is referred to as "the Darling Range peneplain." Later (56) he refers to the vast peneplains of Western Australia as being raised from 1,000 to 2,000 feet above sea-level, and remarks that the determination of the marine fossils (Eocene?) which overlie this peneplain at Lake Cowan is of prime importance for the elucidation of the Kainozoic physiography of Australia.

1911. *C. O. G. Larcombe* (*b*).

This writer states that the great plateau area of crystalline schists and metamorphic rocks, which forms the foundation of Western Australia, may represent the extension of a much greater continent from which the ocean receded in the earliest geological times; that the movement which brought about the elevation of the plateau no doubt commenced in the dawn of geological history, and continued very slowly far into the geological record; that there may have been intermittent periods of rest, but there seems to have been little compensation for the effects of atmospheric erosion by the transference of the eroded material to form ocean sediments. Larcombe holds that great earth movements occurred in late Palæozoic time, but that after the close of the Palæozoic period a period of quiescence occurred over the greater portion of

the State. Later he states there must have been enormous subsidences in Tertiary times which affected the greater portion of the coastal area of Western Australia, and a later elevation brought the Tertiary rocks into existence.

1912. *C. O. G. Larcombe* (*a*).

In this geological monograph the physiography of the plateau at Kalgoorlie receives some attention. The writer states that atmospheric erosion has gone on for ages and its products have been accumulating in hollows of erosion and other depressions, such as might be formed by the retreat of the ocean, for there has been no compensating effect, since the topography of the country does not admit of the carrying away of the waste products into the ocean to form sediments, which may later be elevated into mountains.

1912. *E. C. Saint-Smith* (*a*).

In describing the Darling Fault and Fault Scarp, Saint-Smith referred to a regional uplift of the granitic rocks of the South-West, following which the fault scarp was formed.

1912. *J. T. Jutson* (*a*).

That portion of the Great Plateau forming part of the South-West Division was described as the Darling Plateau or Peneplain, being regarded as a true uplifted peneplain, and the date of uplift was stated to be pre-Pleistocene.

1912. *A. Montgomery* (*k*).

This author summarizes his views as to the origin of the plateau, the "breakaways," the salt lakes, and the "deep leads." (40 and 41.)

The writer diverges here to state that the above summary is taken entire from Chapter I. of Part V. of the first edition of this work, and that it represents the views held as to the origin and age of the plateau to that time. Since then a moderate quantity of literature bearing on the matter has been published, and that is summarized below.

After due consideration it has been thought advisable to retain the earlier summary so as to make a fairly complete résumé of the various opinions to the present time. That at least will be of historical interest, and many of the references should be of value to future workers in the same field.

In the earlier summary, papers by Streich, Campbell, Hinde and Simpson were not mentioned, although Campbell and Hinde's papers were fully referred to in the subsequent discussion. For the sake of completeness the papers are now briefly summarized so far as they bear on the origin and history of the plateau.

1893. *Victor Streich.*

In this paper Streich put forward the idea that the salt lakes of the interior were remnants of the sea.

1906. *W. D. Campbell (a).*

Campbell discovered a marine deposit on the shore of Lake Cowan about 35 feet above its present bed. The age of the deposit was suggested to be either late Tertiary or Recent (22). This deposit is known as the Norseman limestone.

1910. *G. J. Hinde.*

Hinde described sponge spicules from a "deep lead" near the Princess Royal township near Lake Cowan. He came to the conclusion that the deposit was newer than the Cretaceous, but could not give any more definite idea of its age.

1912. *E. S. Simpson (a).*

Reference is now made to this paper in consequence of Woolnough's paper (*a*) on the physiographic significance of laterite. The only point requiring notice here is, that Simpson considers that the laterite of the Darling Peneplain was formed subsequently to the elevation of that peneplain (403).

1914. *J. T. Jutson (b).*

This reference is to the first edition of this work, in which it was shown that the greater portion of Western Australia was a great plateau which was termed the "Great Plateau of Western Australia." The marginal portions were regarded as uplifted peneplains, and were named the Darling, Kimberley and North-West Peneplains. The possibility of the interior portion of the plateau as having been formed by arid erosion at its present level was considered, but the writer inclined to the opinion that it was of similar origin to the marginal portions, and therefore, termed the whole plateau the "Great Peneplain of Western Australia." In the Salt Lake Division two plateaux of erosion were recognized, the old (higher) one—the "old plateau"—being represented by mesas and buttes on the slightly lower present forming plateau—the "new plateau"—the old plateau being regarded as part of the Great Plateau. The new plateau was looked upon as an example of levelling without base-levelling. Following J. W. Gregory the greater portion of Western Australia was considered to be a very old land surface. The date of the peneplanation of the Great Plateau was regarded as pre-Pleistocene and post-Jurassic, probably early or middle Tertiary, and the date of its uplift was suggested to be early or late Pliocene. The various possible theories as to the origin of the "deep leads" (which have a bearing on the origin and history of the Great Plateau) were also discussed. It may be mentioned that

the existence of the old plateau had previously been noted by Woodward (*d*, 9, 10, and *j*, 7, 17), by Montgomery (*c*, 89, *k*, 40, 41), by Gibson (*c*, 31, 60, 65, *b*, 74, *a*, 12), and by Campbell (*d*, 6).

1914. *J. W. Gregory* (*c*).

Gregory deals with the origin of the salt lakes, and his views thereon are referred to when treating of those features. Incidentally, however, he refers to the origin and age of the Great Plateau which (663), he considers was at one time base-levelled to a peneplain. The age of the Norseman limestone is discussed, and although the age of that rock had not then been determined palaeontologically, he comes to the conclusion that its age is probably Miocene, that the peneplanation of the plateau was prior to the deposition of that rock, and that the uplift of the plateau was subsequent thereto.

Gregory's conclusions as to the dates of peneplanation and of uplift thus approach closely to those drawn by the writer in the first edition of this work which was published at about the same time as Gregory's paper. Each author, however, arrived at his conclusions independently.

1915. *Johannes Walther* (*a*).

This paper deals mainly with the origin of laterite as it occurs in Salinaland. Incidentally, however, the author touches on the origin and history of the Great Plateau. He recognizes the old and new plateaux of the present writer, but refers to them as the upper and lower plateaux respectively. Considering that the laterite caps of the old plateau are "fossil," he is of opinion that, if the time that has elapsed since the formation of the laterite could be determined, then the time taken to form the new plateau would be known; and similarly the age of the river valleys, such as that of the Helena, which have been cut through the laterite-capped tableland would also be known.

1916. *J. W. Gregory* (*d*).

From an examination of fossils from the Norseman limestone, Gregory concludes that the weight of evidence points, but not conclusively, towards a Miocene age of the rock.

1916. *J. W. Gregory* (*e*).

In this paper Gregory discusses the origin and age of the Great Plateau, and supports the suggestion of the writer that the plateau is a great uplifted peneplain. He puts the period in which base levelling took place as Miocene, and the period of uplift of the plateau into its present position as Pliocene. He again expresses the opinion that the Norseman limestone is of Miocene age.

1917. *A. Montgomery* (*l*).

This publication is full of physiographic facts relating chiefly to Salinaland, and is, therefore, of great value in all discussions relating

to the origin of the plateaux and their associated phenomena. It also represents Montgomery's mature views on the origin of the plateaux, of the salt lakes, of the "deep leads," and of other physical features. In Salinaland, the old plateau (now represented by mesas and buttes) and the new plateau are again recognized, and his final conclusions are (71-74), that the new plateau is due to marine abrasion (the salt lakes being remnants of the sea which caused the abrasion), and that the old plateau is the remains of an old peneplanated land surface probably antecedent to the last submergence of the land beneath the sea, which mainly determined the existing relief. It may, he states, represent an older marine plain, possibly dating back to the subsidence which led to the formation of the Eucla limestones. Montgomery (91) consequently believes that the surface of Western Australia is of no great antiquity.

1917. *C. S. Honman* (*c*).

This writer (141) confirms the existence of the old and new plateaux in the Mt. Jackson district of the Yilgarn Goldfield of Salinaland. He also notes that there are ranges which attain an elevation of many hundreds of feet above the surface of the old plateau and that they probably represent remnants of a still older land surface. He also points out that the salt lakes represent a later cycle of erosion than that which formed the new plateau, this latest cycle being represented by wide valleys (in which the salt lakes lie) of mature erosion in the new plateau. (This idea was also implicitly stated by Honman earlier in regard to the country between Kalgoorlie and Coolgardie. See *a*, 12 & 13.)

Honman (*c*, 141) also records several levels of breakaways which, however, are not so well defined as the main line which separates the old and new plateaux. The higher breakaways are probably (he states), the remnants of an older system of breakaways, as is the case, he considers, in the country between Kalgoorlie and Coolgardie (10-13).

1917. *J. T. Jutson* (*c*).

The old and new plateaux of Salinaland were again referred to and their characteristics briefly described. It was pointed out (424) that the old plateau was somewhat dissected before the arid cycle of erosion was commenced, and that the ultimate result of the work of the present agents of erosion would apparently be a high level, practically rock-floored plain—the new plateau—surmounted by a few residuals of the highly resistant rocks, but that this result might be prevented by deformation or by the encroachments of the exterior drainage. It was suggested (422) that the old plateau may be a continuation of that in Central Australia represented by the low flat-topped desert sandstone hills with hard chalcedonized caps.

Primary and secondary breakaways were also described.

1917. *H. W. B. Talbot and E. de C. Clarke* (*a*).

The Great Plateau was briefly referred to (39) and the country traversed was classified into two types, the Desert Zone and the Hilly Zone. The Desert Zone is distinguished by an almost complete absence of notable hills and the frequency of breakaway country. The origin and characteristic features of the breakaways were fully described. In the Hilly Zone many hills and ranges rise above the general level (59) which, they state, may be regarded as a large peneplain, and the hills and ranges as monadnocks upon it, the peneplain having been reduced to its present condition by normal erosion, there being no evidence that any of the elevations are due to deformation. The peneplain referred to by these authors, is evidently part of the new plateau. The features of the peneplain and of the higher country are described (61, *et seq.*).

1918. *H. W. B. Talbot and E. de C. Clarke* (*b*).

This paper states in an abbreviated form the facts and conclusions set out in the official report (*a*).

1918. *W. G. Woolnough* (*a*).

In this paper Woolnough maintains that laterization of the Darling peneplain and of the old plateau of Salinaland occurred before the uplift of the peneplain, as, in his opinion, laterization can occur only in areas where drainage is almost at a standstill. He believes that high level laterite is a criterion of elevation of the land, and that difference in laterite level suggests faulting.

1919. *W. G. Woolnough* (*b*).

This paper, as its title implies, deals mainly with the Darling Peneplain, and incidentally with the plateaux of Salinaland. Woolnough maintains that the Darling Peneplain was developed at base-level during a protracted period of crustal stability, and that the laterite, capping the peneplain, was formed thereon before the uplift of the peneplain. Woolnough places the date of the close of the peneplanation of the peneplain as older Pliocene at least, and probably older still, and as the period of peneplanation must have been inconceivably protracted, the beginning of this period must have been much earlier in Tertiary time. Subsequently (he states) a slight elevation took place, following which a series of mature valleys was formed. The base-level of these valleys is named the "Meckering Level." A further sharp uplift of the peneplain then took place, bringing it to its present position, as a result of which it was further dissected, which caused the dismemberment of the mature valleys of the Meckering Level. He assumes the formation of the Meckering Level cycle to have been contemporaneous with the formation of the Norseman limestone, and considers it probable that during the same period mature valleys were developed in Salinaland (below the level

of the old plateau, which he accepts as a continuation of the Darling Peneplain), and that at about the time of the main (final) uplift of the peneplain a change to desiccation in Salinaland prevented strong stream erosion, and thus the mature valleys there, left at the close of the Meckering Cycle, became the sites of the present salt lakes and possibly of some of the "deep leads."

Above the Darling Peneplain is another peneplain—the "Mount Dale Level"—now represented by a few scattered residuals only.

1920. *H. W. B. Talbot* (*d*).

This publication deals with a vast area in the north-central portion of the State comprising parts of Pilbaraland, Salinaland and Sandland. Talbot considers (15) that those portions of Salinaland and Sandland included in his report are parts of an immense peneplain (now a plateau), which is broken occasionally by ranges and hills, and which extends eastwards beyond the South Australian border, and northwards to Kimberley. He believes (16), that the peneplain was formed by normal erosion, when the climate was moister than at present, and that the region has not been submerged beneath the sea since Palaeozoic times (16 and 17).

The area in Pilbaraland covered by the report consists of a plateau or a series of plateaux, now broken considerably by erosion, and to a less extent by fault scarps (39 and 40). The plateaux are the remains of an uplifted peneplain (46 and 47). Plains are now being formed below the plateau as a result of the erosion of the latter feature (50 and 51).

The dates of the peneplanation and of subsequent uplift are not discussed further than indicated above.

1922. *W. R. Easton.*

This writer describes (5) North Kimberley as one vast sandstone tableland or plateau, now broken up by erosion.

1923. *E. S. Simpson* (*b*).

This writer considers that in Tertiary time the ocean covered an area, roughly, extending between the present south coast and lat. 28° S., and between longs. 117° and 130° E. [a vast area in the southern portion of the State], basing this conclusion largely on the close association of the gypsum deposits with salinas, the sub-surface water of which (he states) closely resembles an evaporated ocean water (50).

1923-24. *Arthur Wade.*

This author (37) regards the area, dealt with in his Report, north of the Fitzroy River and north of the same latitude in Northern Australia, as an immense dissected peneplain formed in the Cambrian

rocks, the peneplain being slightly tilted to the north. The peneplain surface he believes to be probably one of the oldest and most persistent land areas in the world (38).

1924. *Frederick Chapman and Irene Crespin.*

This paper deals with the fossils found at Albany, Cape Riche and Norseman, and the conclusion is reached that the beds from which they were collected are of Miocene age.

1925. *Frederick G. Clapp (a).*

In the north-western portion of the State, Clapp (61) refers to two plateaux, one above the other. The lower one, he states, is a widespread one composed of Permo-Carboniferous strata and probably of Tertiary peneplanation; the higher one is represented now only by remnants, and is composed of Jurassic beds. The same phenomena are also described by Clapp in another publication (*b*, 228 and 229).

1925. *E. de C. Clarke (a).*

Clarke (12 and 13) records the occurrence of sponge spicule beds on the north shore of Lake Cowan, similar to those at Norseman.

1926. *L. Glauert and F. R. Feldtmann.*

These authors come to the conclusion from the discovery of species of *Coxiella* (a gasteropod) in some salt lakes, that there was a former northern extension of the Miocene sea in which were laid down the Princess Royal Beds, the Norseman Limestone and the Plantagenet Beds [of Albany and adjacent country].

1926. *E. S. Simpson (c).*

In this paper (656-657) Simpson re-states and somewhat amplifies his conclusions as to the Miocene sea penetrating far into the interior of southern Western Australia.

1927. *T. Blatchford (g).*

This author (10 and 12) divides the Kimberley district into two portions, viz.:—(a) A northerly tableland, which is probably an uplifted peneplain, now broken by rivers, and bounded on the south-west by a fault-scarp (23) (which the present writer has termed the "Napier-Geikie Fault Scarp"). (b) A narrow belt to the south and east, comprising the country drained by the Lennard, Fitzroy and Ord Rivers, and having conspicuous ridges and isolated hills, which Blatchford (10) regards as the remnants of an old and extensive plateau, which has been almost entirely removed by denudation.

A north and south fault scarp to the east of Hall's Creek can be traced for many miles (24).

Blatchford's northerly tableland comprises North Kimberley as defined in this work, together with the belt adjoining on the south-west between the King Leopold Range and the Napier-Geikie Fault Scarp, which the present writer has included in Fitzroyland. Blatchford's second belt comprises the southern portion of Fitzroyland and most of Ordland.

South of the second area he describes a low-lying peneplain which extends far to the south and east. The country to which his description refers is part of Sandland.

1927. *W. G. Woolnough (e).*

In his Presidential Address to the Royal Society of New South Wales, Woolnough refers to the "laterites" of Western Australia and other surface rocks throughout Australia showing analogies with the laterites. He considers (25) that not only have all the rocks mentioned been developed under similar conditions, but that they have been produced homotaxially during an era of highly perfect peneplanation under the conditions indicated, and that those rocks constitute a definite geological formation. (The rocks referred to in Western Australia form the surface of the Great Plateau). Examples given by Woolnough in Western Australia, in addition to the widespread normal laterite caps, are "the Plateau Beds" of Woolnough and Somerville in the Irwin River Valley, where the nature of the surface rocks varies according to the nature of those underlying. This widely distributed hard crust is given the name "Duricrust" (27).

Woolnough (42) discusses the question whether the Duricrust is still forming, and he comes to the conclusion that although some surface hardening is taking place, yet it is local, relatively insignificant, and quite distinct from the formation of the Duricrust proper.

CHAPTER II.

THE ORIGIN AND AGE OF THE GREAT PLATEAU.

CONTENTS.

Delimitation of the Surface of the Great Plateau. Nature of the Surface of the Plateau. Methods of Formation of the Plateau. The Plateau as a Possible High-Level Plain of Arid Erosion. Evidence bearing on the Mode of Formation of the Plateau. (a) Marine Deposits. (b) Underground Waters. The Question of the Great Antiquity of the Surface of Western Australia. The Plateau originally mainly a Peneplain. Warping and Faulting of the Plateau. The Time of Formation of the Great Peneplain of Western Australia. The Date or Dates of the Uplift or Series of Uplifts of the Great Peneplain and the Sequence of Events associated therewith. Brief Summary of the History of the Great Peneplain since its Formation. Nomenclature—"Uplift" and "Depression." The Necessity for Detailed Observations.

DELIMINATION OF THE SURFACE OF THE GREAT PLATEAU.

From the descriptions of the physiographic divisions of the State it should be evident as to what is meant by "The Great Plateau." For convenience and clearness, however, in view of the

discussion which follows as to the origin and age of the plateau as a whole, it is advisable to re-state briefly what portions of the surface of Western Australia the writer considers form "the Great Plateau."

In the first place the plateau is represented throughout the whole of Western Australia, except on those portions of the seaboard which are occupied by narrow coastal plains.

The plateau is practically everywhere more or less dissected, but the character and extent of this dissection vary considerably in the different physiographic divisions of the State. In North Kimberley, Pilbaraland and Swanland, and to some extent in Ordland, the country is easily recognised as having been a tableland or plateau, although now much broken by rivers. Those rivers, however, are mainly in the early mature stage of erosion, so that although they have deeply dissected the plateau, yet they have not removed extensive portions of it by lateral erosion. The original nature of the surface has not, therefore, become masked.

On the other hand, in Murchisonia, Salinaland, Sandland, and a large area of Fitzroyland the country has not been dissected so deeply as in the other divisions mentioned, but it has been eroded laterally far more, with the result that the Great Plateau surface is now represented by the tops of mesas and buttes, and of other isolated hills and ridges, at the base of which is another plateau which (although in Sandland much covered by sand ridges) extends over far more country than the remnants of the higher plateau now occupy. These two plateaux are the "old" and "new" plateaux respectively to which reference has already been made.

The surface of the Great Plateau corresponds, therefore, with the surface of the easily recognized plateau of the first group of physiographic divisions above referred to, and with the remnants of the surface of the "old plateau" in the second group.

Residuals or monadnocks are found on the surface of the Great Plateau.

The physiographic division Euclonia is different from all others in that it is not dissected either deeply or widely. Its surface, however, must be treated as part of the Great Plateau surface notwithstanding the fact that such surface must be in course of slow reduction in height. So far as known Euclonia has few, if any, residuals.

NATURE OF THE SURFACE OF THE PLATEAU.

The greater portion of the surface of the plateau consists of very ancient rocks of the three great classes, sedimentary, igneous, and metamorphic.*

* The widespread laterite cap is neglected in this discussion.

Amongst those rocks are extensive belts of granite and other deep-seated igneous rocks. This fact shows the enormous amount of erosion that the rocks have sustained. Even amongst the comparatively little disturbed sedimentary rocks in the north of the State, the surface must be an erosion surface, otherwise rocks of much younger age would be resting upon them.

It is, therefore, clear that the surface of the plateau is due to erosion, and as the characters of a plateau are clearly discernible, that surface, before dissection took place during the present cycle of erosion, was substantially a plain of erosion. All observers who have written on the subject concur in this conclusion.

METHODS OF FORMATION OF THE PLATEAU.

The plateau surface being recognised as due to erosion, it is desirable to determine, if possible, what the eroding agents were which produced that surface. Such a surface can be produced in the following ways:—(a) By the action of rain, rivers, and the atmosphere under a normal climate. Such action if sufficiently long continued would result in a peneplain, which term implies that the surface was base-levelled. (b) By the long continued abrading action of the sea, resulting in a plain of marine abrasion. (c) By arid erosion at any height above sea-level.

In a vast area, such as is now being considered, there may be different methods of erosion proceeding at the same time. Thus while the main portion of the country was being reduced to a peneplain or to a plain of arid erosion, the coastal portion of the land might be in process of conversion into a plain of marine abrasion; or arid erosion may be taking place in the interior and peneplanation nearer the coast.

If the plateau were originally a peneplain or a plain of marine abrasion, then uplift has taken place, and by that means it has been brought to its present height and is now in course of dissection. It would, therefore, be described as an uplifted peneplain or an uplifted plain of marine abrasion, as the case may be.

If the plateau be due to arid erosion then it may have been formed at its present height, which would mean that there had been an enormously protracted still-stand; or it may have been formed at any other height and since have been elevated or depressed to its present position.

Each of these possible modes of formation will now be considered, and in this connection it may be mentioned that the plateau will be discussed as a whole, thereby varying somewhat from the plan adopted in the first edition of this work, a plan which is now rendered unnecessary by reason of the increase of our knowledge of the subject.

THE PLATEAU AS A POSSIBLE HIGH-LEVEL PLAIN OF ARID EROSION.

In extensive parts of Western Australia (mainly long distances from the coast) the country is passing through a cycle of arid erosion, but there is no evidence that the previous cycle, during which the surface of the Great Plateau was formed, was one of similar character. On the contrary, what evidence is available points to the conclusion, as will be shown later, that since its uplift the plateau has been dissected to some extent by normal erosion prior to the change of climate which ushered in the present arid cycle. If that evidence be read aright, then we know that the existing conditions have not continued back into the plateau-forming period. In order, therefore, to establish the fact that the plateau—either as a whole or in part—is due to arid erosion, a cycle of that kind of earlier date than the present one must be proved. There is no evidence of this, but from the nature of the case where the planation has been so extensive, such evidence may be largely lacking, notwithstanding that processes of the kind referred to may have been at work. If, however, no such evidence be available, it is not justifiable to assume such a cycle, especially in view of the fact that the plateau surface may be explained by processes which are much more widespread than those of the arid cycle, and this view is strengthened by an examination of the plateau as a whole. Except for local fault scarps there is no physical discontinuity between any one portion of the plateau with another portion. The plateau is unmistakably a physiographic entity or unit. There is at present no ground whatever for assuming that in recent geological times the climate of Swanland Pilbaraland, and the three Kimberley divisions (these being the coastal physiographic types in which normal erosion is at present taking place) was less moist than it now is. It is, therefore, justifiable to assume that those areas were not formed under arid conditions. That being so, the natural corollary, in view of the physiographic unity of the plateau as a whole, is that the remaining areas were also not formed under those conditions, although of course desert erosion could be taking place in one area while normal erosion was taking place in another area, as is the fact in Western Australia at the present time.

Subject, however, to the possibility just mentioned, the conclusion that the whole plateau was formed by normal erosion is, in the light of present knowledge, the most reasonable and probable one to be arrived at.

By excluding, therefore, the probability of arid erosion in the formation of the plateau, the problem of determining at what height above sea-level such formation took place has not to be solved, and the remaining alternatives, normal erosion resulting in a peneplain, or marine erosion resulting in a plain of marine abrasion, can now be considered. In either case, relative uplift to the present height of the

plateau since the formation of the peneplain or of the plain of marine abrasion is implied. The evidence, for and against both peneplain and plain of marine abrasion will first be summarized and discussed.

EVIDENCE BEARING ON THE MODE OF FORMATION OF THE PLATEAU.

The positive evidence is scanty, consisting only of certain marine deposits and the character of the underground waters of Salinaland. These features will now be referred to. Subsequently the indirect or negative evidence will be considered.

(*a*) *Marine Deposits.*

The marine deposits which appear to have a direct bearing upon the origin and age of the plateau are the limestone at Norseman ("the Norseman Limestone"), the Sponge Spicule Beds in the same locality and farther north at the head of Lake Cowan (Clarke, *a*, 12), the extensively developed Eucla Limestone, and the Plantagenet Beds of Albany and neighbourhood.

The Norseman Limestone has been described by Campbell (*a*, 22), who states that on the shore of Lake Cowan about 35 feet above its present level, is an opalized remnant of an old sea beach containing various marine organisms. Maitland,* in referring to Campbell's discovery, states that there are four small outliers of the same formation near Lake Dundas (a lake farther south than Lake Cowan).

The Sponge Spicule Bed occurs in a "deep lead" at a depth of 88 feet from the surface at the Princess Royal Township which is about two miles north-east of the Norseman Limestone described by Campbell. It has been described by Hinde (7-24), whose conclusions are that the deposit was formed in the open ocean at some distance from a coast line, so as to be away from sediment-bearing currents and probably at a considerable depth, and that in regard to its geological age he judges that it is newer than Cretaceous but that there are no data to indicate the particular period of the Tertiary or Post-Tertiary in which it may have been formed. Since Hinde's paper was published, sponge spicule beds have been found by Clarke (*a*, 12) at the northern end of Lake Cowan where they form low white cliffs.

The Eucla Limestone is a thick deposit of widespread occurrence in the south-east of the State where its surface forms the Nullarbor Plains.

The Plantagenet Beds have been described by Jutson and Simpson as extending at least from Torbay (to the west of Albany) as far eastward as the Phillips River and northward to the southern side of the Stirling Range. The best known locality is at Albany, where they consist of fine-grained sediments still practically horizontal.

* Bull. 26, Geological Survey of Western Australia, p. 61.

At the time of the publication of the first edition of this work, the age of none of the marine deposits just referred to had been definitely determined, although it was believed that the Eucla Limestone was of Eocene age; but now the Norseman and Eucla Limestones and the Plantagenet Beds are regarded as of Miocene age, although of course not necessarily contemporaneous. (See Gregory, *d*, 320-21 and Chapman and Crespin, 319-322, as to the Norseman Limestone; Jutson and Simpson, and Chapman and Crespin, 319-322, as to the Plantagenet Beds; and Maitland, *k*, 44, as to the Eucla Limestone.) Unfortunately no further light, despite the more recent discoveries, has been thrown on the age of the sponge spicule beds.

The increase of palaeontological knowledge has, therefore, shown that in Miocene times that portion of the State occupied by the deposits mentioned was submerged beneath the sea and that, as the Norseman Limestone is now about 900 feet above sea-level, an uplift to that extent at least has since taken place. Moreover, as there is no physical break between the Norseman area and that farther inland, it may with confidence be assumed that the inland area has taken part in the uplift.

Glauert and Feldtmann (284-286), from the occurrence of species of *Coxiella* (a gasteropod) at Lake Cowcowing, at a salt lake near Nannine, and at Lake Way, have suggested that the Miocene sea extended farther north than the Norseman Limestone, presumably as far as the lakes mentioned.

This conclusion appears to be open to criticism, and is discussed in the Part on the salt lakes.

(*b*) *Underground Waters.*

The highly saline character of some of the underground waters of Salinaland mainly, and the results of chemical analyses of the same have led Montgomery (*l*) and Simpson (*b* and *c*) to attribute an oceanic origin to the contained salts which, in their opinion, have been derived from the cut-off parts of the ocean on the last great emergence of the land, which cuts-off are now represented by the "dry" or salt lakes of Salinaland, the assumption being that most of Salinaland and of the southern portion of Sandland had comparatively recently been submerged beneath the sea. This proposition has been put forward to account for the existence of the salt lakes; but if it be correct that submergence to the extent indicated had taken place, that fact affects the question of the origin of the Great Plateau, for it may then be contended that the plateau was a plain of marine abrasion, since uplifted. Those, however, who advocate the theory of a recent submergence yet believe that such submergence took place after the land had been reduced to a peneplain, and the peneplain had been partly dissected.

The negative evidence is the absence of Tertiary deposits over the greater portion of the plateau. This feature is discussed in the next section.

THE QUESTION OF THE GREAT ANTIQUITY OF THE SURFACE OF WESTERN AUSTRALIA.

In connection with the origin of the plateau, it is well to consider whether the view that has been so widely held—as shown in the summary of opinions in Chapter I. of this Part—that the great mass of Western Australia has not been beneath the sea since early geological times is correct. The restriction of the various marine members of the geological record since Carboniferous times practically to the coastal areas of the State certainly affords strong negative evidence for this conclusion, as it is inconceivable that remnants of some of those formations should not be preserved far inland. The Norseman beds are about 120 miles north from the southern coast, and the farthest north locality yet noted for the sponge spicule beds is about 150 miles from the same coast, but all those marine beds are close to the coast when compared with the greater portion of the interior. Moreover, apart from the Eucla Limestone, the Norseman and adjacent sponge spicule beds are at a much greater distance from the coast than the other Miocene deposits. The Norseman and adjacent sponge spicule beds could represent a long narrow inlet of the sea. The *Coxiella* records are omitted from consideration here, as the writer does not regard them as proving the former existence of the sea where the specimens have been found; and the character of the underground waters can be accounted for otherwise than as due to remnants of the Miocene sea.

Until, therefore, more direct evidence to the contrary is obtained, the great age of the land surface away from the coastal areas may be maintained, after allowing for penetration by the sea a reasonable distance beyond the present known deposits. No intimation, however, of that age can at present be given.

THE PLATEAU ORIGINALLY MAINLY A PENEPLAIN.

From the preceding discussion the conclusion to be drawn, which is probably nearest the truth, is that the surface of what is now the plateau, has been formed as a peneplain. For the reasons already stated, the theory of a plain of arid erosion has been rejected. Similarly in regard to a plain of marine abrasion the negative evidence against a widespread submergence during Tertiary times is at present too strong to be disregarded. Even, however, if such submergence had occurred, it may have been by way of earth movement and not by the slow process of marine abrasion. If the former occurred, the land may have been reduced to a peneplain before submergence took place, and that is the view of the supporters of the theory of a submergence much farther north than the present known marine deposits. If the earth movement theory be correct, then marine abrasion as the chief cause of the formation of the plateau must be eliminated for the plateau as a whole.

If submergence of the whole or part of the peneplain, owing to earth movement, has taken place, then the main stages in bringing the plateau to its present position would be—(1) A long still-stand during which the land was reduced to a peneplain. (2) Submergence of the whole or part of that peneplain beneath the sea. (3) Uplift following probably a period of marine abrasion and of marine deposition.

An earlier period of marine abrasion may have occurred and the marine deposits may have been associated with that abrasion. During the long still-stand during which peneplanation took place, a plain of marine abrasion may have been formed as a fringe to the peneplain, and on the marine plain the marine deposits may have been laid down. Subsequently the peneplain and the plain of marine abrasion would be uplifted together so as to form the Great Plateau.

These views imply major earth movements in one direction only—relative uplift—but by the theory of submergence of the peneplain major movements in two directions are required to be in accord with the theory, viz.:—A relative depression bringing about submergence in part, and a subsequent relative uplift, or series of uplifts, by which the land was brought to its present height.

It may be noted that a dissected surface, such as that on which the Miocene marine beds of Albany lie (Jutson and Simpson, 49), would favour the idea of submergence by earth movement rather than as a result of marine abrasion. So far as known, the features described by Davis (*c*, 40) as characteristic of a plain of marine abrasion do not exist.

Peneplanation, therefore, is regarded as the main process which formed the surface of what is now represented by the remnants of the Great Plateau. That surface formed a mighty peneplain rising probably to a considerable height in the interior, although much less in height than now. The peneplain may be named "The Great Peneplain of Western Australia."

In passing it may be noted that the area occupied by the Eucla Limestone probably represented, at the time of the formation of the limestone and of the underlying rocks, a great sinking gulf (the Eucla Gulf) bounded either by faults or by monoclinal folds. The boundaries remained fairly constant until a great thickness of strata had accumulated, when a further marine transgression took place, which resulted in the laying down of the Norseman and Albany beds in comparatively shallow water. It is difficult to fit the sponge spicule beds in with this history in view of Hinde's belief in their deep sea origin, but his conclusion may not ultimately hold good. It seems to the writer that such spicules, even if they are of a deep sea nature, could be carried towards the land and be deposited in banks in shallow water.

On the view above expressed, the Norseman beds would simply represent an extension of the latest phase of the Eucla limestone sea.

The suggested great Eucla gulf corresponds with the old Murray Gulf of Eastern Australia.

WARPING AND FAULTING OF THE PLATEAU.

The plateau, although as a whole it has a remarkable continuity of surface, is far from being a dead level. The general contours have been referred to when describing the various physiographic divisions, and they are graphically illustrated by the small contoured map of Western Australia (fig. 2). As examples of the variations in height of different portions of the plateau the great flat domes in North Kimberley and Pilbaraland may be mentioned. The country in the vicinity of Mt. Hann and of Mt. Bruce appears to be the centres of the domes in North Kimberley and Pilbaraland respectively, but the Pilbaraland crown is about twice the height above sea-level of that of North Kimberley. A considerable part of the great arid belt stretching between Fitzroyland and Pilbaraland, and portions of the Darling Peneplain, of Pilbaraland, of Murchisonia and of Salinaland are below the 1,000 feet contour. The change, however, from one height to another is usually gentle.

The plateau on uplift would, therefore, appear to have had a vast undulating surface, due to a series of very gentle folds or warps broken occasionally, as noted below, by fault scarps. Associated with the folds and warps there are, in all probability, innumerable minor warpings that are not easily detected. These in an area of normal erosion would be so slight, comparatively speaking, as not to affect seriously the development of the drainage lines, but in the dry interior, the probable effect would be to form shallow deformation basins, doubtless of various sizes, which would be the centres of a number of distinct drainage areas. The deeper deformation basins or sunklands may also have been formed at the same time, but there is no definite evidence as to that.

Some of the "deep leads" may have been short channels leading to, or perhaps actually forming, deformation basins.

In addition to the folds and warps, the plateau has been faulted in various places, as shown by the fault scarps which have been detected in various parts. Since the first edition of this work was published, Woodward (*r*), Talbot (*d*), and Blatchford (*g*) have added to the number of great fault scarps known to occur throughout the State, and it may safely be said that more remain to be discovered. Such fault scarps may be merely mentioned here, as they have already been referred to in the descriptions of the different physiographic divisions, and they are again mentioned in the chapter on the scarps of the State. Amongst the more important, are the Darling (and its bifurcations), the Ophthalmia, the Hamersley, the Nullagine, and the Napier-Geikie Scarps.

Whether the faulting which produced the scarps occurred when the plateau was being uplifted or subsequently thereto has in no instance been definitely proved. The surest physiographic evidence of contemporaneous uplift and faulting resulting in the formation of fault scarps, viz., the occurrence of antecedent rivers associated with the plateau and the scarps, has not yet been definitely forthcoming. Observations made with the idea of attempting to solve the problem of the date of the formation of the scarps would no doubt yield valuable results.

THE TIME OF FORMATION OF THE GREAT PENEPLAIN OF WESTERN AUSTRALIA.

It was pointed out in the first edition of this work that the fossil mammals found in the Mammoth Cave in Swanland were of Pleistocene age (Glauert, 11), and that as the coastal limestone in which the cave occurs had apparently been formed since the uplift of the Darling Peneplain, the date of the uplift was older than the limestone and probably therefore pre-Pleistocene.

Since then the age of the Norseman Limestone and of the Plantagenet Beds in the Albany district has been determined as Miocene (*supra*, p. 200), and the Eucla Limestone is now regarded as belonging to the same great period (Maitland, *k*, 44). Those determinations are of great value in any attempt to fix the period during which the great peneplain was formed and the date of its subsequent uplift. No further light has been thrown on the age of the sponge spicule beds near Norseman, and as Hinde could not assign any definite age to them they may be disregarded until further research takes place.

As already stated, the Norseman Limestone and the Plantagenet Beds may have been deposited while the peneplain was in process of formation, or they may have been deposited after the peneplain was formed owing to a submergence beneath the sea of coastal portions of the peneplain. At present the evidence is insufficient to indicate whether the marine deposits were laid down during or after the formation of the peneplain but, assuming that they were not laid down before the peneplain was formed (which is apparently true, as they appear to rest upon the peneplain surface), then peneplanation must have been completed during or prior to Miocene times.

The next step will be to determine the time when peneplanation commenced.

Near the western coast in the Irwin River district, Campbell's maps and sections bring out clearly the fact that the Jurassic series is faulted against the old granite, and was uplifted with the granite. The fault indicates that the Jurassic rocks no doubt originally extended farther east, but by reason of these eastern rocks forming the high side of the fault, whilst those to the west were down-thrown, the former

have been removed by erosion, and the latter preserved; similar reasoning probably applies to the Cretaceous farther south near Moora, as shown by Blatchford's work (Blatchford, *c*). Thus the peneplain is younger than the Jurassic, and probably also than the Cretaceous.

The formation of the peneplain, therefore, appears to have been commenced after the Cretaceous period and to have been finished during or prior to Miocene times. If such be the case then it was during the Eocene and Oligocene periods, or during those periods and part of the Miocene period that the great peneplanation took place, a conclusion as indicated by the words "probably in the early or middle Tertiary or during both those periods," which was reached in the first edition of this work on more incomplete data.

THE DATE OR DATES OF THE UPLIFT OR SERIES OF UPLIFTS OF THE GREAT PENEPLAIN, AND THE SEQUENCE OF EVENTS ASSOCIATED THEREWITH.

The marine deposits of Norseman, of Albany, and of the Eucla Limestone Plateau were formed prior to the uplift or series of uplifts which converted the great peneplain into a great uplifted peneplain or a plateau—the present Great Plateau of Western Australia. Those deposits being, as already noted, of Miocene age, the uplift or series of uplifts must have taken place during the latest portion of that period (if the marine deposits are not of Upper Miocene age) or subsequently thereto.

On the evidence of the fossils found in the coastal limestone (*supra,* p. 204) the uplift or uplifts is or are regarded as having occurred in pre-Pleistocene time. Most probably, therefore, the earth movements which brought the peneplain to its present position took place mainly in Pliocene time.

The above conclusions have been reached from the palaeontological and stratigraphical evidence. Consideration may now be given to the physiographic evidence.

Taken as a whole, except in Salinaland and Sandland, where arid erosion is taking place, and in Murchisonia, where practically similar agents are working, the drainage of the Great Plateau is immature (as in North Kimberley, Pilbaraland, and Swanland especially), and the great fault scarps, which are probably associated with the uplift of the peneplain, are comparatively little dissected. The river valleys have all been incised in the Great Plateau, and their immature nature, therefore, indicates that uplift has been geologically recent. Enough erosive work, however, has been done to suggest that early Pliocene was probably the time in which the plateau-forming movements occurred.

Having discussed the general uplift of the peneplain, it may now be pointed out that the peneplain has been brought to its present position not by one great movement but by a series of progressive uplifts.

Gibson (*d*) has recorded such a partial uplift, as shown by the occurrence in the faces of the old sea cliffs, some distance back from the present Euclonia coast line and considerably above present sea-level, of water-worn caverns and wave-markings. Woolnough (*b*, 390) has shown that the Darling Peneplain was uplifted to a low height, when a new base level—the Meckering Level—was formed; and that a subsequent sharp uplift brought the peneplain to its present position. Clarke and Williams (167) also consider that in the Helena River Valley near Perth there is evidence of two long pauses in the uplift of the peneplain along the Darling Fault plane.

The evidence of progressive uplift of the Great Peneplain is therefore accumulating.

The development of the river valleys is associated with the uplifts. Such development is dealt with in Part VII., and is merely mentioned here for the sake of completeness in treating of the history of the plateau as a whole. Following the first great uplift referred to by Woolnough, mature valleys were carved out by erosion in Swanland, the bottoms of which form his "Meckering Level." The subsequent greater uplift which brought the peneplain to its present position enabled deeper valleys to be cut. Similar evidence has not yet been obtained in the other coastal physiographic divisions, but examination of the country with this possibility in mind may result in interesting discoveries.

The origin of the "deep leads" of Salinaland is one of the most difficult problems in Western Australian physiography, but the fact that there have been successive uplifts of the Great Peneplain may help in deciphering their history. They are discussed in Part IX., but it may be here remarked that the suggestion was made by the present writer (*b*, 84 & 95) as one explanation of the "deep leads" that after peneplanation but before the great uplift took place which brought the old peneplain to its present position, there may have been a slight uplift, following which shallow valleys were formed which subsequently became some of the "deep leads." This suggestion has been adopted by Woolnough (*b*, 393) as being in harmony with his thesis of a small uplift in Swanland, which resulted in the formation of the Meckering Level.

In Murchisonia, Salinaland and Sandland the Great Plateau has been subjected to shallow vertical erosion, but to such widespread lateral erosion that, as already mentioned, a second extensive plateau—the "new plateau"—has been formed at a shallow depth below the original plateau surface of the Great Plateau, which, in the areas mentioned, is termed the "old plateau" by way of distinction from the lower "new plateau." The new plateau bears on its surface the extremely interesting salt or "dry" lakes which are described in Part X.

The characteristics of the new plateau indicate that such plateau has been formed under conditions of arid erosion which thus indicate a change in climate from the moist climate under which the Great Peneplain was probably formed to the present semi-arid one. Such change has also taken place in Euclonia, but in the remainder of the State the climate has remained normal, although this statement does not necessarily mean that the climate in that area or portions of it was not wetter than at present.

BRIEF SUMMARY OF THE HISTORY OF THE GREAT PENEPLAIN SINCE ITS FORMATION.

When planation took place the climate throughout Western Australia was moister than at present. During or subsequently to planation certain coastal areas in the south and west were submerged beneath the sea in Miocene times. In the southern half of the State (possibly in the north also, but there is no evidence as yet as to this) a slight uplift took place, following which some of the deep lead channels were formed. Subsequently the great uplift (but possibly, however, preceded by another small uplift) of Western Australia occurred, and the land was brought approximately to its present position to form the Great Plateau.

Since then, normal erosion has obtained in most of the coastal divisions. Inland, the same process may have acted for a time, but arid erosion has been the dominant factor for a considerable period. The land on uplift perhaps formed deformation basins in the interior, which became the centres of independent drainage areas. Some of the deep lead channels may then have been formed by degradation, but very soon aggradation in their lower courses and obliteration of their upper portions by lateral erosion commenced. The processes have continued until no trace of the leads is visible at the surface.

Arid erosion has progressed in the interior until the old plateau has been almost removed, and a new high-standing plateau has been formed, upon which numerous shallow depressions, and possibly some deeper ones, forming the "lakes," exist.

In the coastal areas normal erosion has dissected the plateau, various stages occurring in different parts. Comparatively recently some of the valleys have been drowned, and the non-drowned portions of their lower courses have in consequence been aggraded. More recently still, an elevatory movement has been instituted.

NOMENCLATURE—"UPLIFT" AND "DEPRESSION."

In using these words in this and other parts of this work the customary practice has been followed. They have been intended, however, to be read only in a relative sense, and not as implying absolute uplift and depression of the land surface of Western Australia.

THE NECESSITY FOR DETAILED OBSERVATIONS.

The origin of the Great Plateau (upon which some light has been attempted to be thrown by the preceding discussion); the origin of the salt or "dry" lakes; and the process of arid erosion in Western Australia (which two latter subjects are treated in subsequent Parts) are most important matters in Western Australian physiography. Detailed observations are urgently required, although many valuable ones have been made since the publication of the first edition of this work. It is to be hoped, therefore, that the discussion of these various problems will have the effect of stimulating such observations, and that the latter will be made with the deliberate aim of contributing to the solution of these far-reaching and fascinating problems.



PART IX.—THE AURIFEROUS "DEEP LEADS" OF SALINALAND.

CONTENTS.

Description. Outline of Suggested History. Past Climate and the Deep Leads. The Economic Aspect of the Deep Leads.

The "deep leads" of Salinaland are connected with the Great Plateau, so that some consideration must be given to their origin and history.

DESCRIPTION.

Throughout Salinaland a number of "deep leads"—some of which have been very productive of alluvial gold—have been discovered and worked to a greater or less extent. They have been recorded from Kalgoorlie, Norseman, Kanowna, Kurnalpi, Broad Arrow, Paddington, Bulong, Black Range, Darlot, Siberia (Waverley), Southern Cross and Parker's Range. (See Montgomery, *a, b, e, f, g, j,* and *l,* Maitland and Jackson, 43, Blatchford, *a,* 38, Maitland, *a,* Jutson, *q,* and Larcombe, *c.*)

The "deep leads" consist essentially of old stream channels or probably in some cases deformation basins, which have been so choked by detritus that there are now no surface indications of their existence. The detritus consists of gravels, angular fragments of rock, sand and clay, the sand and clay probably being much in excess of the coarser materials. It has been assumed that the component pebbles of the gravels have been formed during the erosion of the channel in which they lie, and this of course can be accepted in most cases. It is probable, however, that where the waterworn pebbles are not plentiful and

are mixed with many angular or semi-angular rock fragments (as in a lead near Lake Darlot) (Jutson, *q*), such waterworn pebbles may be merely re-distributed, and if so they cannot be regarded as evidence of normal stream action where they now occur.

None of the leads has been traced very far, probably on account of payable gold ceasing to be found as the leads are traced "downstream." At Kanowna the most complete system has been located, and individual leads there have been traced for nearly two miles. The bedrock has been proved to be about 100 feet from the surface in several instances, and near Bulong it was 140 feet (Montgomery, *l*, 76). The leads are usually located comparatively close to the surface, and as they are traced they usually deepen.

OUTLINE OF SUGGESTED HISTORY.

With the exception of the determination of the age of the Norseman and Albany beds, and of the discovery of pauses in the elevation of the Darling Peneplain, very little information concerning or that will help to elucidate the history of the leads has been obtained since the publication of the first edition of this work. The various possible theories of the origin of the leads were there set out, but it is not proposed to repeat them here, as the writer feels that many more facts will have to be obtained before any one theory will command general acceptance. He will content himself with stating briefly the views that in the light of all present available evidence he now tentatively holds. Such an outline may have the effect of stimulating thought and observation regarding the origin of the leads.

By way of preface, it may be stated that it is generally assumed that primarily the leads are the indirect result of a change in the recent geological past from a wet to a dry climate. The thesis is that the hollows were formed by stream action in the wet climate, but on the change to a dry climate erosion practically ceased, and the hollows became filled with detritus. The writer, however, is of opinion that every deep lead is not necessarily evidence of a change of climate, and that the various deep leads may belong to different epochs. The Princess Royal Lead, near Norseman, presents a difficult problem by reason of the fact that the sponge spicule beds have been found in its workings. Without further remarks, however, the suggested outline of the history of the leads is now given.

At the time of the completion of the great Peneplain of Western Australia, the surface would not be a dead level, but probably would be an undulating lowland with shallow valleys. After completion of peneplanation portions of the southern areas of the State became submerged beneath the sea and during this submergence the deposit forming the Princess Royal Deep Lead and also the Norseman Lime-

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At the time of the completion of the great Peneplain of Western Australia, the surface would not be a dead level, but probably would be an undulating lowland with shallow valleys. After completion of peneplanation portions of the southern areas of the State became submerged beneath the sea and during this submergence the deposit forming the Princess Royal Deep Lead and also the Norseman Lime-

stone and the Plantagenet beds were laid down, the Princess Royal beds in a shallow valley. The Eucla Limestone beds had long been accumulating in what was a great inland gulf (the Eucla Gulf) occupying the site of the present Nullarbor Plains. As a result of the depression, aggradation occurred in those portions of the valleys which were not submerged.

Following submergence a slight uplift took place and the land remained stationary for a time. During this period shallow valleys were eroded in Swanland (as shown by Woolnough, *b*, 390), in Salinaland, and probably in all other divisions of the State, although there are yet no definite records for those other divisions. Those valleys reached base-level approximately. Minor uplifts occurred which doubtless caused some modification of the land forms. Then came the great uplift which brought the land to its present height. Associated with or probably following closely upon the uplift, the great fault scarps, and also deformation basins or sunklands, such as Lake Cowan, Lake Disappointment, the Marsh Sunkland, the Coolgardie Sunkland, and others were formed. In addition a general warping of the surface took place. As a result the old drainage channels were disrupted. The change to aridity followed before the drainage lines could be re-formed and connected with the sea. Hence a large portion of the drainage became interior and has since remained so.

New drainage lines were cut in places leading into the deformation basins, but as the latter filled up, degradation of the stream channels ceased and aggradation took place. The disrupted old drainage lines also became aggraded, and in both these ways the deep leads were formed.

Some of the deformation basins may be narrow in proportion to their length, and hence what appears to be a true stream channel may be merely an attenuated basin filled with debris and containing alluvial gold.

If the history suggested be true, then it accounts for the paucity of true waterworn pebbles in the leads, contrasted with the large quantities of angular debris often there found.

In the way suggested many of the basins and inequalities of the surface which resulted from the great uplift have been respectively filled and removed; but in consequence of the aridity of the climate, the drainage is still almost entirely interior, although there is a tendency for the coastal streams to capture the interior drainage, showing that with more rainfall, permanent connections with the sea would soon be established.

There is, however, still much land rising above the lowest portions of the country, and provided this higher land is not covered by drifting

sand, it is still subject to erosion. Hence in the hills and ridges, canyons have been and are being developed, and, in the more undulating country, wide valleys, so shallow in proportion to their width as to be almost imperceptible without close observation, have been and are being eroded. As the resulting detritus is not being carried to the sea, it must be filling the shallow hollows that still exist. In this way, therefore, a great levelling is taking place at a very considerable height above sea-level. This aspect is fully discussed in treating of the major land forms of the arid areas, but in the meantime it is suggested that the present drainage lines are independent of the "deep leads," and have been developed almost entirely since the valleys or basins containing the "leads" were blotted out. There may be a distant relationship between the deep leads and the present valleys, but probably such a connection occurs in a limited number of cases only.

PAST CLIMATE AND THE DEEP LEADS.

The above general statement indicates the writer's opinion that the channel of every deep lead has not been formed when the climate was moister, and during the same period. His contentions are (1) that the channels have been cut under both normal and arid climates at different periods and at different elevations of the land; and (2) that the filling up of the channels (thereby completing the formation of the "leads") has taken place mainly under arid conditions, but probably in part by aggradation under a normal climate owing to deformation of the land.

THE ECONOMIC ASPECT OF THE DEEP LEADS.

A large amount of gold has been obtained from the deep leads. It is, therefore, economically important to obtain as much actual information concerning the leads as possible, so that a theory of their origin, which shall satisfy all the known conditions, can be formulated. Armed with such a theory, the mining community could proceed systematically in a search for new leads and in the further prospecting and exploitation of known ones. The subject, however, from its very nature, is and is likely to remain obscure, but facts apparently of no importance may throw unexpected light on the question. Hence the necessity for careful records of any relative facts.

Examples of the various possibilities may be given. Thus if the suggested history be correct, large old river auriferous deposits are not likely to be found. Many of the leads are close to the "dry" lakes. If the latter have thick detrital deposits and the leads run into the lakes, the deposits of the latter may be payably auriferous. On the other hand the recognition of a deep lead as a closed basin would prevent wasteful expenditure of money in seeking to trace the lead system.

Another point is that the upper portions of some of the auriferous leads may have been entirely removed by erosion, with the result that the gold now appears as ordinary surface alluvial gold. (See fig. 85.)

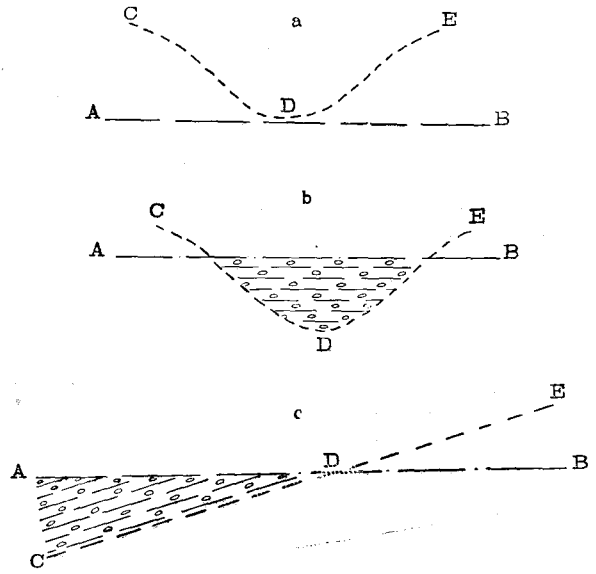


Fig. 85.—Diagrams (*a*, *b* and *c*) illustrating changes in the land surface since the formation of "deep lead" valleys.

AB—Present surface.

CDE—Old surfaces before the formation of the "lead."

In *a*, a cross section, the "deep lead" valley has been entirely removed, and the surface is now a plain. In *b*, a cross section, the old valley has been filled with detrital material, thus forming a "deep lead," but the upper portions of the sides of the valley have been removed, leaving a plain, on which the "deep lead" is not easily detected. In *c* (a longitudinal section down a "deep lead" valley), the "lead" in the upper portion of the valley has been entirely removed, thus corresponding with *a*, but in the lower portion of the valley the "lead" remains, thus corresponding with *b*.

If, however, it could be identified as deep lead gold such identification might result in the discovery of a payable lead.

In conclusion, it may be stated with some confidence that further auriferous leads remain to be discovered. Such discovery should not only be of value for the gold found, but for the facts (bearing on the origin of the particular lead and indirectly on the leads in general) which will become available and which should be carefully recorded.

PART X.—THE SALT OR "DRY" LAKES OF SALINALAND.

CONTENTS.

Introductory Remarks. General Description. Theories and Trend of Thought regarding their Origin. Origin of the Lakes. (a) Deformation or Tectonic Lakes. (b) Erosion Lakes. Migration of Lakes. Former Greater Lakes. The Effect of Migration of Lakes on the Vegetation.

INTRODUCTORY REMARKS.

The salt or "dry" lakes are mainly confined to Salinaland, and are so interesting from a geographical point of view, the more so in view of the fact that no unanimity of opinion as to their origin has yet been reached, that, although a brief description of their main characteristics has already been given when treating of Salinaland as a physiographic division, it is now proposed to give in this Part a somewhat more detailed account of them, and to indicate and discuss briefly the various theories of their origin. Similar "lakes" occur in Sandland, but they are not abundant and very little attention has been given to them.

GENERAL DESCRIPTION.

The lakes in Salinaland cover many square miles of country, and in size vary in both length and breadth from many miles to a few hundred yards. Some of them are isolated, but many are more or less connected in long strings; yet the individual lakes so loosely connected have very different outlines and areas. After heavy rains the lakes may be covered wholly or in part with sheets of water, which are usually not more than an inch or two to 12 inches deep. With very heavy or fairly long-continued rain, water may flow from one lake to another; but this is probably not very common. Moreover the flow rapidly ceases, and the connecting arms become merely attenuated portions of the lakes. In some instances, the connection between two lakes is so rare that the intervening country is completely clothed with vegetation. The evaporation is so great that the lakes rapidly dry up, and remain so for most of the year. Some water must also percolate into the ground, but as the level of the water table is in perhaps most cases very close to the surface, direct percolation from the lake floor is probably limited. On evaporation of the surface water, some salt and gypsum are usually precipitated, but as scarcely any thick deposits of these, as precipitated, are found, they must be blown away by the wind year by year; small dunes of seed gypsum and of the powdery impure form known as "kopai" occur on the borders of some lakes.

The dry floors of the lakes are abnormally smooth and level. The lakes are in some cases actually rock-floored in part at least, especially along their western borders, and these rock-floors form "billiard table" surfaces. Other portions are covered with fine detritus, brought mainly in suspension by the surface water, the thickness of which detritus in some cases is only a few inches. The detritus is probably of considerable thickness in some lakes, but our knowledge in this direction is as yet very limited. Quartz and other pebbles, miniature earth-pillars, and miniature hollow domes, which are often broken, occur on the lake floor.

The lakes are frequently bordered by low sandy country. The sand in places forms wide level tracts, but elsewhere it forms dunes a few feet high, composed chiefly of quartz grains, and partly covered with vegetation. In some places cliffs of rock occur, the more decomposed rocks, if possessing a hard cap, forming breakaways of the type described in Part XI., Chapter I. Steep-sided, rocky islands of quartz, greenstone, and jasperoid rocks and also sand ridges, all of which are of varying size, occur in some lakes. Narrow stream-like channels often lead into and out of a lake, and may or may not actually connect with other similar lakes. The lakes lie along the general drainage lines of the sub-arid country, although much water that falls never reaches the lakes. Towards the coast the lakes are connected with some of the seaward-draining streams; and hence a small portion of the surface water may ultimately reach the sea. The exterior drainage on the south and west is generally encroaching on to that of the interior.

As the lakes lie chiefly along the main drainage lines of the country, the writer (*g*, 306, note 1) has suggested that the term "stream-lake system" may be applied to the phenomena as a whole.

The chief rocks of the lake floors are granite, greenstone, and sedimentary rocks, the first-named being most common; a fact which may be explained by the wide distribution of the granite as compared with the other rocks, and by the fact that granite in Salinaland weathers more rapidly than greenstones, thereby enabling the eroding agents to exercise a selective power.

Reference may be made to figs. 51, 52, 53, 54, 55, 56, 57, 58 and 86.

THEORIES AND TREND OF THOUGHT REGARDING THEIR ORIGIN.

In 1897 H. P. Woodward in a short but comprehensive paper (*g*) discussed the origin of the lakes, and concluded that they are merely wind-planed flats. He pointed out the south-easterly fall of the main drainage lines, the chains of shallow lakes, their practically rock-floored character, and the action of the wind in blowing away the fine mechanical deposits and precipitated salts. He explained their remarkably level floors as due to the subterranean water being always so near to the surface that the moisture rising from it by capillary attraction, held

together the particles, thus preventing either the superficial deposits, or the disintegrated rock below a certain level, from being removed by the wind. Woodward's idea that the wind is the controlling agent in the formation of the lakes was briefly re-stated by him in 1914 (*q*, 15-18).

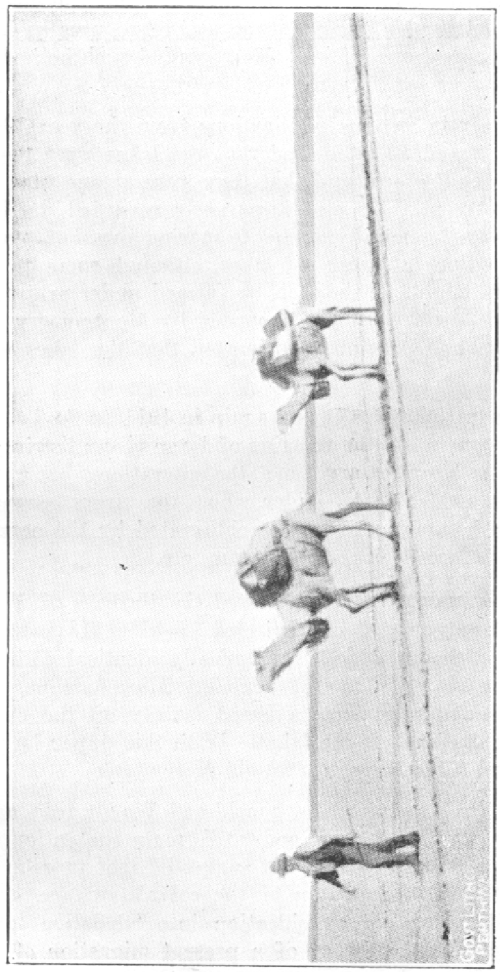


Fig. 86.—Camels crossing the northern portion of Lake Lefroy, Salinaland. The boggy nature of the surface of the deposit of fine silt, after evaporation of the transient waters, is well shown.

Chewings, speaking with regard to the lakes generally, had previously (1896) stated that, as a rule, the bedrock was close to the surface, and also that the wind removed all loose material from the surface of and carried it far beyond the bounds of the lake. He also considered that flood waters after rain remained long enough to smooth the surface of the lake.

Maitland (*a*, 21, 22) in 1900 remarked on the bare rock floor of a lake where deep leads would be expected to enter it, and in 1903 (*c*, 51, 52) he also noted the thinness of the detrital deposits in valleys running into Lake Carey, a large lake in the Yerilla district.

W. D. Campbell in 1906 (*a*, 23) suggested that the deep hollows (now filled with detritus) of Lake Cowan and of an area at Coolgardie may have been scooped out by ice. He regarded such hollows as rock basins.

A. Montgomery in various publications from the year 1909 to the year 1912 (*h*, *i*, *j*, and *k*) suggested that the lakes were the remains of a widespread shallow sea, and that they were at one time more extensive than at present. He also apparently regarded the lake cliffs and the "breakaways" generally as due to marine abrasion, and in some cases as the shore-lines of large old lakes, although some of the topographical features might, he thought, be formed under arid conditions. Probable beach deposits were also recorded by Montgomery. Victor Streich (91 & 99) had previously suggested that the lakes were remnants of the sea.

C. G. Gibson in 1909 (*d*, 12) and again in 1911 (*e*, 11-12) regarded the salt lakes in general as the remains of large rivers flowing into the sea in Tertiary or pre-Tertiary time, the alteration being due to a change to a more arid climate, under which the rivers ceased to run, and their sources became more or less obliterated by the accumulation of wind-driven surface debris, sands, loam, etc.

In 1914 J. W. Gregory (*c*) reviewed the theories of Woodward, Campbell, and Montgomery, but rejected each. He independently brought forward a theory which is practically identical with Gibson's, that the lakes are river systems of probably Miocene time, since dismembered. Gregory's argument is based mainly on the distribution and height above sea-level of the lakes. With this paper he published a map connecting up the lakes into an old river system.

In 1914 (*b*) the present writer considered Woodward's and Montgomery's schemes, and accepted Woodward's main contention as to the wind origin of many of the lakes; but suggested that possibly some of the lakes were due to deformation of the earth's surface, and consequently proposed a twofold classification into "deflation lakes" and "deformation lakes." The theory of a present migration of the lakes was also brought forward.

C. O. G. Larcombe (*a*, 31) had previously stated that many of the so-called clay-pans represented depressions which may be due to a warping of the earth's surface, or perhaps unequal erosion.

In 1914 C. S. Honman independently showed that some lake cliffs are receding (*a*, 12), while sand is accumulating elsewhere on the lake-

shores. He has also suggested (*a*, 11 & 13) the occurrence of former higher-level lakes, the margins of which are marked by the line of higher-level "breakaways."

In 1916 J. W. Gregory (*e*) further discussed the origin of the lakes, and the possible old courses of the ancient rivers.

In 1916 Montgomery (*l*) re-stated his views at considerable length on the lines of his previous publications. He also suggested (83) that many extensive plains, which he termed "brown soil plains," and which he claims are more or less surrounded by higher sandy country, were the beds of lakes older and larger than the present salt lakes. Montgomery also came to the conclusion (86) from a study of the chemical composition of the underground waters, that they have been derived from a marine source rather than directly from integral constituents of the bedrock; and he expressed the opinion (91) that the salt of the underground waters had been derived from sea water "within a space of time so recent, geologically speaking, that it has been insufficient to allow of the salt being either carried back to the sea or concentrated entirely in the low-lying salt lakes." Montgomery (93) also points out that on the great uplift, deformation took place, and that the deep ground (about 400 feet in depth) at Coolgardie can only be explained on the assumption that it is a small sunkland.

In 1917 the present writer (*c*) discussed the origin and migration of the lakes at some length, and re-stated his view that some of the lakes probably occupied deformation basins. In regard to the other lakes he considered that there may be some distant connection between the old Miocene rivers and some of the existing lakes, but he was unable to accept the view that such lakes were, in the main, merely the dead remains of such a river system. He held the opinion that the existing agents were competent to produce the existing phenomena, including valleys, plains and lakes, and that many factors were responsible for the results obtained, amongst which the wind was regarded as playing a prominent part. The method of lake migration was stated and it was suggested that the lakes were migrating westwards; attention was also drawn to the remarkable "billiard-table" rock-floors of the lakes.

In 1917 T. Blatchford (*d*, 24) considered that the lakes of the district north of Southern Cross were migrating westwards.

In the same year Honman, in regard to the lakes of the Mt. Jackson district (*c*, 144) agreed with J. W. Gregory that they represented a dead river system.

In 1917 in a later publication than that noted above under his name, Honman (*d*, 17) observed that the chief lakes of the Yerilla district were rock-floored with escarpments on their western sides, but had sand dunes on their eastern sides; that the rock-flooring was probably due to the migration of the lakes; and that the great length and narrow course of Lake Raeside suggested that it was the stagnant remains of an old river.

In 1918 the present writer (*g*) showed that over a wide area the lakes had rock-cliffs and rock-floors on the western, north-western, south-western, and, to a less extent, on the northern sides of the lakes; and that such cliffs and floors were absent on the eastern, south-eastern, north-eastern, and southern sides of the lakes, the place of such cliffs and floors being taken by sand dunes, sand plains, and silts.

In the same year he also separately recorded (*f*) that Lake Goongarrie, in the Goongarrie-Comet Vale district, possessed rock floors and rock cliffs on its western side, and sands and silts on its eastern side; it was also suggested that shallow rock basins were apparently being formed, and that the lake and the whole adjacent topographic system were migrating westwards.

In 1920 H. W. B. Talbot (*d*) as a result of the examination of an extensive area in the north of Salinaland and adjacent thereto, reached the conclusions (*d*, 38) that the lakes were remnants of rivers which flowed south; that the flow of such rivers was obstructed by an uplift of the southern coastal area, and by possible warping of the country behind; that the lakes were migrating owing to wind erosion; and that the salt of the lakes was derived from the weathering of Palaeozoic rocks, which at one time extended farther south than at present.

In 1923 (*b*, 49-50) and again in 1926 (*c*) E. S. Simpson, basing his conclusion on the chemical composition of the underground waters and of the marine character of the Norseman and associated beds, held that in Tertiary time there had been an extensive marine invasion over much of the southern half of the State.

In 1924 W. E. Wood in referring to the increase in salinity in certain streams in Swanland suggested that the salt was derived from the sea and was air-borne, that is "cyclic" salt.

In 1925 Clarke (*d*, 19) supported the ancient river theory of the lakes.

In 1926 Glauert and Feldtmann (284), by reason of the discovery of species of *Coxiella* in some of the lakes, came to the conclusion that there had been a widespread marine invasion in Miocene times.

In 1926 W. K. Weller (633) showed that a large quantity of salt was being brought to the catchment area of the Mundaring Reservoir near Perth; and that it was derived from the ocean, carried by the wind, and precipitated with the rain. See also E. S. Simpson (*c*, 638), where the chlorine contents of the rain are given for various localities, amongst which are Coolgardie, Cue and Wiluna.

In an undated publication (presumably issued about 1928) L. J. H. Teakle (11 and 12) refers to the possibility of the salt of the salt lakes being cyclic, and also, in the Esperance-Norseman area, as being due to the evaporation of the sea water left after emergence of the land from the sea. He also suggests that local cycles occur,

the salt being blown from the surface of the lakes, to be re-deposited on the soil when the movement back to the lakes begins. The same idea was put forward by Göczel 40 years ago (*a*, 15).

In 1928 Blatchford (*i*, 3 and 4) considered that though some of the salt may have been derived from Miocene sea waters, yet it is mostly cyclic.

ORIGIN OF THE LAKES.

The lakes as they exist to-day, whatever their primary origin, are undoubtedly, in some instances at least, due to accumulations of detritus, mostly in the form of wind-blown sand which has drifted across the drainage lines and so formed lakes. From this obvious fact the conclusion has been drawn that the drainage lines are the remains of old Tertiary rivers, a thesis which the writer does not consider to be proved, or even probably true. Moreover, although wind-blown sand may be found on all or certain sides of the lakes, it has not been established in many cases that an old drainage channel does continue under the sands which apparently cut across and block the drainage. A lake could occupy a closed rock basin, around the whole or parts of which blown sand could accumulate, and so give the appearance of a blocked drainage channel, especially in view of the fact that the lakes as a whole appear to lie along the lowest lying portions of the country.

Admitting, however, that some lakes have been formed by the encroachments of drifting sands on drainage lines, further points requiring consideration arise, such, for instance, as—

(1) The nature and origin of such lines.
(2) The time they were formed.
(3) The changes (if any) that have taken place in the lakes since their formation.

Thus the primary origin of the lakes may be considered from two standpoints, viz.—that of deformation and that of erosion; and hence the lakes may be classified in the broadest way into Deformation or Tectonic Lakes and Erosion Lakes. The latter term is sufficiently wide to include all lakes the primary characters of which may have arisen from any kind of erosion, whether wind, stream, ice or the sea, and the term itself has the merit of indicating no particular theory of erosion.

Where blown sand is actually responsible for the lake, the deposition of the sand may be regarded as the second chapter in the history of the lake, the first being the earth movements or the erosion which stamped the face of the country with the contour it possessed when the sands were deposited. A third chapter comprises the changes in the lake since its formation, which changes may be due either to erosion or to deposition, and in the case of the latter the deposits may be either blown sands or material laid down under water.

Bearing the above remarks in mind, the primary origin (earth movements or erosion) of the lakes, their migration, and the possibility of former greater lakes, will be mainly considered. Insufficient observations have been made to say much about the deposition of wind blown sand in the formation of the lakes.

(*a*) *Deformation or Tectonic Lakes.*

Examples of these lakes are perhaps Lake Disappointment and Lake Cowan. The Coolgardie deep area, now filled in with detritus, although not now the site of a lake, may have been. Other deformation lakes will probably be discovered in time by boring, but as that will be only when economic information is desired, such discoveries must for many years be few. Reference should be made to the chapter on the sunklands in Part XIII.

The origin of the deformation lakes is indicated by their name, but the warping that resulted in the formation of the basins doubtless occurred when the great uplift of the Great Plateau took place, and may have been aided by the existence of pre-existing valleys which by warping became probably in some instances transformed into closed basins.

(*b*) *Erosion Lakes.*

The summary of theories given above shows that unanimity as to the origin of these lakes has not yet been reached. Various aspects of the problem will, therefore, be touched upon.

As finality is approached, it will perhaps be found that two or more theories will have to be combined, or that one theory may be true for one set of phenomena relating to the lakes, and another theory for another set of phenomena. In other words, it may ultimately be shown that different observers have formulated their respective theories in relation to certain aspects of the problem, to which they may have been more or less unconsciously attracted. The various papers that have been published in recent years have brought out new facts and different points of view which have clarified the problem considerably.

The writer believes that any theory that neglects to take into account the great modifications of the land surface by erosion that have taken place since the great uplift, will fail to do justice to the subject. When due consideration is given to the large amount of valley erosion that has occurred in the coastal areas since that event, and to the erosional processes now at work in the interior, it will be admitted that such modifications have been substantial.

The ancient river theory in its early form neglected those changes, the chief results of which are the rock floors and rock cliffs of the lakes, to account for which the river theory was quite inadequate. Wind erosion and marine abrasion were each suggested as the cause of those features, and the theory of lake migration, mainly by wind action, was brought forward.

The later supporters of the river theory have recognized that the rock floors and rock cliffs could not have arisen by ordinary river action; and they have accepted the theory of lake migration, and that such migration is accomplished, in part at least, by wind action.

Similarly the original wind theory has been somewhat modified by a more complete recognition of the fact that many of the lakes lie along valleys, which may be distantly connected with the valleys existing at the time of the great uplift, although it is still maintained that the lakes are not merely the dead remains of the old Miocene rivers.

The marine theory originally was based upon the saltness of the lakes, the characters of the rock-cliffs and of the rock floors of the lakes, and the occurrence of the Norseman limestone, which was regarded as of comparatively recent age, and which suggested that there may have been a much greater extension of the Norseman beds to the north. The characters of the "breakaways" were also claimed as supporting the theory.

In 1916 (Montgomery, *l*) the chemical composition of the underground waters was suggested to be confirmatory of the marine theory.

The absence, however, of marine deposits over most of Salinaland, although negative evidence only, was a serious bar to the acceptance of the marine theory; but that objection was answered by the assumption that erosion had removed the marine deposits over wide areas. That assumption, therefore, implied a considerable lapse of time since the great uplift, but there was the contrary assumption that the breakaways and rock-floors were practically the same as when they were moulded by the sea, implying, of course, a very short period since the great uplift.

Those who opposed the marine theory, from a study of the evidence of the amount of subaerial erosion which had taken place since the great uplift, contended that a considerable time had elapsed since that event and that the "breakaways" and rock-floors were the result of that erosion. The recent determination of the Norseman limestone as of Miocene age is not opposed to that contention. Thus the first-named assumption in support of the marine theory may be true, but there seems to be little doubt that the second is false.

The study of the chemical composition of the underground waters appeared to strengthen the marine theory; but doubt has been thrown on the validity of the inference that such composition was the direct result of an invasion of the sea in Miocene times, owing to the possibility, as suggested by Talbot (*d*, 37), that the salt may have been derived from Palaeozoic rocks since removed by erosion, and to the fact that large quantities of salt are now being carried inland from the ocean by the wind and are precipitated with the rain (Weller, 633; Simpson, *c*, 638; Teakle, 11 & 12; and Blatchford, *i*, 3 & 4). How

much is carried into Salinaland is not known, but it may be assumed that all the salt carried by the wind is not deposited in the coastal districts, and therefore, that a portion is being carried to and deposited in Salinaland. During a long period the amount would be considerable, and probably all the salt of the salt lakes can be accounted for in that way despite the fact that the wind may perhaps lift salt from the lakes, into which it may find its way back by precipitation from rain. Further investigation of this important matter is desired, and the results will be awaited with interest.

The occurrence of the gasteropod *Coxiella* and the claim made that it proves the existence of a Miocene sea far inland, have been referred to in Chapter II. of Part VIII., which treats of the Great Plateau. If such claim be valid, then there has been a widespread invasion of a Miocene sea. It appeared, however, to the writer that the evidence was too slender to justify such a generalization, and that it was probably capable of another interpretation. He therefore referred the matter to Mr. F. Chapman, A.L.S., F.G.S., the Commonwealth Palaeontologist, and that gentleman has kindly submitted the following statement:—

The argument in favour of *Coxiella* being a thalassoid type, as held by the late Chas. Hedley, is its supposed external resemblance to the marine shell *Truncatella*. Proof of relationship should be based on the structure of the radula, which, although known in the case of *Truncatella*, seems not to be known in *Coxiella*.

The arguments in favour of *Coxiella* being a typical freshwater genus with adaptive powers of living under brackish conditions are—

(1) The association of undoubted typical freshwater genera of other groups, as species of the bivalved ostracod *Cypris*.

(2) The association of the gasteropod *Bythinella*, typically a freshwater genus, of streams and ponds.

(3) The occurence of *Coxiella* far inland, where no later invasion of the sea has occurred probably since Cretaceous times, as at Lake Eyre.

The conclusion from the above points in evidence is that *Coxiella* appears to be a freshwater mollusc that has adapted itself as much, or more than any other aquatic species, to brackish water conditions; the marine transgression theory, therefore, is not supported by facts."

Mr. Chapman's weighty remarks need no comment.

The marine theory may therefore be regarded as untenable until some more reliable evidence than that hitherto brought forward is produced.

It may be remarked that even if a widespread marine invasion be ultimately proved, it will not account for the lakes as they now are. If some of the lakes have deep detrital deposits, then the deposits must rest in deformation basins or deep valleys, with the formation of both of which the sea has nothing to do. Similarly, the rock-cliffs and rock-floors can only be accounted for by subaerial weathering. The "deep leads" constitute another body of phenomena difficult to corre-

late with a marine invasion. It would, therefore, seem that if the latter occurred, then over the greater part of Salinaland it was for a very brief period, and it practically made no imprint on the landscape. The arguments in favour of marine invasion and erosion have been set out fully by Montgomery (*l*) and the reader is referred to his statement of the case.

Wind erosion (of course combined with insolation and other factors, which may be regarded as the advance agents of erosion) accounts for the rock-cliffs and rock-floors, and the migration of the lakes, without the aid even of the gentle transporting action of rain, which, however, is considered in Part XII., Chapters I. and II. The floors here considered are those either actually bare or covered by thin detrital deposits. Wind erosion does not account, however, for the deep detritus-filled hollows which, as stated above, must be deformation basins or buried river valleys. Neither does it account for the present valleys along which the lakes lie. Some of those valleys, in the writer's opinion, have been formed by normal erosion either before the great uplift or since that event, but prior to the change of climate to aridity, and have been modified subsequently to that change. Other valleys have been formed apparently almost wholly after the same change, since when, the modifications of the older valleys and the formation of the new ones have been due to stream action, assisted in their later developments by the wind.

In speaking of valleys it is well to remember that the features referred to are, as a rule, now merely faint drainage lines on the new plateau. They are described in Part XI., Chapter I.

A valley becomes choked by sand; water and salts collect; the vegetation dies; detritus accumulates (either by decomposition of the rocks *in situ,* or by being brought by wind and rain), and remains or is blown to form dunes on the lake shores; rock-floors and rock-cliffs form or are modified; and the lake migrates. Such in brief is the probable life history of an erosion lake.

During the course of that history, the writer believes from observations made by him (*f*) at Lake Goongarrie, that wind erosion may actually scoop out the floor, so as to make a distinct, although shallow rock basin (which becomes the lake basin) or a series of small rock basins on the floor of the lake. This action of course is facilitated by the destruction of the vegetation as a result of the deposition of salt.

J. W. Gregory (*c,* 659, *et seq.*) has pointed out that the lakes conform in altitude to the general southerly fall of the country, which fact, he contends, makes the marine theory improbable. It is, however, equally confirmatory of the Miocene river theory, and of the theory advanced by the writer, that the forces at present operating have been mainly responsible for the formation of the erosion lakes.

The ancient river theory fails to recognize that wide long valleys are being formed at the present time, that they are growing headwards, that capture or union of one valley and of one lake with another is taking place, and, in short, that drainage systems, although interior, often indistinct and often disconnected, are in process of formation and development, despite the accumulations of sand, which have in the past broken up, and are now breaking up other systems, or portions of the same systems, of drainage. Hence the fallacy of assuming that because one lake may be connected with another by an ill-defined channel, that channel is necessarily evidence of the existence of an old river valley. It may be, but it may equally be evidence of a channel that has been cut by headward or other erosion from the one lake to the other since, and not prior to, the formation of the two lakes. Perhaps, however, as investigation proceeds, these ideas will be more widely accepted, just as the formation of rock-cliffs and of rock-floors, and the migration of lakes, under present conditions, have been recognized.

Lakes may be divided by the cutting off of arms or of one main portion from another by blown sand; and probably two or more lakes may be again united by the removal by the wind of the dividing sand.

The work of the wind is again referred to in Part XII., Chapters I. and II. (in the latter under the heading of "The Salt Lakes").

MIGRATION OF LAKES.

(See figs. 87-92.)

As stated above many of the lakes are bordered by cliffs (either "breakaways" or the ordinary steep cliffs of practically undecomposed

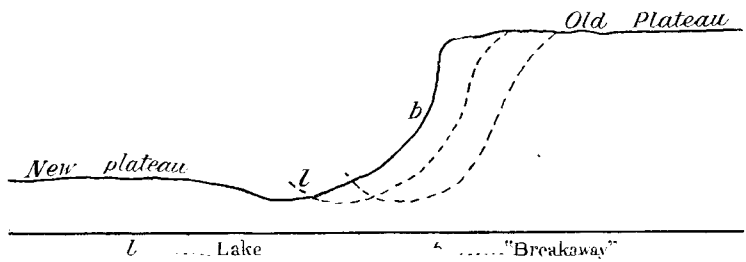
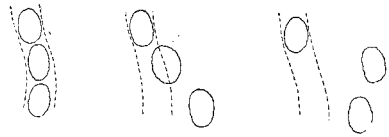


Fig. 87.—Diagram, illustrating in section, the migration of a salt "lake" (*l*) by the recession of a cliff ("breakaway," b) and the deposition of detritus on the opposite side of the lake. The depth of the lake has been exaggerated for the purpose of illustration.

rocks without a hard cap) of various rocks on one or more sides, but it has been found that the cliffs occur mainly on the western, north-western and south-western sides (which for the sake of brevity are subsequently included in the general term "western sides"). Sands, in

Fig. 88. Fig. 89. Fig. 90.



Figs. 88, 89, and 90.—Diagrams, illustrating in plan the migration of salt "lakes."

Fig. 88.—Original valley with lakes, which become connected at times after heavy rains.

Fig. 89.—A later stage showing that two of the lakes have migrated.

Fig. 90.—Further stage, showing the continuous migration of the middle lake and the complete isolation of the three lakes.

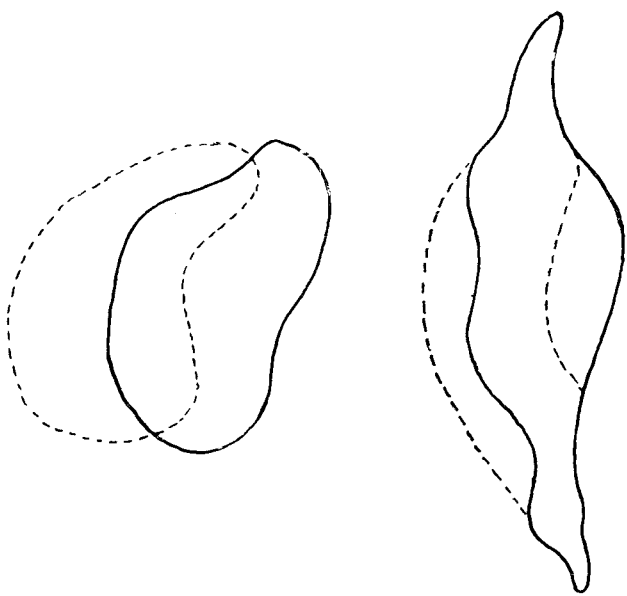


Fig. 91. Fig. 92.

Figs. 91 and 92.—Diagrams, illustrating in plan, the migration of salt "lakes."

Fig. 91.—Showing the migration of a more or less elliptical-shaped lake.

Fig. 92.—Showing the migration of portion of an elongated lake.

The continuous lines represent the present outlines of the lakes; the broken lines represent the outlines, or part of the outlines, of the lakes prior to their migration.

the form of sand dunes and sand plains, occur on the eastern, north-eastern and south-eastern side (which for the sake of brevity are included in the general term "eastern sides"). On the western sides of the lakes, rock floors either absolutely bare or covered by a film of detritus are fairly common, but are usually absent from the eastern sides, where the detritus is in most places of some depth, but what that depth is remains unknown at present in most instances.

By erosion the cliffs are in process of removal and their place is taken by smooth rock-floors ("billiard-table" floors). The cliffs, therefore, are receding to the west and the rock-floors are also growing in that direction.

On the eastern sides, the sands and silts appear to be steadily encroaching on to the lake surface owing to transportation by wind and water, so that on each side of the lake the boundaries may be in course of displacement. When rain falls in sufficient quantities water will be found at the foot of the rock cliffs, but it will not occupy the position of former years on the eastern side of the lake, as the encroachment by sand and silt tends to displace the water laterally towards the receding cliffs, that is to the west. These processes indicate, therefore, that the lake is migrating; and, so far as known, the direction of migration is westwards.

If the processes of erosion and deposition described above be continued for a long period, which is likely where there is a dominant wind, a lake may be slowly entirely transferred from its original site to another position, and by the growth of vegetation the original site might be quite obscured.

The migration now appears to the westwards, but it is possible that in times past, a change in the opposite direction of migration may have occurred, and by that means, a lake, as some of the present ones are, could be in the middle of a wide flat with saline vegetation.

If migration be accepted as a fact, it follows that many lakes, which from casual observation have apparently been larger than at present, are satisfactorily explained without the necessity of assuming a recent shrinkage in their areas.

A lake of Salinaland is somewhat analogous to a river at grade. Such a river has ceased to corrade vertically but is corrading laterally. Concurrently, however, with such lateral corrasion on one bank, deposits are being laid down on the other, and the course of the river is changing continually. If the process continue, the wide river plain, through which the river meanders with frequent changes, is the result. In the dry interior, grade is not actually reached, but as erosion must sway laterally the analogy can be used. So by virtue of the two processes of lateral erosion and deposition, the lake, like the river, must migrate.

It must not be assumed that every part of a lake is migrating at the same time, or, if such be the case, that all parts are moving at the same rate. The presence or absence of cliffs and, where present, their height and the character of their component rocks would necessarily affect the rate of progression. Other factors are the quantity and kind of detritus that may accumulate on a shore or on a lake floor, the strength and direction of the dominant wind and the nature and quantity of the rain that falls.

This irregular migration would in some instances tend to split the lake into two or more distinct lakes, and thus form the scattered lakes that occur in places. In other instances, it may result in a greater curving in the outline of a lake, or a wide bulge followed by a normal narrow portion.

Where the lake is entirely bounded by low and sandy shores, the fact of migration may not be evident, but if it be taking place where hard rock cliffs exist, it will apparently also be acting, and with greater force, in many places where such cliffs are absent. The deposition of detritus on either side would tend to displace the lake floor.

At present there is no direct evidence as to the extent the lakes have migrated or as to the time they have been migrating. Probably they commenced to move laterally from the time they were formed on the change to aridity of climate, so that if the date of that change could be satisfactorily determined the period of migration would be fixed. In Central Australia, such change has been suggested to have occurred in Post Pliocene time (Baldwin Spencer, Narrative, 174). Howchin (171-175) believes it to have occurred in or even later than Pleistocene time. (See also Mawson (222) as to the comparatively recent change of climate to aridity in the Broken Hill district of New South Wales). In any event, however, the time seems to have been long enough to have produced substantial changes of position in some of the lakes.

The dominant winds in the southern portion of Salinaland appear to be from the west (Jutson, *g*, 313; Honman, *a*, 11; and Blatchford, *d*, 23, 24). Farther north the prevailing (and presumably dominant) winds are south-east (Talbot, *d*, 35).

FORMER GREATER LAKES.

It has been suggested that many of the present lakes are mere remnants of older and larger ones; and Talbot (*d*, 31 & 35) states that Lake Disappointment has been proved by bores to have extended at least 4 miles beyond its present limits. That lake, therefore, appears to be an example of one that has much shrunken in recent times. There are doubtless others, but it is not safe to assume that every apparent example of a shrunken lake is actually one, since, if the migration of

lakes be a fact, the lateral shifting of the lake would, in some instances, give the impression of it having at one time been much larger, although this might not be so.

Former great lakes may be divided into those that have always been much the same as now, that is, merely shallow ephemeral lakes, which, owing to change of local conditions have shrunk; and those which were deep permanent salt or fresh water lakes. Of the second class, there is as yet no definite evidence. If they had existed, shore cliffs would probably be produced, but the position (mostly on one side only) of the present cliffs forbids the assumption that they represent cliffs cut by deep lakes. Rock benches are characteristic marks of former deep permanent lakes, but there are no records of those features. The deposits in the lakes should give some indication of their origin, but those that have been examined apparently afford no help. They may have accumulated under present conditions. The deep alluvial deposit at Coolgardie which contains the leaves of plants is not connected with any present lake.

Further investigation on the subject is desirable.

THE EFFECT OF MIGRATION OF LAKES ON THE VEGETATION.

The vegetation immediately surrounding a lake is frequently of a distinctive halophytic character, samphire and mesembryanthemums predominating (fig. 52). As a lake migrated and new deposits (practically free from salt) accumulated on the deserted area, the vegetation might in time change to the more ordinary non-halophytic type, and so remove the last indications of the ground having been at one time occupied by a lake. The change would be facilitated by reason of the fact that the rain would tend to wash out the salt from the old lake bed.

A striking example of a change of the kind indicated apparently taking place is observable from the Kalgoorlie-Leonora railway, a few miles south of the Malcolm railway station, where Lake Raeside crosses the line and where the lake is only a few chains wide. A wide area of country, however, in the vicinity, retains evidence of its former occupation by lakes, judging by the character of its vegetation.

PART XI.—THE NATURE AND ORIGIN OF CERTAIN LAND FORMS OF SALINALAND.

CHAPTER I.

THE MAJOR LAND FORMS.

CONTENTS.

Scope of this Chapter. Nature of the Great Plateau on Uplift. The Valleys. (a) Short V-shaped Valleys. (b) Short U-shaped Canyons. (c) Broad flat-bottomed Valleys with steep Sides. (d) Valleys "born mature." The New Plateau. Cliffs ("Breakaways") and Associated Forms.

SCOPE OF THIS CHAPTER.

The land forms of Salinaland are unique and their origin well merits attention. They comprise the residuals on the old plateau; the remnants of the old plateau (chiefly in the form of mesas and buttes); the new plateau; the cliffs or "breakaways" connecting the two plateaux; the canyons in the old plateau; the miniature V-shaped valleys in the higher land; the wide shallow valleys; and the salt or "dry" lakes. Several minor forms, such as rock hollows, natural bridges, and others, are described in the next chapter.

The nature, origin and periods of uplift of the old plateau, the surface of which is part of the Great Plateau of Western Australia, have been discussed in Chapter II. of Part VIII., in which the residuals on that plateau have also been referred to. It is not necessary, therefore, to deal further with those features, except as noted below, and to indicate that, as a result of such discussion, it was concluded that the old plateau as part of the Great Plateau was an uplifted peneplain.

The nature and origin of the salt lakes have also been discussed in Part X. They will not, therefore, be further considered, except incidentally in the course of any description or discussion of any associated land forms.

The general characteristics of Salinaland as one of the physiographic divisions of the State have been described in Chapter VIII. of Part VI.

Land forms similar to those of Salinaland also occur in Sandland, but as the latter is comparatively little known and much of the area is covered by sand ridges, it has been deemed advisable to restrict the discussion practically to Salinaland. The latter also has the great advantage, from the point of view of the study of land forms, that it is far more accessible than Sandland.

NATURE OF THE GREAT PLATEAU ON UPLIFT.

At the time of the last great uplift it has been suggested, when discussing the origin of the Great Plateau and of the "deep leads," that the plateau was probably scored by shallow valleys, certain of which may be some of the present buried channels which now form the "deep leads." It has also been suggested that when uplift took place warping of the plateau surface occurred, and that probably a number of deformation basins or sunklands were formed which would act as receptacles for the drainage of their surrounding respective areas. Subsequently to the great uplift a change of climate from a moist to a dry one took place, and the present land forms are largely due to the forces that have been operating since that change, with the result that such land forms are different from those which would have been produced under a normal climate.

It must also be remembered that hills and ridges—residuals of the cycle of erosion which formed the old plateau as a peneplain—of hard rocks, such as greenstones and "jaspers," rise well above (in some instances for hundreds of feet) the old plateau, and also that such plateau over wide areas was covered by a hard lateritic cap, beneath which the rocks were apparently, as now, much decomposed for a moderate depth. The lateritic cap and the decomposed rocks beneath have, in combination, had a profound influence on the shapes of the resulting land forms.

Whatever the exact nature of the surface of the old plateau was after uplift, we may feel sure that it was not a dead level, and that consequently erosion by rain and streams could and did take place, and that even if portions of the drainage were able to reach the sea for a time, yet when the arid change came, practically the whole of the drainage became internal.

THE VALLEYS.

These may be divided into four types.

(*a*) *Short V-shaped Valleys.*

These are eroded by the action of rain in many of the rounded or sharply cut hills and ridges which rise above the general level of the country, and which are usually monadnocks on the old plateau. The rocks are greenstones, hematite-quartz rocks and others of metamorphic origin, which are resistant to erosion, and which in consequence occupy their present elevated positions. The valleys are short, partly on account of the comparatively small areas originally occupied by the harder rocks, and partly by reason of the fact that these higher belts are now in process of removal by lateral planation.

The erosion of these valleys may be described as quite normal.

(*b*) *Short U-shaped Canyons.*

These are cut in the laterite-capped surface of the old plateau, the cap being a few feet thick, with usually decomposed rocks below. Since temporary base-level, which, however, is many hundreds of feet above sea-level, is soon reached, the canyons are of necessarily little depth (perhaps about 50 feet on the average). The typical narrow canyon is usually short, not exceeding 200 or 300 yards. This shortness is chiefly due to the fact that the tablelands or mesas (as in the case of the greenstones and other rocks in which the V-shaped valleys above described occur) are being planed away by lateral erosion, as will be later described. The cliffs surrounding the mesa may be receding as fast as the canyons are growing by headward erosion, and perhaps in some instances faster.

The canyons end on the elevated plain at the foot of the mesas, and it is this plain which constitutes the new plateau.

Rain is the chief agent in the formation of the canyons. The rain tends to coalesce above the heads of the canyons into shallow channels that are often mere furrows, which form "hanging valleys" in the tablelands, and the water passes from the latter into the canyons as waterfalls or cascades, by this means undermining the hard caps, which subsequently collapse. In that way headward erosion proceeds. On account of the low rainfall, the waterfalls and canyons are usually "dry" except for very brief periods after the infrequent rains. Hence these "dry" waterfalls and canyons correspond with the "dry" lakes of the country. A canyon, however, is not always connected at its head with the surface of the old plateau by a steep rise, the slope often being quite gradual.

Some canyons are formed without any perceptible stream or stream channel in the old plateau above their heads. The process of their formation is then akin to that which produces the cliffs or "breakaways" bounding the tableland or mesa, and the type of valley now to be described.

(*c*) *Broad flat-bottomed Valleys with steep Sides.*

These exist in some areas as the result of the lengthening and widening of the canyons of the hard-capped old plateau or its mesas. The sides of the valleys are steep and they form typical "breakaways." The change from the canyon to the wide valley is not due to the occasional very small streams which may have chiefly caused the canyon; for such stream has practically no power of lateral erosion, as is shown by the facts that there is no meander system, and that there are practically no spurs.

The widening is caused chiefly by the action of the rain on the decomposed rocks of the cliff face beneath the hard cap, which is

thereby undermined and collapses; and by the action of the wind and of the rain in removing the detritus from the foot of the cliff. As the cliff recedes a rock plane is formed at its base. This plane frequently has a gentle downward slope from the base of the cliff, but in places the plane appears practically horizontal over small areas.

As the cliffs recede the canyon becomes transformed into a wide gently undulating plain broken only by flat-topped residuals (buttes or mesas of the original old plateau) and traversed in places by faint drainage lines. The plain formed in this way is part of the new plateau. (See figs. 47-50.)

A related type of valley to the last mentioned may also be observed where the higher country does not possess a distinctively hard cap, but where some rocks are harder than others. These factors sometimes result in a wide flat-bottomed valley with steep ridges of hard rock—usually greenstone—bounding its sides.

(*d*) *Valleys "born mature."*

The next type of valley is one which in a normal climate would be classed as very old, but which in the area under review (to use W. M. Davis's expression) has been "born mature," that is to say, that it has apparently from its inception never had the features of immaturity. Such a valley is very wide; has long very gently sloping sides, which from some points of view are hardly appreciable; is flat-bottomed at the middle, with irregular channels usually not more than four to six feet deep, and often "braided"; possesses no spurs; has, as a rule, hardly any incised channels on the valley sides; and has no meander system developed within it. The rocks forming the valley sides have no hard caps. If such caps ever existed, they have been removed long since.

The mode of development is evidently due to the fact that vertical stream corrasion has been so slow that the sides of the valley, under the influence of ordinary weathering and disintegration, with the removal of the waste by rain and wind, have been cut down almost as fast. As temporary base-level is reached, the valley sides become of greater width and of decreasing slope, until ultimately a gently undulating plain is formed traversed by a small drainage channel. A number of valleys so created and reaching approximately the same stage at a considerable height above sea-level, as in parts of Salinaland, would thus form a plateau with faint and, in places, almost indistinguishable drainage lines, in which stream corrasion is of a very slight character or practically negligible. Corrasion may ultimately cease and deposition take its place, which will result in raising the height of the valley floor and in a further levelling of the country, by means of which the valleys may lose their identity.

The same result is reached by the development of the wide flat-bottomed valleys with steep sides, described above under the third type of valley.

If there are old valleys or deformation basins partly or wholly filled with detritus, the floors of the newer valleys may, in part, correspond with the detrital surface of the buried valleys or basins.

It is along some of the wide shallow valleys described above that the salt or "dry" lakes occur, and as explained in Part X., the sides of the valleys may be cut into by lateral erosion during the process of lake formation or migration.

It is not intended to convey the idea that all valleys of Salinaland have originated wholly since the change to aridity took place. Some may have been commenced under conditions of normal erosion, but their present stages (except those of the first type of valley described) are essentially due to arid erosion.

THE NEW PLATEAU.

The mode of formation of this plateau has been indicated in the above descriptions of the various types of valleys. Briefly stated, the plateau has resulted from the rapid attainment of a temporary high-level base-level of erosion, by stream action and from the widening and practically the union of the valleys at that level, combined probably with the filling of deformation basins and valleys existing prior to the change to aridity.

The processes which have brought about this result are still at work, so that the new plateau is ever widening. The ultimate result, if no interruption occur, will apparently be a high-level, practically rock-floored plain, surrounded by a few residuals composed of rocks highly resistant to erosion. Deformation, or the encroachments of exterior drainage, may, however, prevent this. The new plateau apparently forms, therefore, a striking example of Passarge's great generalization as to the production of plains of erosion much above what may be termed normal base-level (that is, approximately close to sea-level), or, in other words, of levelling without base-levelling.

The transition from the old to the new plateau is in places very gradual, but in many localities it is abrupt, the connection being by means of the cliffs which form the "breakaways," or of the steep sides of hills of greenstone or other hard rock.

The evolution of the new plateau is certainly far advanced, but to what extent its formation is due to the erosive agents working since the change to the present arid climate, and to what extent to those working prior to that change is not at present known.

A point that may be referred to here is the apparent concurrent erosion of the surfaces of the old and new plateaux. There is little doubt that the surface of the old plateau, which, of course, is subject to disintegration by insolation and the chemical action of rain, is being

lowered by the rain and the wind; and, as shown in Part XII., the "exportation" of fine detritus by the wind from the surface of the new

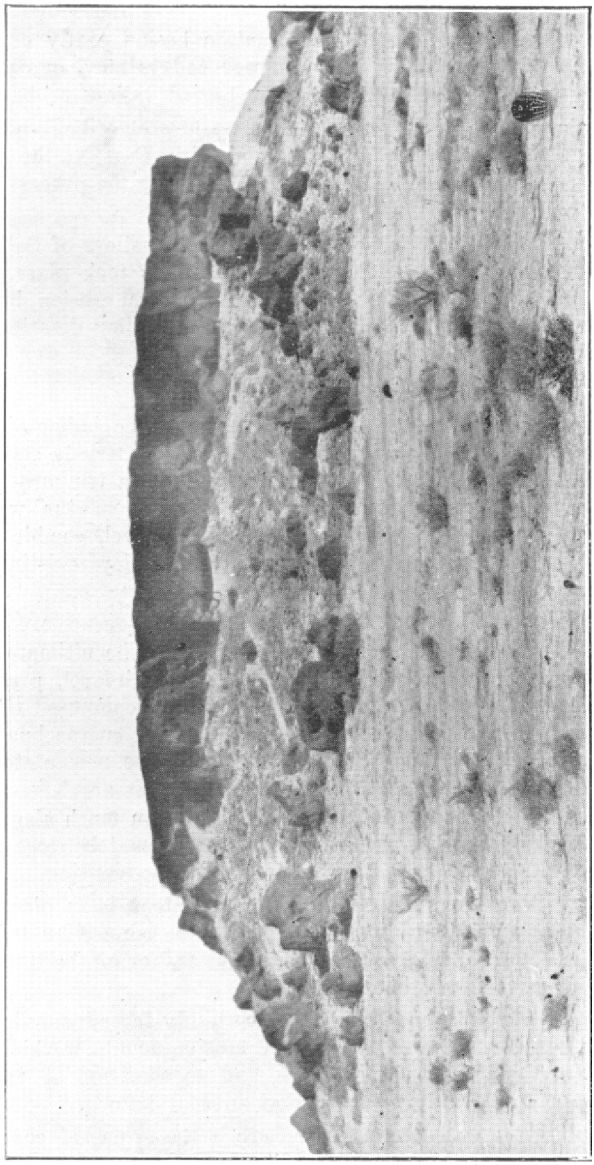


Fig. 93.—Flat-topped hill of granite. Cue, Salinaland. A residual of the old plateau. Beneath the lateritic cap the granite is much decomposed. Note the blocks fallen away from the cap.

plateau, will lower the latter, even if it be assumed that no detritus is being removed by stream action to the sea which, however, is improbable.

CLIFFS ("BREAKAWAYS") AND ASSOCIATED FORMS.

The steep cliffs (locally termed "breakaways," which is a useful term to indicate a particular type of cliff in the interior of Western Australia), in many places connect the old and new plateaux and constitute a remarkable set of phenomena. They therefore well merit a description somewhat in detail.

The cliffs vary from about 30 feet to 100 feet or more, but average perhaps about 50 feet, in height.

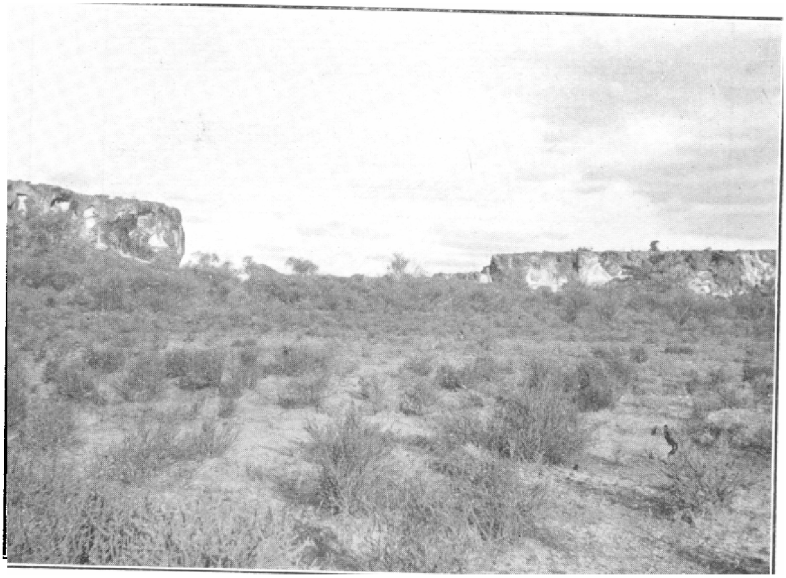


Fig. 94.—"Hell's Gates," Sandstone district, Salinaland, showing two lines of vertical cliffs ("breakaways") of decomposed granite, the tops of which form part of the old plateau.

The component rocks are shales, sandstones, conglomerates, schists, gneisses, greenstones and granites. The latter predominate in most places, but the other rocks, except the greenstones, are fairly common. The rocks are usually considerably decomposed, but they are protected by a hard lateritic cap, which may be mainly ferruginous or siliceous, according to the nature of the underlying rocks. The toughness of the cap and the easily eroded material beneath, offer almost ideal conditions for cliff formation. (See figs 93-95.)

The cliffs run in sinuous lines with indentations and tongue-like projections. The latter are the "Zungenberge" of Walther (*b*, 20). Small masses—buttes—separated from the main area, also occur. The

indentations comprise short canyons either straight or curving, with gradually decreasing width headwards; short bottle-necked steep-sided canyons (fig. 96); and wide-mouthed open "bays," the sides of which may be either steep or of moderate slope, but usually approach the latter.

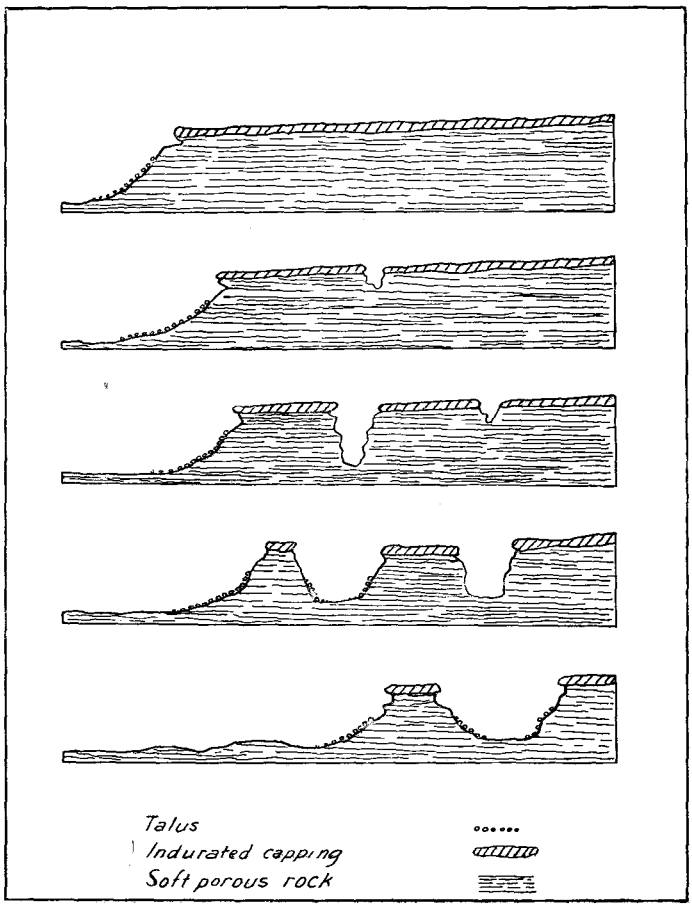


Fig. 95.—Diagram showing the progressive weathering of a "breakaway" in horizontal sediments. Country between Laverton and Townsend Range. (After Talbot and Clarke, fig. 13, p. 45, Bull. 75.)

The heads of the canyons may be either precipitous walls, or a series of rock steps, narrow horizontally and high vertically, or wide horizontally, and low vertically, these features giving rise, during times of heavy rains, to small waterfalls or cascades, according to the nature

of the rock surface. In dry periods they constitute the "dry" waterfalls and cascades of the semi-arid regions. Hume in his valuable summary of the characters of arid lands refers (370) to the dry waterfalls of the half desert.

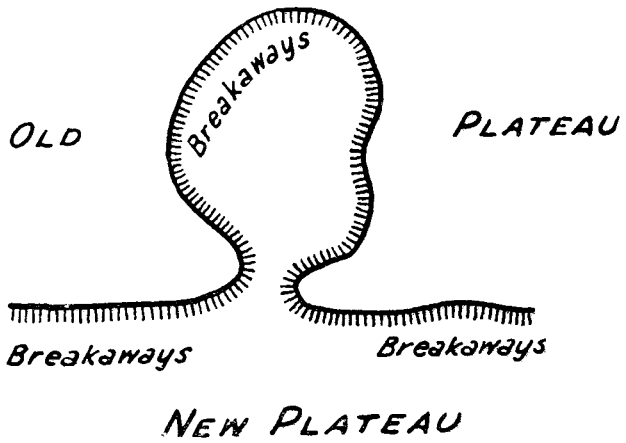


Fig. 96.—Plan of a bottle-necked canyon in the laterite-capped old plateau of Salinaland.

The faces of the cliffs are much diversified. Thus where the hard cap is thin or has been almost entirely removed, the cliff may descend from top to bottom without any distinct hollowing out. Frequently, where a thick cap exists rock hollows extending back horizontally, up to 15 feet or more, may be produced beneath the cap. At weak spots, more or less circular holes are sometimes made, extending from the roof of the rock hollow upwards, or from the surface of the plateau downwards, producing "blowholes." Where buttes or "peninsulas" occur, the gradual narrowing of the crest and the formation of rock hollows on either side may result in "natural bridges," generally not more than two to 15 feet high and a few feet long. Around a butte the formation of rock hollows on all sides produces a falling of huge blocks from the hard cap, which encumber the slopes and disclose clearly the origin of the boulders. Similarly along many lines of cliffs, the breaking off of these blocks may be seen in all stages from the first crack to the boulders at the bottom of the cliffs. (See figs. 93 and 97.)

By the processes described, a butte may become smaller and smaller until the whole of the hard cap is removed. When this occurs the decomposed rocks are soon worn away and the butte completely disappears.

Beneath the hard caps, the softer more decomposed rocks forming the cliff face may become more or less covered with thin sheets of talus usually not more than a foot thick, which in places becomes cemented

together by iron, and in consequence acts as a protection to the softer rocks below. Weak spots are, however, generally found, and heavy rains will often furrow the surface, so that in course of time the fur-

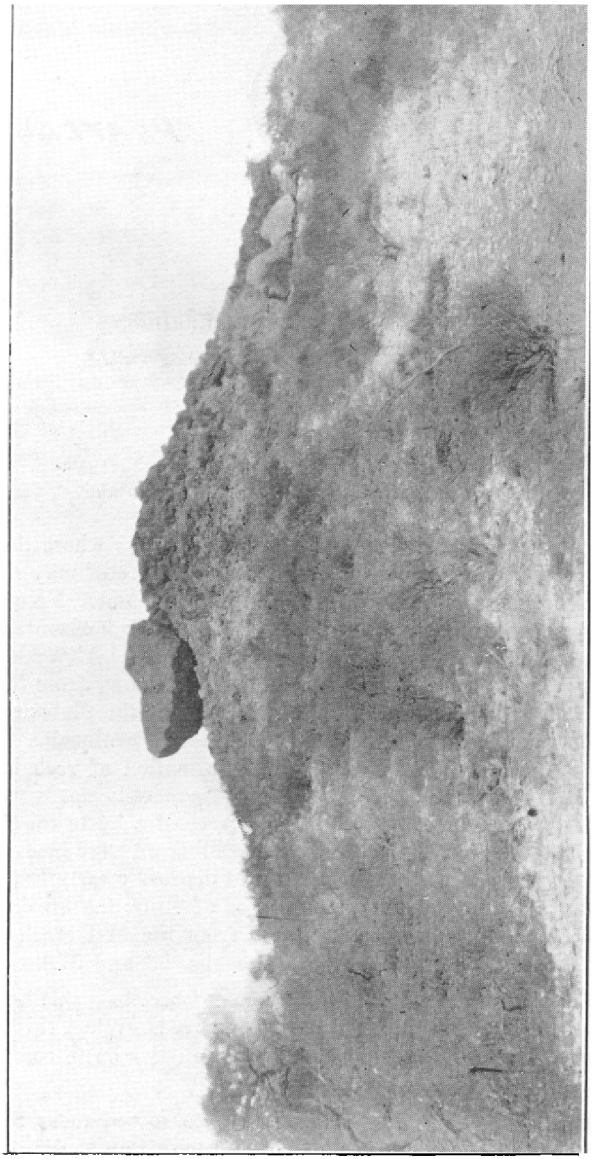


Fig. 97.—Destruction of a butte. The last piece of the lateritic cap has been undermined and overthrown, leaving the soft, decomposed, underlying granite an easy prey to the weather, and the consequent removal of the butte. Cue district, Salinaland.

rows may develop into small gullies with a steep fall, broken in places by small rock steps. In other places, the rain when once it can get

to the softer rocks, will rapidly gouge out hollows of various shapes, which are later described as "natural quarries" on account of their close resemblance to quarries in a hillside.

"Breakaways" tend to form wherever a hard cap exists at the surface, with soft decomposed rocks below. Thus a line of cliffs may indicate the removal of portions of a high level belt of country, commenced

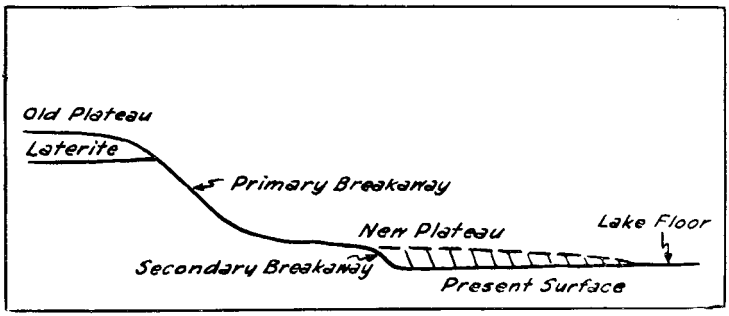


Fig. 98.—Section showing primary and secondary breakaways, with the migration of a "dry" lake floor by recession of the secondary breakaway. (From the Geog. Journ., December, 1917, p. 423, fig. 3.)

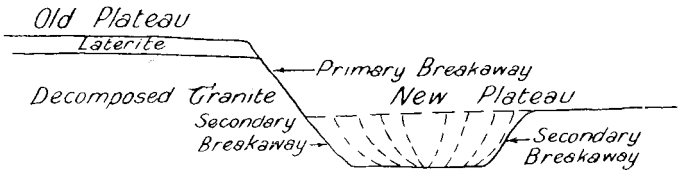


Fig. 99.—Section showing the formation of the new plateau with a primary breakaway; later dissection of the new plateau, with secondary breakaways. (Adapted from the Geog. Journ., December, 1917, p. 422, fig. 2.)

by the formation of a canyon, or the removal of portions of a steady slope, the cliffs in the latter case gradually gaining height as they cut into the slope. A second type may occur in valleys or at the edge of a lake where the ground slopes gently to the lake. In the last mentioned example, the new plateau is being further reduced to bring it to the level of its lowest-lying part (fig. 98). Again, low cliffs may form in a platform that has been produced by the recession of a major cliff. Those low cliffs may be termed "secondary" cliffs or breakaways (figs. 98 and 99). They are due to a revival of erosion to a new local base-level, and to the hardening of the surface of the platform in which they are cut. On a valley side, cementation of a thin band of detritus provides in places sufficient hardness to allow a cliff to form.

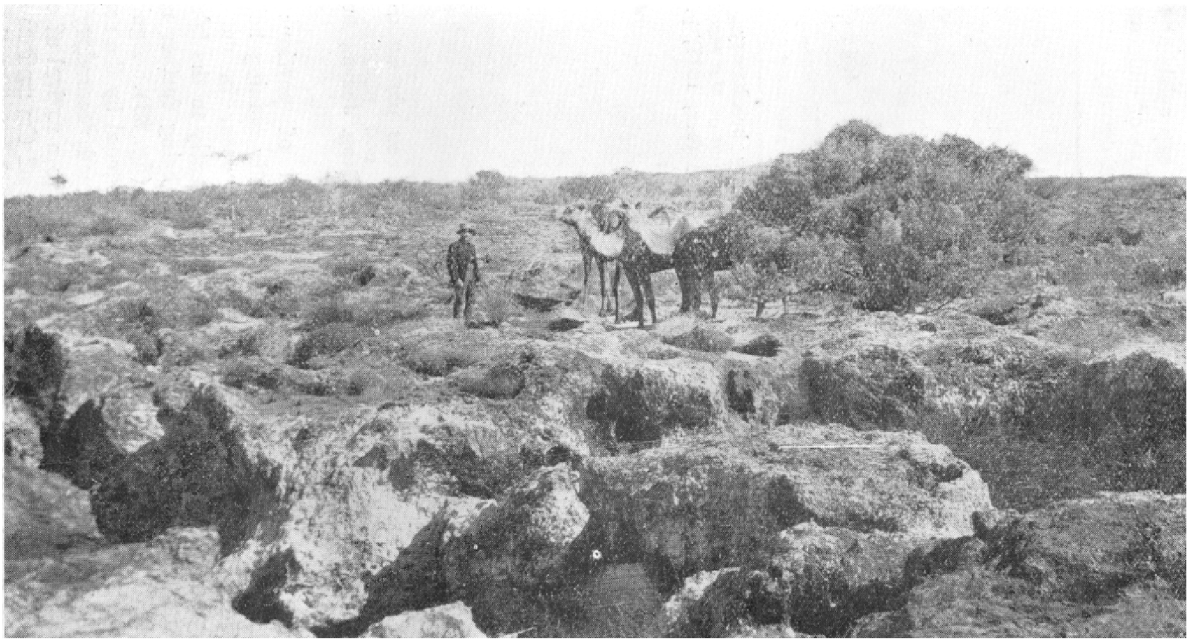


Fig. 100.—Weathered granite of the old plateau, showing the pitted surface that results where the laterite cap is absent. 60 miles E.N.E. from Wiluna, Salinaland.

If the hard cap by any chance becomes removed, the cliff rapidly loses its steepness.

A line of cliffs may bound an area of the plateau on one or more sides, but such area is still attached to the main portion of the plateau. In other instances, the breakaways may entirely isolate a fairly large belt from the plateau, so as to form a mesa.

In the granite portion of the old plateau, it may be noticed that, so long as the lateritic cap persists, the surface of the plateau or of a mesa remains fairly level. When, however, the cap is removed, the surface becomes most uneven by the formation of large irregularly shaped depressions, often with sharp edges, which make travelling difficult and tedious (fig. 100). This indicates that the rocks below the cap have either not been entirely decomposed, or that since decomposition an irregular surface hardening has taken place, either before or since the lateritic cap was removed.

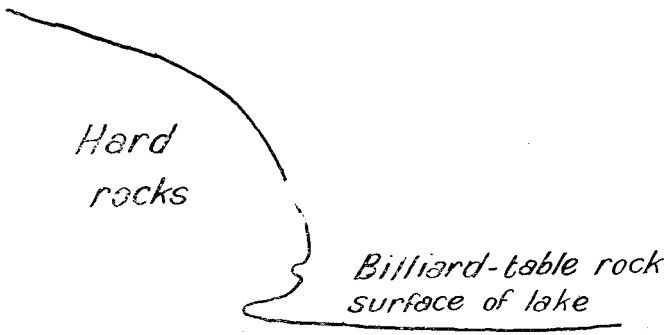


Fig. 101.—Section of a lake cliff of hard rock (granite or greenstone) with a rock hollow or shelter (salt lake type). (From the Geog. Journ., December, 1917, p. 425, fig. 7.)

The above description applies to cliffs with a hard cap and more or less decomposed rocks beneath, whether bordering lakes or not. But when the rocks of high lake cliffs are practically undecomposed with no distinctive surface cap, the cliffs as a rule rise sharply to a height of 40 or 50 feet, and then recede at fairly high angles to the horizontal. They may be considerably undermined at their base. (See fig. 101.)

Other writers have described and discussed the mode of formation of "breakaways," the chief of whom are Woodward (*q*, 20-24, 56-57, granite), Talbot and Clarke (*a*, 43-59, horizontal sediments), and Montgomery (*l*, 71-74).

CHAPTER II.

THE MINOR LAND FORMS.

CONTENTS.

Rock Hollows or Shelters. (a) The "Breakaway" Type. (b) The Salt Lake Type. Natural Bridges. Natural Quarries. Miniature Soil Terraces. "Stone Fields" and "Desert Pavements." Clay-pans.

Rock-holes and gnamma holes are minor land forms, but they are described and their origin is discussed in Chapter III. of Part XV., so that no further reference is made to them here.

ROCK HOLLOWS OR SHELTERS.

The term rock hollow or rock shelter as here used, is intended to mean a cavity some feet in length, height and breadth, which penetrates more or less horizontally a cliff face. The inner wall is not far enough away, as a rule, from the cliff face for the hollow to be called a cave, to which, however, it approximates. Rock hollows may be divided into two groups, which may be referred to as the "breakaway type," and the "salt lake type."

(*a*) *The "Breakaway" Type.*

This type is characteristic of "breakaways" and is a common feature in Salinaland. The hollows are formed immediately beneath the hard lateritic cap by the removal of the much softer decomposed rock. They pass inwards for 15 feet or more, but naturally vary in measurement in that direction. They may be a few feet in length or may run continuously along the face of the cliffs for several yards, and in height they vary perhaps from two to six feet. (See figs. 102 and 103.)

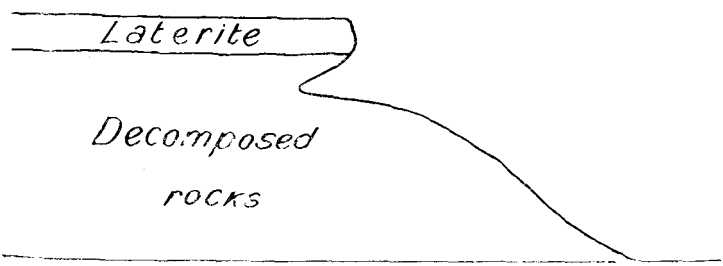


Fig. 102.—Section showing a rock hollow or shelter (breakaway type) beneath a lateritic cap. (From the Geog. Journ., December, 1917, p. 425, fig. 6.)

The soft rocks underlying the hard cap are at first disintegrated by insolation and by rain, but as the hollow develops, the rain, even though wind-driven, cannot directly reach the inner rock surface, and so the direct beating action of rain ceases.

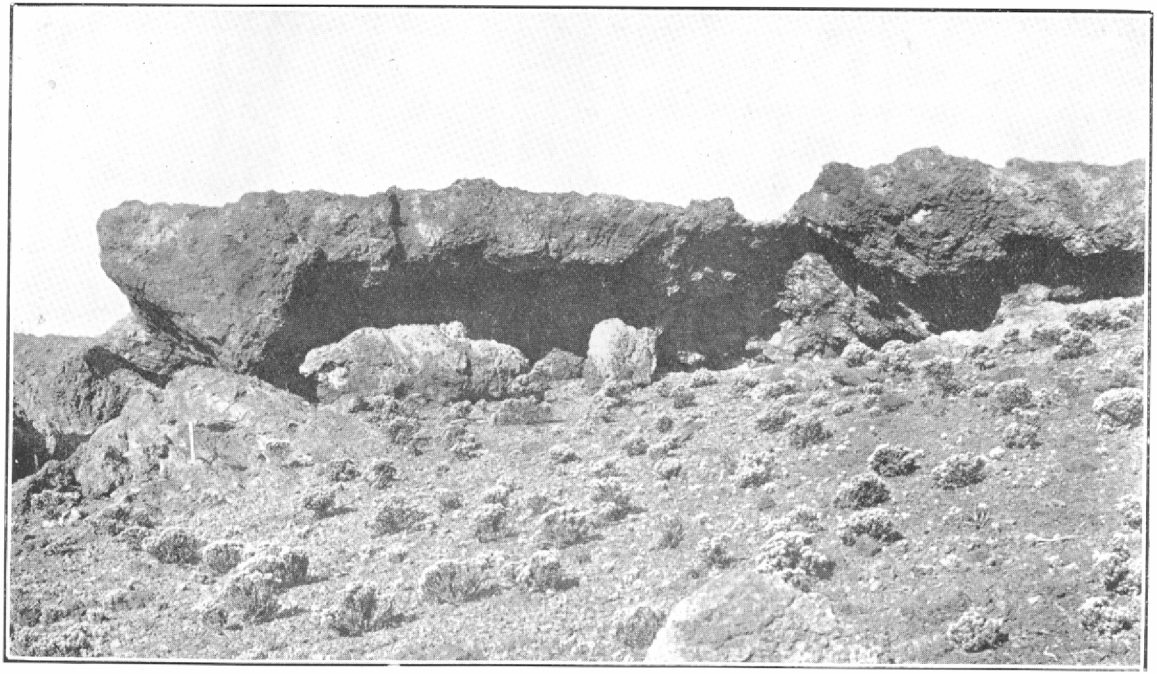


Fig. 103.—Laterite, showing the hollowing out of the decomposed rock beneath, thus forming a rock hollow or shelter. Ora Banda, 40 miles north-west of Kalgoorlie, Salinaland.

The rain may, however, act in two other ways. First, if, as happens in places, there are cracks in the surface cap or the latter is not entirely impervious, the rain will pass downwards through the cap, and tend to weaken further and then to remove the softer rock on the walls and roof of the hollow. If in sufficient quantity, it will also form tiny streamlets on the floor and carry away portions of the fine detritus. Secondly, the rain may possibly act in the way described by Kirk Bryan (*b*, 3 6) in regard to pedestal rocks, by the formation of a "drip curtain," which is due to the rain gradually working its way from the outside as a film along the roof of the hollow and then forming a curtain of falling drops or "drip curtain." The dropping of the water disintegrates the soft rock of the floor; tiny rivulets form and carry the fine material away. The film of water probably also extends beyond the drip curtain and further weakens the rock. Insolation no doubt also plays its part in the scaling off within the hollow of minute particles, which form the "meal of disintegration" (see Talbot & Clarke, *a*, 56 and 57, and Whitman Cross), and which are doubtless partly removed by the rain in the manner described above, and also partly by the wind, which would have free play under the conditions described. As the sun's rays gradually are excluded, the work of insolation may become very weak, if not practically negligible.

Aboriginal man and animals also assist in the work of erosion, as they take shelter in the hollows, and by their movements must loosen, pulverise and remove some of the material.

Again, there is reason to suspect that water charged with salts is brought to the surface of the floors and walls of the hollows by capillarity. The water evaporates, and crystallisation may take place, causing a breaking down of the rock surface, and so assisting in the decay of the rock.

Thus the formation of the simple-looking rock hollow is really a complex process, and it forms a striking instance of the inter-play of the various forces of Nature.

Some rock hollows are merely excavations beneath the laterite cap, where the vertical height of the hollow is much greater than its horizontal length inwards. It would be more correct to describe such instances as overhanging cliffs.

Associated with the rock hollows are "blowholes," which are more or less circular openings in the laterite cap, passing downwards from the surface of the cap to the roof of the rock hollow. They probably represent lines or areas of weakness along which the erosive forces have worked with ease. Where the hole has not reached the roof of the rock hollow, it may contain water and thus form a rock-hole. In other cases, debris may drift into and fill up the hole, which may be subsequently exposed in section by the cutting back of the laterite cap.

(*b*) *The Salt Lake Type.*

This type (fig. 101) is usually only to be found to a height of about four feet from the base of rocky cliffs at the edge of a salt lake, the rocks generally being greenstones so far as noticed. The hollows or irregular caves vary, both in breadth and height, from a foot or two to several feet, but their floors are not always coincident with the lake floors, although they frequently are so. The hollows in places increase in height away from the cliff face, that is the roofs become more dome-like. This doming is helped by the tendency to form resistant films on the cliff face.

The undermining may be more or less continuous for some yards; and where strong vertical joints or other division planes occur, a roughly rectangular outline may be given to the part attacked.

The roof, sides, and floors may be damp, and the roofs and sides have a very scaly appearance owing to innumerable thin rock flakes (of from one-half to two inches in length and breadth, and usually from one-eighth to one-quarter of an inch in thickness) being shed from the parent rock. On account of their thinness and of their decay during the process of splitting off, these flakes can usually be broken by the fingers.

The writer has suggested (*e*, 167) that the flaking is chiefly due to the force exercised by the crystallization of salts (of which the chief is common salt) brought to the surface of the rocks in solution by capillarity, the underground water of the salt lakes being intensely salt.

Meteoric water percolating from the surface downwards must assist the process by acting as a solvent, thereby weakening the rocks. That water also, by passing down joint planes and dripping on to the floors of the hollows, helps to enlarge such hollows, one mode of enlargement that has been noticed being the scooping out of small lens-shaped hollows in uneven floors along joints.

Insolation no doubt helps in the early stages, but as the hollow is enlarged the sun's rays never reach its sides and roofs, and it is difficult to say what effect (if any) insolation has under those conditions. For similar reasons the direct beating action of rain must be excluded, and the wind must take little part in the actual wearing away of the rock.

The rock flakes further break up on the floor of the caves and in time the debris is removed, mainly, the writer believes, by deflation, assisted, however, by the meteoric water which finds its way downwards into the hollow, and which must help to bring the detritus from the hollow to the lake floor. For further details, the paper (*e*) on the subject by the writer may be consulted.

These have been referred to in describing the "breakaways." They result from the denudation of the "peninsulas" and buttes of the old



Fig. 104.—London Bridge, a natural bridge in lateritic deposits, about 2 miles south-east of Sandstone, Salinaland.

plateau which have a hard lateritic cap and decomposed rocks beneath. The cap is undermined on opposite sides, and if the process be con-

tinued long enough a hole of varying size beneath the cap is formed, and so a natural bridge will be constructed (fig. 104). Natural bridges in Salinaland are only found under the conditions mentioned, so far as the writer is aware.

NATURAL QUARRIES.

On some cliff faces and hillsides, excavations are found which have a close resemblance to quarries, but they are clearly due to natural agents. The writer has, therefore, termed these excavations "natural quarries." Their outline on the surface slope may be circular, rect-

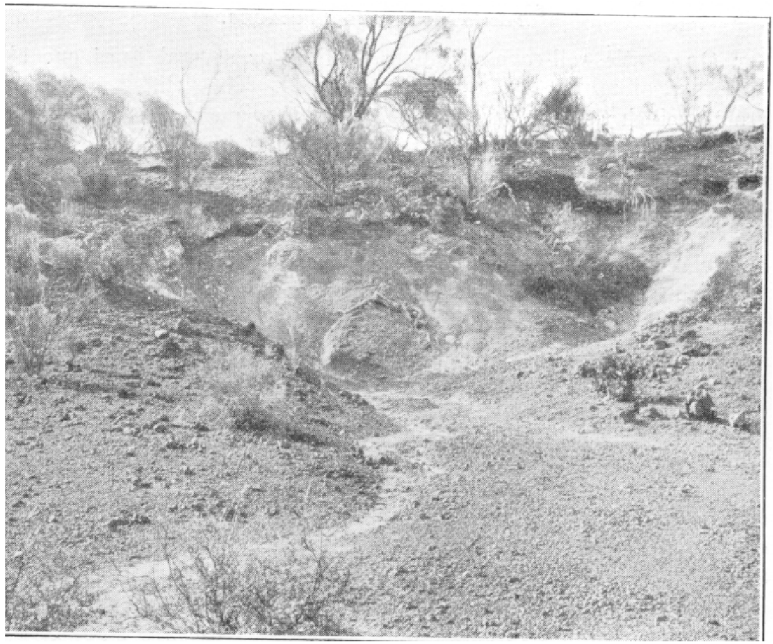


Fig. 105.—A circular "natural quarry," Niagara, Salinaland.

angular, or triangular. Other shapes doubtless occur, but those just mentioned have been the only ones noted by the writer. There is, moreover, a certain amount of transition between the different forms.

The circular quarries (fig. 105) range in diameter from a few feet to perhaps 40 or 50 feet, and in depth from a foot or two to five or six feet. They are generally shallow in proportion to their surface area. The rectangular quarries are usually small, the average dimensions being about eight to 10 feet high, six to eight feet broad, and 10 to 12 feet long, although some greatly exceed those measurements. The triangular quarries range from 10 to 15 feet in all dimensions, to a large quarry having a "back" perhaps 100 feet in length, measured horizontally along the top.

The rocks in which the quarries form are mostly decomposed and are of various kinds. They are usually associated with harder bands in the form of caps, surface covers, or more or less vertical abuttals.

The formation of the natural quarries is chiefly due to the mechanical gouging or undermining action of rain under certain special conditions.

For a detailed account of these interesting minor features, reference may be made to the paper thereon by the author (*d*).

MINIATURE SOIL-TERRACES.

On gentle soil-covered slopes, a line, or several lines one above the other, of minute cliffs may be observed. The "cliffs" may be only from an inch to six inches in height, but they may extend laterally for many yards. They are composed of soil, the surface film of which is of slightly firmer material than that below. This is doubtless due to the precipitation of minute quantities of salts brought to the surface by capillarity. This surface hardening tends to resist erosion by the thin sheets or rills of rain water which pass over the surface without furrowing it, especially when the soil is a sandy loam. When the surface film becomes broken, the underlying softer material is quickly removed by the rain, and miniature waterfalls are formed which in turn produce the miniature cliffs described, above which the ground forms a miniature "soil terrace."

The actual edge of a terrace is gently curving and each curve presents a minutely crenulated edge. This appearance suggests some force that has gently clawed away the soil, and as the rain is the agent of erosion, its action has been termed by the writer the "clawing" action of rain (*i*). Tiny furrows may run from the "clawed" edges, indicating the directions of the minute rills. The furrows, however, unite within a few feet of the terrace, and within a few more feet they die out, and as they do so the transported soil is spread fairly evenly over the ground. By this "clawing" action of the rain the transportation of the soil towards the lowest ground is helped.

Rock fragments on the slope may be undermined by the formation of the "cliffs," with the result that such fragments topple forward, and in this way their migration down the slope is largely accomplished.

"STONE FIELDS" AND "DESERT PAVEMENTS."

One of the most striking features in sub-arid Western Australia is the widespread stony detritus on the surface of the ground. The areas covered by this detritus may be divided into "Stone Fields" and "Desert Pavements," of which the former are much more common than the latter.

(*a*) *Stone Fields.*

The component rocks of stone fields are chiefly quartz, ironstone, and jasperoid rocks, with hard greenstones in very limited areas. Owing to its whiteness quartz is the most conspicuous detrital rock, and where numerous quartz lodes outcrop the glare from the littered surface is trying to the eyes.

The rock debris can be traced down the slopes of hills and ridges far out on to the plains, in fragments varying in size from large boulders to small pebbles.

They are split by insolation and remain angular, but become smaller as they travel from the parent rock. They topple forward as the rocks fracture and as they are undermined by the removal of fine soil by the rain and by the wind. This gravitational transport must be very slow; but the fragments travel considerable distances, as the rocks mentioned are resistant to erosion. Other rocks decay rapidly; hence their absence. The wind and the rain remove the soil that becomes mixed with the rocks, and the characteristic stone fields result. In one locality the writer noticed that the gravitational drift of quartz debris was in parallel lines (*o*). (See fig. 106.)

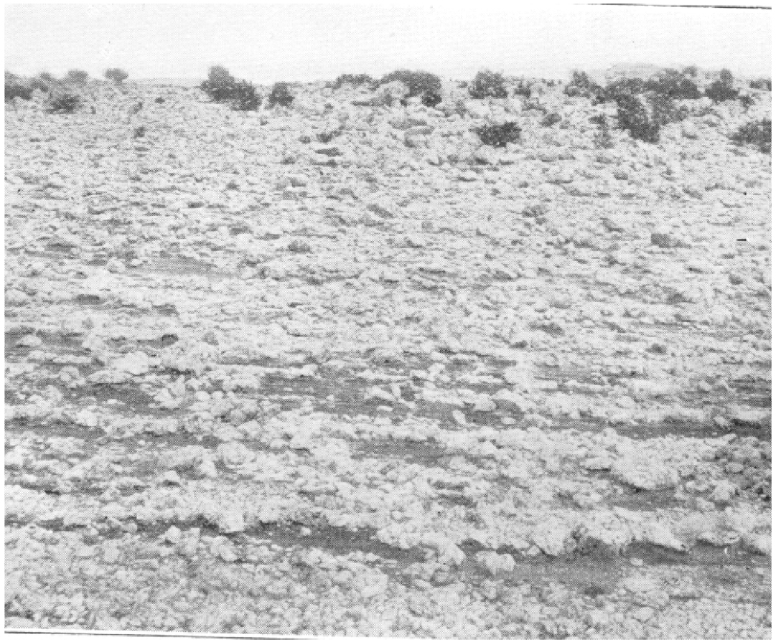


Fig. 106.—A "stone field" of quartz, showing the fragments arranged in roughly parallel lines. Lake Goongarrie, Salinaland.

(*b*) *Desert Pavements.*

These are formed of angular pieces of white quartz so arranged on the surface of the ground as to form a "mosaic." The fragments have been derived from outcropping quartz lodes, and vary in size from about half an inch to one and a half inches. It is difficult to account for the way in which the different fragments have corresponding sides. It appears to result from a "trial and error" method, a space being filled only when a fragment of the right dimensions and shape topples forward. This, however, appears to be incredible, but the writer has no alternative to offer, which shows the need for investigation of this interesting minor problem.

CLAY-PANS

These are shallow depressions, generally circular in outline, and varying in diameter from a few to several hundred yards (fig. 107). They are floored with clay, and are bare of vegetation. After rain they hold fresh water which, however, soon evaporates.

They appear to form where the conditions, such as even a barrier of blown sand, are suitable for the damming of water and the consequent destruction of the vegetation. Thereafter any deepening that takes place must be due to deflation.



Fig. 107.—Clay-pan, Canning Stock Route, Sandland.

PART XII.—THE AGENTS OF EROSION IN SALINALAND AND THEIR RELATIVE IMPORTANCE.

CHAPTER I.

THE AGENTS AND HOW THEY WORK.

CONTENTS.

Insolation. Frost. Crystallization of Salts. Rain—Chemical Action. Rain—Mechanical Action. (1) The Formation of Canyons. (2) The Formation of wide flat-floored Valleys. (3) The Destruction of Cliffs ("Breakaways"). (4) Transportation of Detritus along gentle Slopes. (5) The "Clawing" Action of Rain. (6) Formation of Rounded Pebbles by the direct Beating Action of Rain. (7) Sheet-Flows or Sheet-Floods. (a) The Rill Type. (b) The Smooth-bottomed Valley Type. (c) The Furrowed-floor Type. Wind. (1) Corrasion. (2) Deflation. (a) The Movement of Sand and the Formation of Sand Ridges and Sand Plains. (b) The Movement of Dust including Dust whirls. (c) "Exportation of Detritus."

The agents of erosion and their relative powers are controlled largely by climate, which has already been described and need not be further systematically referred to.

The land forms of a country are, of course, the result of the work of the various erosional forces, which, however, are in turn influenced by the geological structure and lithological characters of the surface rocks, the effect of which are briefly indicated in Parts V. and XVI.

With the exception of the wind and of the crystallization of salts at the surface of the rocks, the agents of erosion in Salinaland are the same in kind, although different in degree, as those of a normal climate. Insolation and frost are examples.

The wind as an eroding agent is practically negligible in fairly moist countries, and no effects of salt crystallisation have been recorded in such countries, so far as the writer is aware.

In this chapter the parts played by these various agents in moulding the surface of the country will be briefly described.

INSOLATION.

Insolation plays a prominent part in the breaking down of the rocks, although over the flat ground exposures are not numerous. Where, however, hills or cliffs occur, the surface is but little protected

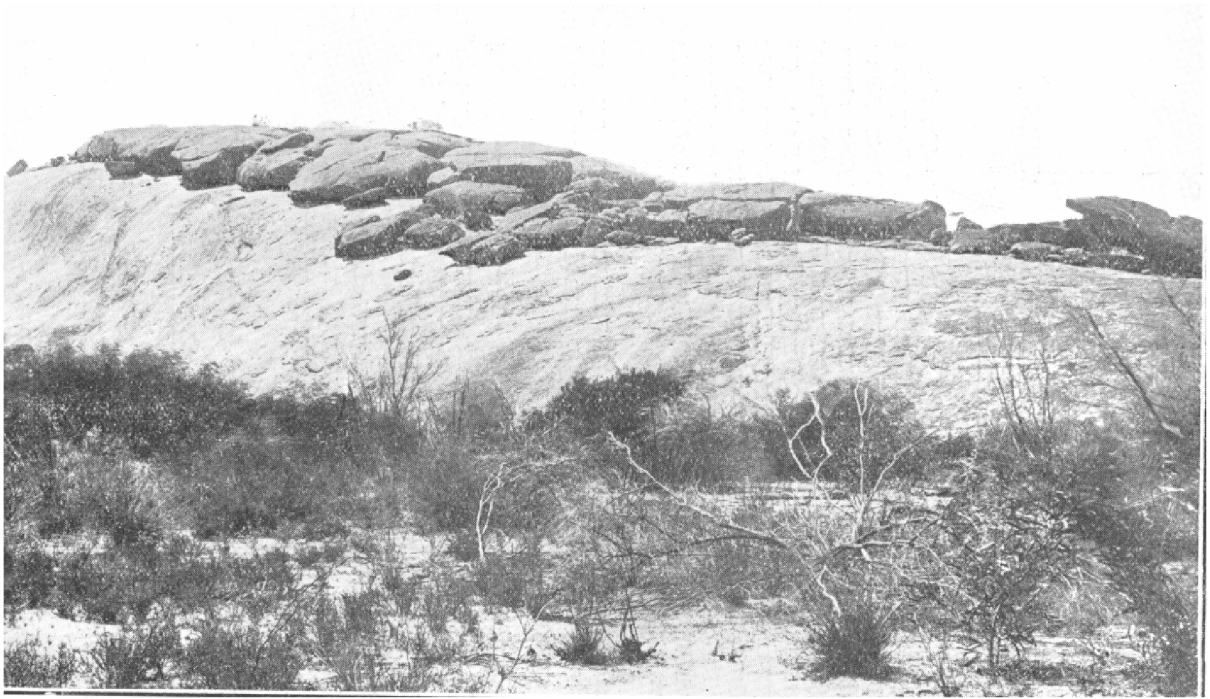


Fig.—108.—Weathering of granite. Yorkrakine, Yilgarn district, Salinaland. Exfoliation, combined with block weathering, is well illustrated.

by vegetation from the sun's heat, to which in summer the rocks are exposed day after day often at a high temperature, which may fall rapidly in the evening. The conditions for the shattering of the rocks are, therefore, ideal, and the effect of insolation may be seen in the waste from the laterite which caps the cliffs connecting the old and new

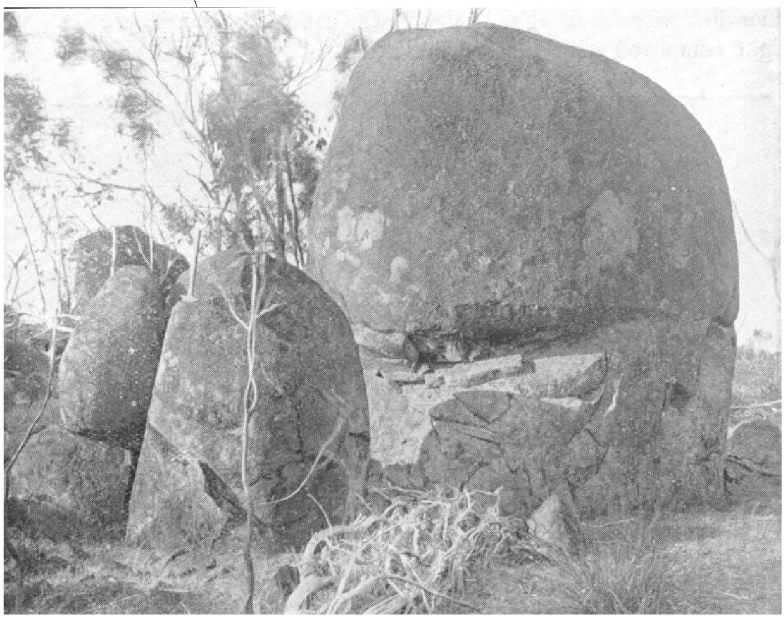


Fig. 109.—Weathering of coarse-grained greenstone, Yulgering district, north-east of Perth, Swanland.

plateaux. Over fairly extensive areas the ground may be littered with gleaming white quartz from the high quartz "blows" which are such a feature in many parts.

On granite knolls the effect of insolation may be seen in the huge split blocks of the rock (fig. 108). On coarse-grained greenstone hills similar, but much smaller blocks of the greenstone may occur (fig. 109). On hills of fine-grained greenstone, insolation has split the rock into thousands of small angular fragments up to about 4 inches in size.

These examples will suffice to show the potency of insolation, although in places it is not easy to determine whether insolation or frost has caused the shattering of the rock.

A striking example of rock expansion by temperature variation has been recorded by the writer (*j*.) (See fig. 110.)

FROST.

The night temperatures in winter are at times low enough to permit the freezing of water contained in joints or other cracks in the rock, and hence to aid in their destruction. It may be doubted though whether there is sufficient water available to cause frost to act much as a disintegrator of the rocks, and the action of frost is probably very light compared with that of insolation.

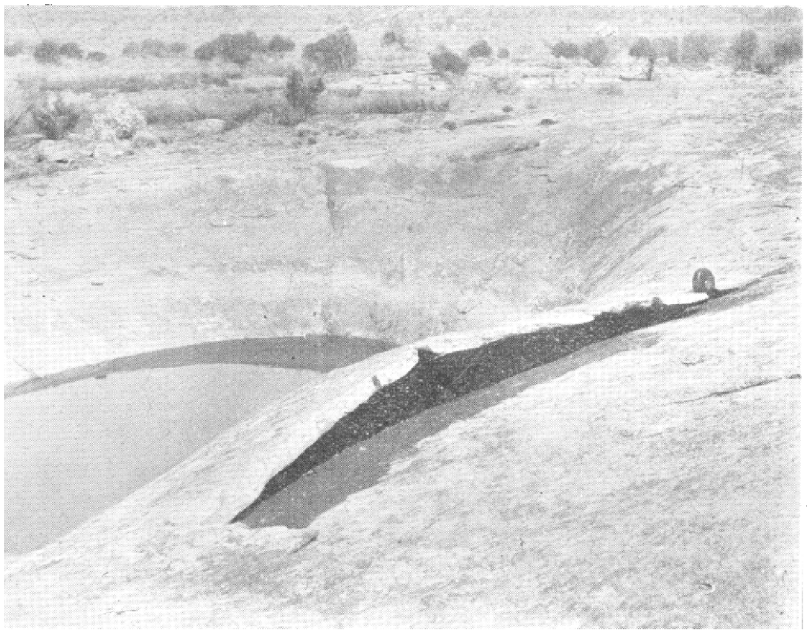


Fig. 110.—A striking example of the expansion of a rock (biotite granite) owing to temperature variation. Comet Vale district, Salinaland.

CRYSTALLIZATION OF SALTS.

The writer believes that on the floors and at the foot of the cliffs of the salt lakes, disintegration of rocks takes place owing to the crystallization of salts from solutions which are brought to the surface by capillarity. On the floors fairly soft rocks easily crumble, and at the foot of the cliffs the action is best observable where the rocks are still fairly undecomposed. There the action appears to cause a rapid flaking of the rock which results in an undermining of the cliff at its base. (See figs. 101 and 111.)

It is also suggested that possibly the same action (except that grains rather than flakes of rock are broken away) takes place in the "breakaways" in the soft material immediately below the more or less impervious lateritic cap, and that this action, which may be described

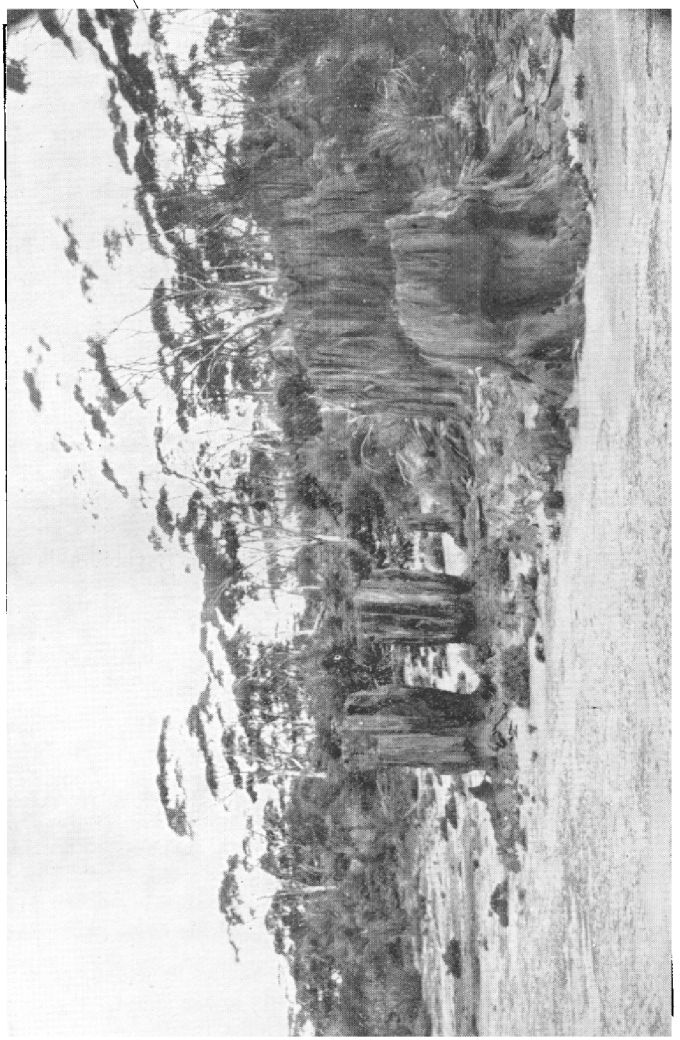


Fig. 111.—Undermining of greenstone, probably due to salt crystallization. Edge of salt lake, Yelladine Road, Yilgarn Goldfield.

as *granulation* in contrast with *flaking*, helps to form the rock hollows beneath the laterite cap which are so commonly associated with the breakaways. (See the section on Rock Hollows or Shelters in Chapter II. of Part XI.)

Reference may be made to the writer's paper (*e*), and to Walther (*b*) for further details, but the whole subject is still somewhat obscure and requires further investigation. The process is also referred to as "exsudation."

RAIN—CHEMICAL ACTION.

The chemical action of rain in Salinaland is very similar to that in more normal climates, that is, it breaks down some minerals of the rocks, and thereby destroys the coherence of the component parts of the rocks. Sands and clays result. It is, therefore, merely necessary to point out that in Salinaland, besides the general weakening of the rocks, the rain in its chemical aspect, largely helps by solution to form the interesting small rock-holes which are known as "gnamma" holes, and which are described in Part XV. Similarly, it causes the shallow pits found in some rocks, examples of which occur at "The Tombstones," Lake Goongarrie, for details of which the reader is referred to a paper by the writer (*r*).

RAIN—MECHANICAL ACTION.

(1) *The Formation of Canyons.*

In its mechanical aspect, the rain carves out the U-shaped canyons of the tablelands and mesas of the old plateau, and the V-shaped valleys in the higher, harder rocks like the fine-grained greenstones and the haematite-quartz rocks, in the course of which it collects into small but entirely ephemeral streams. In these respects, its action is quite similar to that of normal climates.

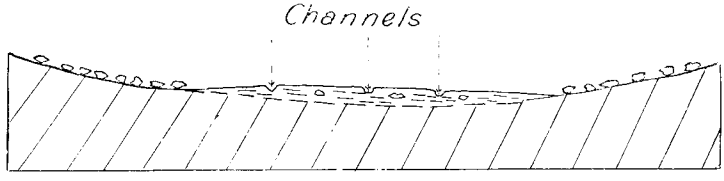


Fig. 112.—Cross section illustrating smooth-bottomed valley type of sheet-flow, Salinaland. (From Amer. Jour. Sc., Vol. XLVIII., December, 1919, p. 438, fig. 1.)

(2) *The formation of Wide Flat-floored Valleys.*

As the U-shaped canyon or other valley begins to widen, or where such a valley passes out from higher to lower land, the small ephemeral stream formed by the rain continues to deepen the valley by a slight furrow, until local base-level is reached, when the stream becomes an agent of deposition instead of erosion. In this way wide valleys tend to become flat-floored and covered with fine detritus, in which may be streaks of angular rock fragments brought down from the higher country by exceptionally heavy rushes of water (fig. 112).

(3) *The Destruction of Cliffs ("Breakaways").*

The bare soft faces of the breakaways beneath the lateritic cap form excellent targets for the rain, with the result that gouging and furrowing take place, and much material is carried to the foot of the cliff and there deposited. The rain is the most potent force in the actual destruction of the cliff face.

(4) *Transportation of Detritus along Gentle Slopes.*

The rain also removes fine material from the rock plane at the foot of the cliff (where the plane, as it frequently does, has a definite fall) and carries it down the gentle slopes towards the lowest-lying portions of the country. Not only from the base of breakaways but everywhere where the slopes of the land are very gentle, the rain is gradually transporting the fine products of disintegration to the lowest portions, although mostly without making any definite channels. The slopes in many places are probably not more than from 2 to 5 degrees from the horizontal, so that the process is very slow. In this way, which may be described as sheet erosion, the rain probably accomplishes more work, although the results are only recognisable on close observation, than in its much more obvious and spectacular character of the maker of canyons and other young valleys.

Although the work of the rain in its gentle transporting action is so important, yet in the writer's opinion it is only as co-worker with the wind that it forms or helps to maintain the low-angled slopes of the type described. This aspect is referred to in Chapter II. of this Part.

(5) *The "Clawing" Action of Rain.*

The work of the rain in its "clawing" action resulting in the formation of miniature soil-terraces, and in assistance to the gravitational drift of rock fragments, is referred to in Part XI., Chapter II.

(6) *The Formation of Rounded Pebbles by the Direct Beating Action of Rain.*

The writer has shown (*k*) that, on the goldfields, rounded pebbles of greenstone, decomposed quartz porphyry, and some soft sediments occur, which have probably been formed chiefly by the direct beating action of rain on the exposed surfaces of the rocks.

(7) *Sheet-Flows or Sheet-Floods.*

The sheet-flood is a well-known phenomenon in arid and semi-arid countries. The classical description is that by McGee, by whom considerable erosive power was attributed to the sheet-flood. In parts of Salinaland, in a wet season, sheet-floods occur, but the writer prefers to use the form "sheet-flows" rather than "sheet-floods," so as to in-

clude in the former all kinds of wide, shallow, moving bodies of water, no matter how gently they may flow. Certain types could hardly be classed as floods, hence the suggested nomenclature.

Sheet-flows in Salinaland are broad, shallow, but not necessarily continuous sheets of water, which traverse the gently-sloping sides and the flat bottoms of wide, open, shallow valleys and the floors of plains. They are divided into three classes, viz.:—The rill type, the smooth-bottomed valley type, and the furrowed-floor type. They appear, on the whole, to be agents of deposition rather than of erosion.

(a) The Rill Type.

This consists of the broad sheets of water which flow down the smooth surface of the long, undissected, gently sloping sides of shallow, wide, open, slowly-corrading valleys. There is no limit to the width of water that may flow, except the length of a valley side, and the area affected by the fall of rain which causes the occurrence. The water is not actually continuous across the line of flow, but the sheet is made up of countless rills of varying width and not separated by more than a few feet. These rills may be merely films of water not more than one inch in depth, or they may reach a depth of perhaps six inches, this variation being due to the very slight inequalities of the ground. The water is so widespread and shallow that even with a moderate slope, and on soil-covered areas, the water usually has no power of cutting even the smallest trench or furrow; the surface of the ground remains quite smooth and unbroken, although the spaces between the small trees and shrubs are commonly bare of vegetation.

The rills of water, however, transport fine detritus to the bottom of the valley in the manner described above under "Transportation of Detritus along Gentle Slopes," which applies to transportation of fine detritus along all kinds of gentle slopes. The detritus is deposited on the bottom of the valley. The rill type, therefore, both transports and deposits, but probably does not directly corrade.

(b) The Smooth-bottomed Valley Type.

This occurs in wide flat-bottomed valleys, possessing fairly well-marked drainage lines along their floors by means of one or more shallow, narrow channels, the drainage often being "braided." The channels occur in wide, smooth, level, soil-covered flats, which consist of detritus (chiefly fine) brought by the water and spread evenly over the floor of the valley (fig. 112).

The water comes from the narrow, comparatively deep valleys of the more hilly country and also from the numerous rills of the type described above. The water overflows the channels in a broad shallow

sheet and its main function outside the channels appears to be neither to corrade nor to transport, but to deposit fine detritus, and thus to widen, raise and smooth the general valley floor.

(c) The Furrowed-floor Type.

This is particularly characteristic of some wide, treeless salt-bush and samphire flats in which there are no definite channels, but in lieu of which a flat may be scored by numerous furrows averaging perhaps 9 inches in depth and 18 to 24 inches in width. The water sweeps and swishes around and among the small shrubs, scouring the detritus out to form furrows, and depositing it around the shrubs until they may be half buried. The furrows must be ever changing as the ever varying small streams gouge out in one place and fill up in another. (See fig. 113.)

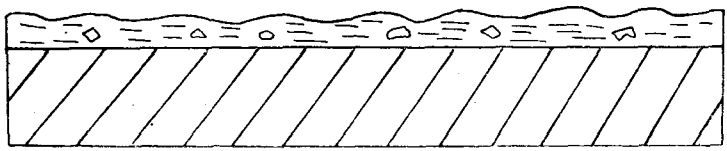


Fig. 113.—Cross section illustrating furrowed-floored type of sheet-flow. Fine detritus, containing occassional pebbles, rests on the bedrock. (From Amer. Jour. Sc., Vol. XLVIII., December, 1919, p. 439, fig. 2.)

The net result of much of the water action seems to be merely the redistribution of the detritus over much of the area, although rock waste must, of course, be brought from the higher portions of the country. Much of the fine waste, however, is doubtless removed by the wind.

For further details of the action of sheet-flows the reader is referred to the writer's paper on the subject (*l*), from which the above condensed account is taken.

In addition to the sheet-flows described above, there may be a sheet-flow on the floor of a salt lake. After heavy rain the small creeks which in places flow into a lake may bring down a fairly large amount of water, which when it enters the lake will spread out into a wide, shallow sheet. Its velocity will be checked but for a time there may be a slow movement, which perhaps will level off the fine detritus as it is deposited from suspension.

The same action doubtless results when a body of water existing on the lake is blown about by the wind.

WIND.

The wind acts in a double capacity, that of corrasion and that of deflation.

(1) *Corrasion.*

The corrading power of the wind in Salinaland has been but little studied. It probably does not operate to any great extent over most of the country, but certain areas appear to have been subjected to wind corrasion. Thus the writer believes that the formation of the "billiard-table" rock-floors of the lakes and the removal of the rocky cliffs which bound the lakes are partly due to the corrasive action of the wind.

In areas other than those occupied by the lakes, similar work is no doubt proceeding, but it may be masked by the work of other agents.

At Lake Goongarrie some of the rocks are rectilinearly grooved in a remarkable manner, the grooves being more or less vertical in many instances. Horizontal grooves and small pits of various kinds also occur. The grooving and pitting are usually limited to a height of about three feet from the surface of the ground, which fact appears to be indicative of wind corrasion. At the same lake, miniature pedestal rocks occur on the floor, but close to the western edge of the lake, and these rocks also suggest wind corrasion. For details the reader is referred to a paper by the present writer (*r*). (See also figs. 114 and 115.)

Rock fragments may be rounded by wind attrition, and small rock fragments have been noticed to be smoothed by the action of the sand-blast, so that they, to a limited extent, resemble the well-known dreikanter of desert countries.

Further observations are required before much can be said about wind corrasion in Salinaland.

(2) *Deflation.*

(a) The Movement of Sand and the Formation of Sand Ridges and of Sand Plains.

The effects of deflation are much more evident than those of corrasion. In Sandland the enormous number of sand ridges attest the great transporting power of the wind. In Salinaland, about the borders of the salt lakes, and in various other localities, sand ridges are fairly common. These ridges consist either of quartz or gypsum grains, the gypsum, where so occurring, being termed "seed gypsum." There can be no doubt that some of this material has been blown from the lake floor, which accounts for the absence or thinness of detritus on some lakes or on portions only of other lakes.

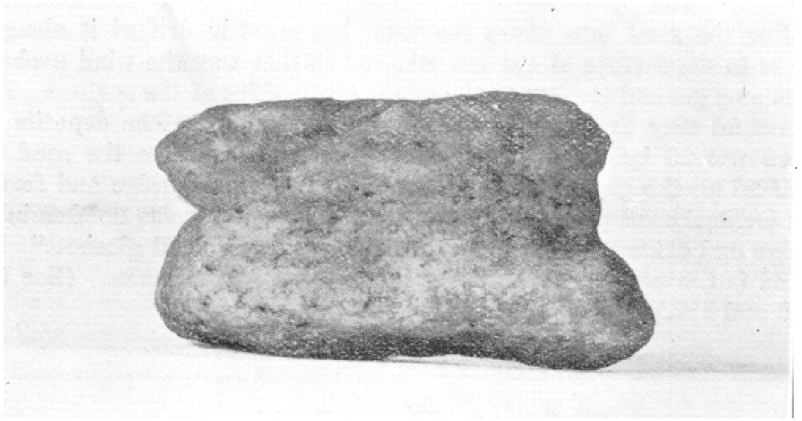


Fig. 114.—Grooved quartz fragment, due to wind corrasion. Western shore of Lake Goongarrie, Salinaland.

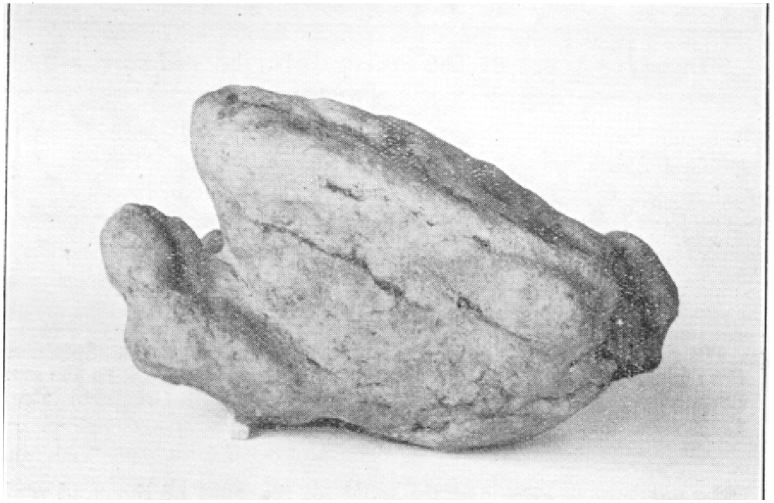
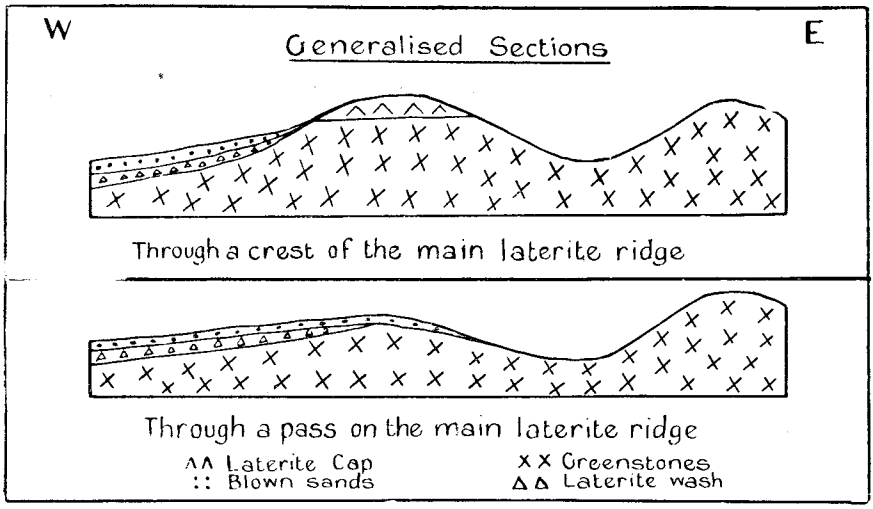


Fig. 115.—Grooved jasperoid rock, due to wind corrasion. Western shore of Lake Goongarrie, Salinaland.

In other instances, the sands may have been blown from other localities to a shore of the lake. The deposition of sand in that way aids in the migration of the lake.

The sand plains are also formed partly by deflation. Instead of piling the sand into dunes the wind has steadily drifted it along or close to the surface of the ground; and in that way the wind probably acts as a general leveller of the minor inequalities of the surface. That the sand may drift uphill and over pre-existing surface deposits has been proved by the writer (*h*) at Comet Vale, where the sand has drifted up the gentle slopes at the foot of a laterite ridge and formed an inclined sand plain. It has also passed through some notches in the ridge and extended down the other side as small "sand glaciers." The wind is the only agent that can bring about such results. (See figs. 116 and 117.)



Figs. 116 and 117.—Generalised sections across the sloping sandplain and the dissected high lands, showing the relation of the sand to the crests (upper figure) and passes (lower figure) of the main (western) laterite ridge at Comet Vale, Salinaland.

The continuous action of the wind on the sand of the sand plains was well shown at Comet Vale on the sloping sand plain referred to above. The country was clothed with a fairly dense growth of mulga scrub, with an abundance of shrubs, but there was nevertheless much exposure of the sand. When rain fell the sand took well-defined impressions of the drops, so that the whole of the sand surface, where bare, became minutely pitted, but no rain furrows were formed, the

rain sinking straight into the sand. Within a couple of days or so after the cessation of the rain, the pits had disappeared. The wind had levelled off the surface again. This was repeated on several occasions, and it proves the great power of the wind acting in an undemonstrative way.

(b) The Movement of Dust, including Dust Whirls.

In addition to the transportation of sand as shown by the sand ridges and sand plains, the finer material is removed as dust by the wind. Almost everywhere there is much bare ground between the various trees and shrubs which constitute the vegetation, and in some areas, such as at the foot of some "breakaways" and on the surfaces of barren tablelands, there is scarcely any vegetation, and on the lake surfaces none at all. These conditions favour the action of the wind, which, apart from the dust whirls to be mentioned presently, works in gusts by means of which the fine material is raised and transported from the surface. This work may be described as "wind-brush," to use an apt term employed by W. M. Davis.

Dust whirls, locally termed "willi willies," are frequent in the afternoon during the summer months on calm days or on days with a gentle breeze. Many are only a few feet in height and in diameter, but others are hundreds and probably thousands of feet high and perhaps of considerable diameter. The dust whirls are essentially moving columns or pillars of dust, and they rotate both clockwise and anti-clockwise.

High dust whirls may be practically vertical, or curved, or bent at a high angle to the ground. They travel in different linear directions across the country, and in whirls near enough for close observation the linear movement is rapid, but no estimate of the velocity of dust whirls in Salinaland has yet been published. A low whirl, as a rule, dies out within a minute or two, but a high whirl may be visible many minutes or possibly some hours.

A dust whirl, even a small one, is quite violent in its action. Dust, sand, grit, and old tins and other rubbish are lifted from or driven along the ground with great force.

If the whole of Salinaland be considered, a vast amount of fine sand and dust must be displaced even in the course of one favourable day. The dust is lifted well into the air, and the fine sand is dragged along or kept close to the surface of the ground. The movement of the sand has been described as a saltatory action.

The fine sand immediately settles again when the dust whirl dies out, but during its journey some of it would tend to collect and to remain in hollows, thus aiding in the removal of inequalities in the surface of the plateau.

The dust may be carried some distance or even "exported" out of Salinaland before it settles down again. The "exportation" of fine detritus lifted by the wind is dealt with in the next section.

The dust and sand when re-deposited tend to increase the thickness of soils locally, and also to make those soils of a more heterogeneous character.

For further details of dust-whirls in Salinaland the reader is referred to the writer's paper on the subject (*m*).

(c) "Exportation" of Detritus.

Whatever the power of the wind may be as an eroding agent compared with that of rain, it seems clear, in view of the quantity of dust and probably fine sand which must be carried high into the air by dust-whirls and other winds, that a considerable quantity of this dust is being removed or "exported" from Salinaland to other localities, and much of it must ultimately reach the sea. This "exportation" may be carried on in stages by means of temporary deposits which are again picked up and farther removed from their source.

If the general surface of the new plateau is being lowered, then such must be due largely, if not almost entirely, to the "exportation" of the fine detritus by the wind, as, except for the occasional connection with the sea by means of the overflow of the lakes into coastal streams, the drainage is wholly internal.

CHAPTER II.

THE RELATIVE EFFICIENCY OF WIND AND WATER AS ERODING AGENTS IN SALINALAND.

CONTENTS.

Introductory Remarks. Canyons. Broad Shallow Valleys and the New Plateau. "Breakaways" and Steep Hills. The Salt Lakes. The Surface of the Old Plateau. Conclusions.

INTRODUCTORY REMARKS.

From what has been said in Chapter I. of this Part, it is apparent that the writer considers that the surface features of the country are due partly to the mechanical action of rain and partly to the action of the wind, after taking into consideration the effects of insolation, chemical weathering, frost and salt crystallization, which may be termed the advance agents of erosion.

When, however, one asks whether wind or water has had the greater influence in moulding the landscape, no satisfactory answer can be given to the question. A great deal of close quantitative observation will be necessary to enable an approach to be made to a definite solution of the problem.

At the present time different observers may record their impressions, but they are not likely to be much more than impressions. Those impressions may, however, approximate towards the truth, and therefore it is well that they be recorded. Such a record also has the advantage of stimulating further inquiry.

It may be pointed out that though, for instance, water may be more powerful under one set of conditions, yet the position may be reversed under another set. Hence in discussing the question the conditions involved must be clearly stated.

With these introductory remarks the writer will proceed to a brief discussion of the subject.

CANYONS.

As already shown when treating of the major land forms of Salinaland, the wind has no share in the formation of the U-shaped canyons and V-shaped valleys of the old plateau and of the higher land respectively. Insolation, chemical decomposition and rain account for those features.

BROAD SHALLOW VALLEYS AND THE NEW PLATEAU.

In the broad shallow valleys which gradually develop, wind and rain both play a part. The valley itself is formed by stream action, but as the base-level of vertical corrasion is soon reached, the widening of the valley and the wearing away of its sides are due to the disintegration of the surface rocks by insolation and chemical decomposition, and secondly to the transportation of the detritus by wind or rain or both. It may with confidence be re-affirmed that even on very gentle slopes, rain will slowly carry fine detritus down the slopes. The rain is, therefore, partly or wholly responsible for the removal of the rock waste.

The action of the wind is not so easily determined, but in view of the often scanty vegetation, the great amount of bare ground that occurs, the fineness of the detritus, the fact that, in places away from the salt lakes, sand ridges occur which are not always fixed, the frequency of dust-whirls, and the occurrence of dust gusts, the writer believes that the wind plays no insignificant part in the removal of the fine detritus from, and the consequent lowering of, the valley sides.

As the valleys widen, the slopes become gentler, the floors become covered with fine detritus, and adjacent valleys tend to merge into one another; in this way a slightly undulating plateau—the new plateau—is formed, and base-level determined by the height above sea-level of the detrital floors of the deformation basins. During the progress to

this stage, rain action must weaken. All rain corrasion has practically ceased; and transportation by rain is at a minimum so long as the conditions do not permit an outlet for the drainage. On the other hand, all the surface that is free from vegetation is exposed to the action of the wind, which, therefore, should be at its maximum, and although that maximum may not be very great, still what transportation does take place is mainly due to wind action.

In this connection it may be mentioned that Davis (*a*, 303, and *d*, 370) maintains that the operation of the wind in arid areas relatively increases the more level the surface becomes.

The corrasive action of the wind has not been considered in the above discussion, as until the action of the rain approaches its minimum, the corrasive action of the wind appears to be negligible or almost so, except perhaps at the base of the cliffs ("breakaways") or other steep hills, to which point attention is given in the next section. But when a wide plateau, with only a few residuals, has been formed, wind corrasion should come into play, and wind hollows may be formed. They would probably, however, be shallow, as rain action would become more active and would supply sufficient detritus to prevent further hollowing out, in accordance with the generalization of Passarge (208).

Of course, if from any reason a new base-level of erosion were established in any part of the plateau, rain action would come into play again in that part, and the cycle outlined above would be repeated until a plateau was formed at the new base-level. The revival of rain action is always likely, owing either to a gradual encroachment of the coastal drainage on that of the interior or (where two drainage basins adjoin) to the removal by erosion of the lip separating the two basins.

So long as any higher land remains, stream action in the narrow valleys of this higher land will carry away detritus, and deposit it chiefly as small alluvial fans or as a miniature piedmont plain at the foot of the higher land. The occasional small stream that issues from the narrow valleys will continue for a short distance to corrade and to transport the detritus; but, so long as the slope is sufficient, the rain in its gentle action is the chief water agent in transporting the detritus, whether the latter be brought from the valley or be the direct waste from the hill slopes. The rain carries the fine material to the lowest ground, and there the floor of the valley or drainage basin will be raised, which will incidentally help towards the union of adjacent valleys or basins.

"BREAKAWAYS" AND STEEP HILLS.

At the foot of the "breakaways" and of steep hills of fairly hard rocks (like greenstones and haematite-quartz rocks) away from the salt lakes, there is often a narrow strip of ground with a very scanty

vegetation of salt bush and similar low-growing plants. The detritus from the cliffs and hills on this strip is often thin, showing that it is being removed as it is formed. Transportation by rain occurs if there be sufficient fall, as there frequently is; for the plane that is formed by the cutting back of the cliff or hill often slopes gently away from the foot of the higher land. The remarks made under the last section as to the gentle transporting action of the rain apply to the slopes mentioned.

At the foot, however, of some "breakaways" and hills (including those away from the lakes) the ground is practically level over wide areas, so that rain transportation is almost negligible.

The conditions mentioned are favourable to deflation, and the writer inclines to the opinion that in the narrow areas referred to, the wind is a more powerful factor than the rain in the removal of the fine detritus, although, as already stated, the actual wearing away of the cliff or hill face as a whole is due to rain action, following disintegration.

At the foot of the cliff or hill, however, the wind may corrade and so help in the destruction of such cliff or hill. No definite evidence on this point is known to the writer, and the matter, therefore, awaits further investigation.

The narrow strip of ground above referred to with the veneer of detritus forms a pediment in accordance with the meaning given to that term by Kirk Bryan (*a*, 52, *et seq.*)

The paper by Kirk Bryan just referred to and one also by A. C. Lawson contain most valuable and elaborate discussions on the origin of arid land forms, but they cannot be further referred to here.

THE SALT LAKES.

In the production of the rock-floors and rock cliffs of the salt lakes the wind appears to exercise a more powerful influence than the rain. Where the cliffs are "breakaways" with the soft decomposed rock beneath the hard cap, rain corrades the cliff. Many lakes, however, are bounded by hard rocks, and rain corrasion of those rocks and of the rocks forming the floors appears to be almost negligible.

Insolation, ordinary chemical weathering, and crystallization of salts break down the rocks, and though portion of the debris may be removed by the gentle transporting action of the rain, the greater part appears to be carried away by the wind, which also planes down the floors and cuts away the base of the cliff.

Detritus is brought by rain or stream action to the edge or on to the floor of the lake (the lowest part of the country) and there deposited. This deposit may be removed at its outer edge and lowest part, and, in some instances, in such a manner that low cliffs of the

detritus are formed; the rock floor on which the detritus rested is then reduced to almost a dead level. (See fig. 118.) That such a sequence of events has occurred at Lake Goongarrie has been shown by the writer (*f*); and such sequence is not peculiar to that lake. It is difficult to imagine how the rain could effect those changes, and consequently rain action must be excluded.

Since, therefore, the remarkable "billiard-table" rock floors, the steep rocky cliffs, and the scarcity of detritus at their bases are not, in the writer's opinion, to be explained by the action of rain, and as other explanations, such as the eroding action of the transient shallow waters that sometimes cover the lake floor, marine abrasion, or abrasion by

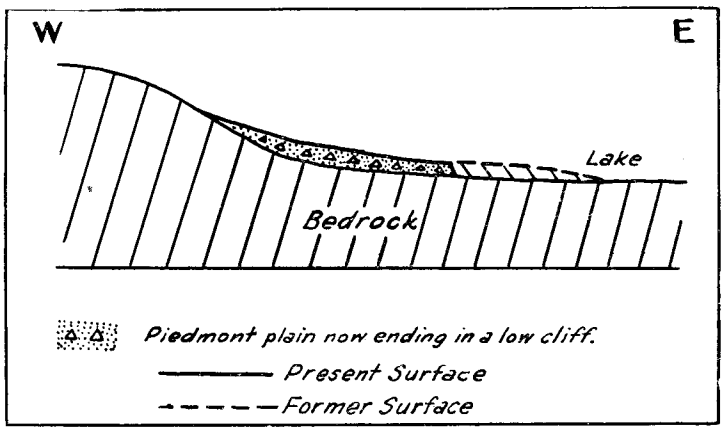


Fig. 118.—Generalized section on the western side of Lake Goongarrie, at Goongarrie, Salinaland, showing the formation of a cliff in the detritus of a piedmont plain, and the consequent westward extension of the lake floor.

former large fresh water lakes (the existence of which is hypothetical) have been rejected by the writer, the wind, acting in both its corrasive and deflative capacity, is regarded as the principal erosive force and that which stamps the landscape of the salt lakes with the highly characteristic features referred to above.

The evidence adduced by the writer (*r*) in regard to the pitting and grooving of rocks and to the formation of miniature pedestal rocks on the western shore of Lake Goongarrie appears to corroborate the wind theory.

Woodward (*g*) in his original paper in which the wind theory was brought forward, has noted the retarding effect of the ground-water table on wind erosion on lake-floors. Honman (*b*, 56) also believes that during lake migration the rock-floor is kept level by

moisture. This is a possible explanation of the very even surfaces of the billiard-table rock floors, but it would only apply on the assumption that the eroding agent was the wind. If rain were the eroding agent the moisture would not prevent erosion, nor would it produce such level surfaces.

The rock floors, however, are apparently not so saturated that no further wind erosion can take place. The rocks, especially those near the cliffs where the actual erosion occurs, are certainly not so saturated as to prevent the disintegration and transport by the wind of fine material, or the rasping of the floor or base of the cliffs by wind corrasion. Such ground-water as reaches the rock floor surface evaporates, and if salt be precipitated, it must in most places be blown away.

Where, however, fine silt covers the rocks which are *in situ* the effect of the ground-water is different. The salt is precipitated on the surface of and through the silt, and tends to bind the silt into a firm moist mass. Wind erosion is certainly retarded, and so long as the silt remains firm and moist, there will be little transportation. The silt may in fact be increased by the wind carrying from the lake shore dust or fine sand which may be caught by the moist surface, a point which Göczel (*a*, 25) in effect noted long ago. On the other hand, the quartz and gypsum dunes which so frequently border the lakes must have been blown in part from the lake floor; so that whatever is the position of affairs now, in the immediate past the wind has been active as a transporting agent. It may be that the zone of saturation has just been reached, but that indicates a rather too remarkable coincidence over wide areas of varying heights to be true.

Assuming, however, the firm moist surface, that surface is not universal. Over much of that surface, owing presumably to the deposition of salt-laden silt and to crystallization, miniature hollow domes of the salt are formed (Saint-Smith, *b*, 43, and Jutson, *c*, 426). These break up and lie in fragments and grains on the surface. As such they can and must be transported by the wind. Salt crystallization also detaches individual grains and fragments from the main silt mass, and portions of the surface of the latter must dry under a parching sun sufficiently to permit disintegration, the material of which can also be carried across the lake. This mode of transportation is not seen from a distance. Hence although scarcely any dust may be seen being lifted from a lake floor, yet transportation in the way described may be proceeding.

Esson (9) has also recorded the lifting and transport of gypseous material on a lake surface by the wind.

It may be noted that Göczel (*a*, 25) remarked that the salt and dust of the lakes are scattered by the wind over the surrounding country, supplying its soil with a considerable quantity of salt; and he makes the important observation, that the extension of a saline

vegetation far beyond the limits of the lake is due to the salt so supplied. If such be the case, it has an important bearing on the question whether greater lakes at one time existed.

THE SURFACE OF THE OLD PLATEAU.

The surface of the old plateau consists in many places of the flat tops of tablelands and mesas. The vegetation is frequently stunted and sparse with much bare ground. Where any trenching of the plateau has taken place the rain will carry fine detritus into the valley, but where the plateau is level and practically free from trenching the wind must remove much detritus, and on the whole is probably more potent in this respect than the rain.

CONCLUSIONS.

Which of the two agents, water or wind, is the more powerful in moulding the whole surface of the semi-arid country is a difficult question to decide. It has been indicated above where in particular areas or under a particular set of conditions one or the other predominates, but viewing the country as a whole the writer inclines to the opinion that *for the present stage of erosion* the rain is the predominating, but not necessarily the overshadowing partner. As erosion proceeds, an observer might determine from the then character of the country that the wind was the chief denuding agent.

The writer's conclusion is based upon the fact that the gentle undulations of the new plateau represent faintly defined valleys, the outlines of which appear in the main to be due to stream and rain action.

The most important matter requiring attention is the determination of the thickness of detritus on the new plateau. Over wide areas it is known to be very thin or practically absent. In other areas a moderate thickness has been proved. Probably greater areas with thin detrital deposits have been proved than those with thick beds of detritus; but this fact carries little weight, as the thinness or absence of detritus is more easily proved than the thick deposits. If it be ultimately established that, taken as a whole, the detritus forms only a thin mantle, then the power of the wind must have been very great, and it would probably be the greater denuding agent.

The writer would, therefore, urge that as much information as possible concerning the detritus on the new plateau be obtained and carefully recorded, as opportunities present themselves.

The above discussion and conclusions relate only to Salinaland. When one considers the vast development of sand ridges in Sandland, it may well be that the wind is or has been by far the greatest agent of erosion. The writer has expressly refrained from discussing that part of the country, as he has no personal knowledge of it, and few observations have been made by reliable observers.

It will be noted that the conclusion as to the relative efficiency of wind and water in producing the surface features of Salinaland, modifies considerably the ideas expressed by the writer in the first edition of this work, as to the predominance of the wind. Those ideas were formed largely in consequence of the recognition of the general absence of stream corrasion outside the higher lands, and of the non-recognition of the great importance of the slow, but steady transportation of fine detritus on gentle slopes over wide areas by the action of the rain. Subsequent detailed studies in the field in a wet season vividly brought home to the mind of the writer the power of gentle flowing rain, and the conviction consequently that the wind had not the importance previously assigned to it.



PART XIII.—THE MOUNTAINS, THE SCARPS AND THE SUNKLANDS.

CHAPTER I.

THE MOUNTAINS.

CONTENTS.

The Stirling Range. The Fitzgerald Peaks. The Porongorup Range. The Mt. Barren Range. The Mt. Bruce Belt. Mt. Augustus.

Of true folded mountains or of great earth blocks, which stand pre-eminent above the surrounding country, Western Australia possesses few.

Most of the ridges and hills are simply the remains of elevated dissected plateaux, or monadnocks on the latter, and as the plateaux are discussed in separate Parts, attention will only here be given to those eminences which, by reason of their absolute or relative height, and their more or less isolated positions may, with some degree of truth, be termed mountains.

The Stirling Range, the Fitzgerald Peaks, the Porongorup Range and the Mt. Barren Range in the south, Mt. Bruce and adjacent heights in the north-west, and Mt. Augustus, also in the north-west, are almost the only physical features in Western Australia worthy of the name of mountains.

THE STIRLING RANGE OR HORST.

These mountains have been described by Brown (9 and 10) and by Woodward (*b*, 49 and 50); and have been referred to by Maitland (*i*), David (10, fig. 3) and J. W. Gregory (*a*, 518). The most complete and recent description is that given by Woolnough (*d*).

The Stirling Range is a great block about 50 miles long from east to west, is narrow in proportion to its length and has mostly precipitous sides. The component rocks are quartzites and slates, mostly horizontal, but locally very considerable crumpling, in places associated with over-thrusting, has occurred (Woolnough, *d*, 112). The highest points rise between 2,000 and 3,000 feet above the vast sandy plain at the foot of the ranges, which itself is from 800 to 900 feet above sea-level. The plain is composed mainly apparently of metamorphic rocks consisting largely of gneissic granite. On the northern side of the range the plain is swampy, and numerous salt lakes occur. "Several broad 'passes' whose floors rise very little above the level of the 'sand plain,' traverse the range completely, and afford a very easy passage across the mountain area." (Woolnough, *d*, 83.)

From Woolnough's researches (*d*, 110) the range appears to have been a well defined narrow sunkland bounded on the north and south by faults. Along the fault planes on which the area originally subsided, an upward movement commenced, and the Stirling Range block was thrust upwards to its present position above the general level of the plateau, so that what was formerly a sunkland, has now become a horst. The range is also bounded on the east by a fault.

When the Stirling Range rocks formed a depressed block and part of the great peneplain, streams originally ran across the site of the present range to the Southern Ocean, which then extended farther north than at present. The uplift of the range proceeded so slowly at first that the streams could maintain their courses, but the movement towards its close suddenly became so rapid that the streams became diverted, leaviing their old channels through the range as air gaps, which are the great "passes" already referred to.

Such are the conclusions arrived at by Woolnough from field study, and they indicate a remarkable and unique history of this most interesting area. (See figs. 119, 40 and 41.)

THE FITZGERALD PEAKS.

The Fitzgerald Peaks (in the southern portion of Salinaland about midway between Ravensthorpe and Dundas) are two striking hills, Peak Charles and Peak Leonora. They are described by Woodward (*e*, 15) as rising abruptly above the plain (hereabout 700 feet above sea-level) to an elevation of 2,000 to 3,000 feet. Mr. A. Gibb Maitland informed the writer that these hills were composed of granitic rocks.

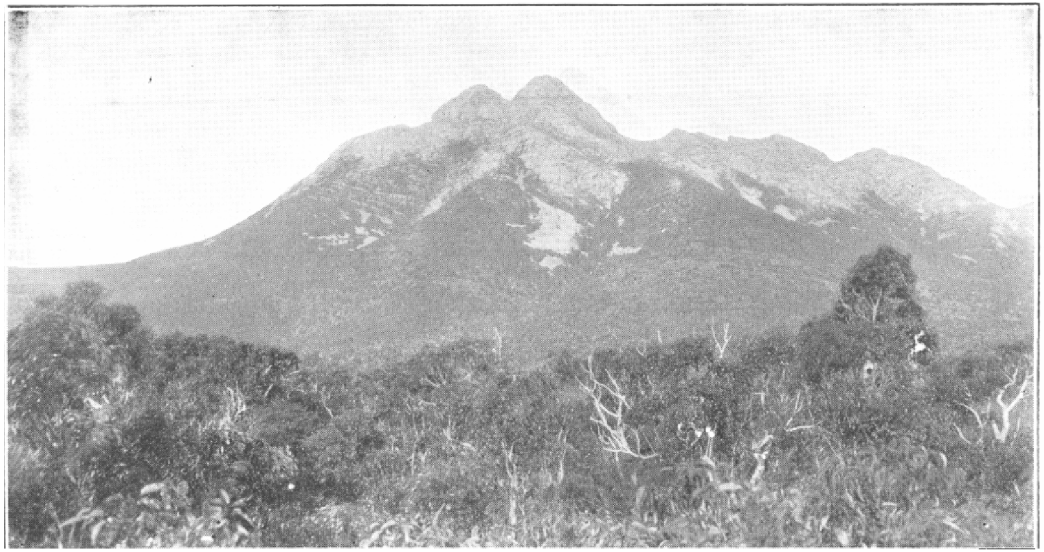


Fig. 119.—Toolbrunup, Stirling Range, Swanland, from the north-west.

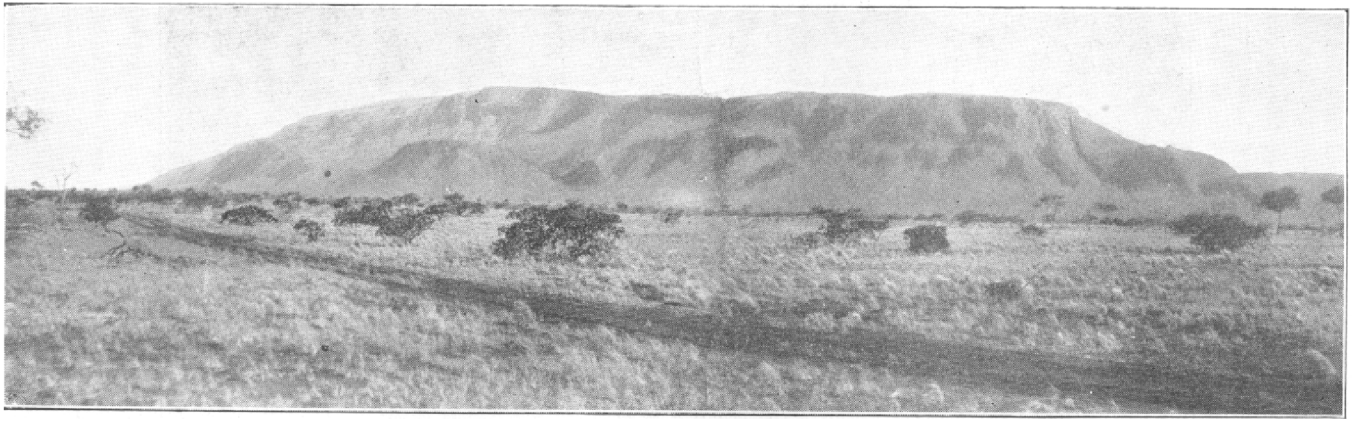


Fig. 120.—Panoramic view of the northern face of Mt. Augustus, Lyons River, Murchisonia.

The surrounding plain appears to be granite. These hills may be either monadnocks or up-faulted blocks, but if, as seems probable, their component rocks are younger than those of the adjacent plains, they are probably monadnocks.

THE PORONGORUP RANGE.

This range lies to the south of the Stirling Range, and, like the latter, runs in an east and west direction. It rises to a height of over 2,000 feet above sea-level, and granite forms the chief rock mass. Very little appears to be known about the range.

Woolnough (*d*, 109 & 111) has suggested that, although the Stirling and Porongorup Ranges are quite distinct in geological structure, yet the two ranges may have had a similar physiographic history.

THE MT. BARREN RANGE.

This is a southern coastal range of considerable height extending approximately from Doutbful Island Bay to Mary Ann Harbour. It has three prominent peaks, known as the West Mt. Barren, Middle Mt. Barren, and East Mr. Barren. Nicolay (*a*) describes the component rocks as "schistose."

THE MT. BRUCE BELT.

This belt of country forms the highest land in the State, Mt. Bruce itself being 4,024 feet above sea-level. Mt. Bruce and other peaks in the belt are apparently monadnocks on the Great Plateau of Western Australia, which in this district attains its greatest elevation above sea-level. The component rocks are largely of sedimentary origin.

MT. AUGUSTUS.

The mountain (fig. 120) attains a height of somewhere about 4,000 feet above sea-level, and from Maitland's description (*g*, 45-48) consists of a huge block (about five miles long from south-east to north-west, and about two miles in width) of a gritty conglomerate, towering hundreds of feet above the surrounding plateau. In structure it is an unsymmetrical anticline, the axis of which strikes north-east and south-west. Its northern limb dips north-westerly at about 40°, and its southern one south-easterly at about 25 to 30°. The outline of the hill corresponds with its structure, the gentler southerly dip producing a long slope, and the steep northerly dip a tendency to scarps. See fig. 121, which is reproduced from Maitland (*g*, 47).

Judging from these particulars, the mountain appears to be either a gigantic monadnock or an up-faulted monoclinal block. The latter seems to be the more probable.

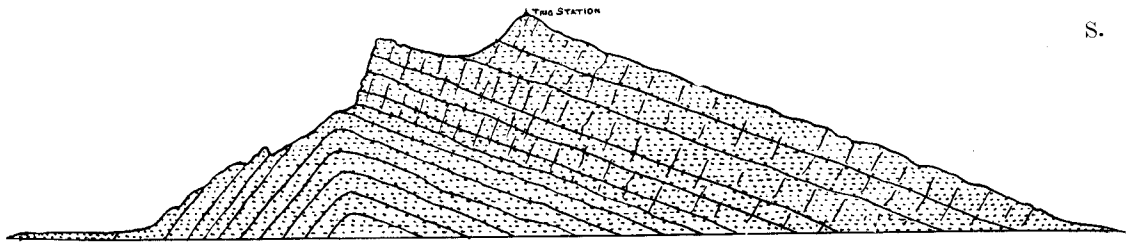


Fig. 121.—Section illustrating the structure of Mt. Augustus, Lyons River, Murchisonia. (After Maitland.)

CHAPTER II.

THE SCARPS.

CONTENTS.

Fault Scarps. (a) Revived Fault Scarps. (b) Normal Fault Scarps. Erosion Scarps. (a) Normal Erosion Scarps. (b) Fault-line Scarps.

Both fault and erosion scarps occur in Western Australia, and each may be subdivided. Thus fault scarps may be those which originated either along an old fault or along an entirely new one; and erosion scarps may be either wholly due to erosion apart from faulting, or to differential erosion along an old fault separating two series of unequally resistant rocks. Most fault scarps in Western Australia appear to be comparatively little dissected.

FAULT SCARPS.

(a) Revived Fault Scarps.

An example of a young fault scarp and of comparatively recent faulting along the line of an old fault is the Darling Fault Scarp and Fault, the main lines of which run roughly parallel and close to the western coast (towards its southern end). These have been described in the chapter on Swanland as a physiographic division (p. 83). The scarp is due to recent faulting, but as shown by the mapping of the country to the north of the Geraldton-Mt. Magnet railway (where the fault* but not the scarp exists), this recent faulting is apparently along a line of old faulting, of which all evidence from the inequalities of the surface had been previously destroyed by denudation. Fault scarps of this nature may be termed "Revived-Fault Scarps."

As also shown in the chapter just referred to, the scarp bifurcates both to the north and to the south of Perth, the minor branches running north-westerly and south-westerly respectively. (See figs. 38 and 39.)

The possibility that the Darling Scarp may be either a fault-line scarp or a monofold-line scarp must be borne in mind. This point, which is very important, is discussed in the chapter on Swanland.

(b) Normal Fault Scarps.

Another possible young fault scarp, but which is not known definitely to be along a line of old faulting, is the Great Bight or Bunda Scarp, along the south-eastern coast. This rises to between 200 and 400 feet above sea-level (fig. 70).

* The continuation northward to the Lyndon River of (on the whole) the remarkably straight line separating the old crystalline rocks from the sedimentary beds suggests strongly that this line is a fault, and a continuation of the Darling Fault. If this be so, this major fault would constitute one of the greatest structural features in Australia.

In the extreme south-western corner of Swanland are the Naturaliste Scarp, running along the coast from Cape Naturaliste to Cape Leeuwin, and the Dunsborough-Augusta Scarp, which is parallel to and in the same latitude as the Naturaliste Scarp. Both these scarps are believed to be young fault scarps, and they have been described in the chapter on Swanland (p. 87). If both the scarps mentioned are fault scarps, then the Naturaliste-Leeuwin Ridge (which lies between the two scarps) is a horst.

Woolnough and Somerville (106 and 107) have described the escarpment overlooking the coastal plains of Dongara, Walkaway and Geraldton, which they believe to be due to faulting. To the fault and scarp they have applied the name "Moonyoonooka."

The Moonyoonooka Fault is, however, apparently identical with the writer's "Geraldton Fault," which was suggested (with the possibility of a scarp in places) in the first edition of this work (*b*, 163 and 164, fig. 85) as occurring close to the coast and extending from the Irwin River to at least as far north as the Hutt River. The terms "Geraldton Scarp" and "Geraldton Fault" will, therefore, be used in this publication for the features mentioned. (See fig. 38.)

The reasons for the occurrence of the suggested Geraldton Fault were stated (*b*, 163) to be "the straight western boundary of the Jurassic rocks, their rather elevated position (the basal rocks being in places above sea-level, as disclosed by the underlying granite, where the rivers have dissected the country); and the sudden great depth of the sedimentary rocks close to the western side of the possible fault (as at Dongara, where the bore shows Jurassic rocks down to 2,111 feet, after the first 140 feet (Campbell, *c*, 31) and as at Geraldton, where 1,436 feet of the same rocks occur below sea-level) (Campbell, *c*, 56). Campbell (*c*) states that they have been proved inland to be above sea level to a height of 1,180 feet, and a bore from about this height showed 1,418 feet of sediments apparently of the same rocks (Campbell, *b*). This, however, would not indicate that the beds shown by the coastal bores have not been faulted down."

The confirmation of the Geraldton Fault independently by Woolnough and Somerville leaves little doubt of its existence.

The Stirling Range is bounded on the north, south, and east by great fault scarps. It has been described in the chapter on the mountains of the State.

Another possible fault scarp in Swanland is the south-western face of the Wongan Hills, north-east of Perth. Woodward (*f*, 115) states that this face presents a bold escarpment of about 300 feet above the surrounding clay flats, and that such face has probably been caused by a line of fault, which would also account for the springs near the base of the hills.

The south-western side of the belt of high land comprising the Napier, Oscar, Geikie and Rough Ranges, which are composed mainly of massive Lower Carboniferous limestones, forms a great fault scarp traceable for 200 miles (Blatchford, *g*, 23) which the writer has named the Napier-Geikie Fault Scarp.

Another fault scarp has been described by Blatchford (*g*, 24) in the southern portion of the Ord River system in the Kimberley district. The throw is to the east, and the scarp, which runs northwards, forms, for many miles, a conspicuous, almost vertical wall, formed chiefly of quartzite of Lower Cambrian or Pre-Cambrian age. The writer has named this scarp the "Ord Fault Scarp."

Some prominent fault scarps occur in Pilbaraland, the best known of which are the Hamersley, the Ophthalmia and the Nullagine Scarps. The two first named fault scarps bound the Hamersley-Ophthalmia Plateau on its northern and southern sides respectively. The Nullagine Scarp is on the northern side of the upper Fortescue River and faces the Hamersley Scarp on the opposite side of the same river, the stream in that portion of its course occupying a rift valley. Some details of the scarps mentioned are given in the chapter on the physiographic division of Pilbaraland. (See figs. 23, 24 and 25.)

North of and parallel to the Nullagine Scarp is the north-facing West Pilbara Scarp (fig 25) which is shown on Woodward's geological map (*n*). The writer has suggested that the scarp may be due to faulting, but little is as yet known about it.

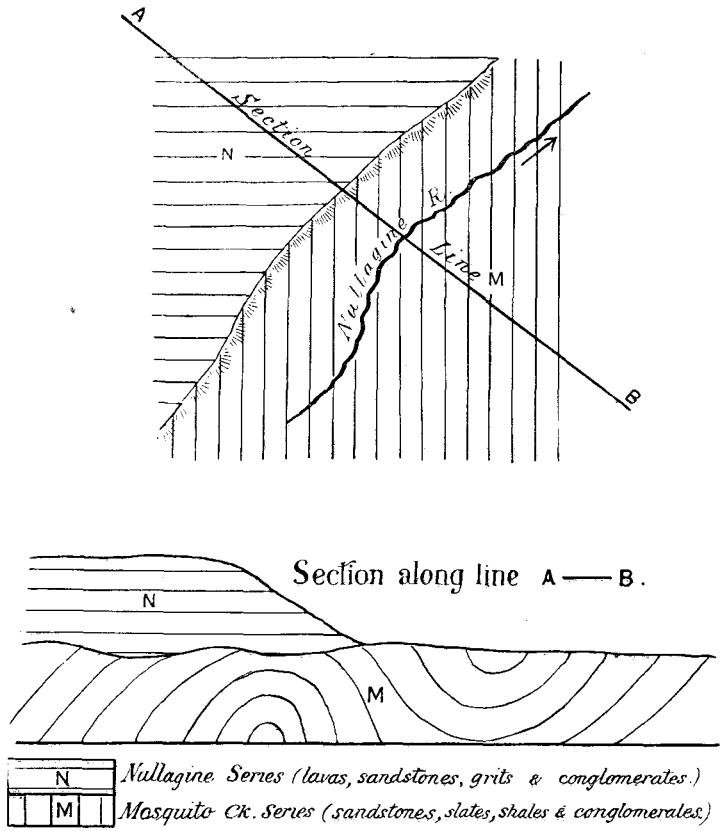
In Murchisonia, according to Clapp (*a*, 53), a scarp can be traced intermittently for 150 miles forming the eastern faces of the Kennedy, Carrandibby, and probably the Moogooloo Ranges. The writer has suggested the name of "Carrandibby-Kennedy-Moogooloo Scarp" for this feature, but a shorter name is required. For more details, reference should be made to the chapter on the physiographic division of Murchisonia.

In the first edition of this work (*b*, 167) the Kennedy Scarp was regarded as an erosion scarp. If, however, it can be traced the distance mentioned by Clapp, the scarp may be due to faulting. Further investigation of this interesting feature is desirable.

An escarpment, many miles in length, in Sandland, south of the Fitzroy River, described by Clapp (*a*, 51, *et seq.*), as "the North Escarpment of the Interior Plateau" in the Desert Basin, is suggestive of a fault scarp. Details are given in the chapter on the physiographic division of Sandland, where the writer has suggested that the scarp be termed the "Great Desert Scarp," a briefer, and, therefore, a more convenient term than the name used by Clapp.

(*a*) *Normal Erosion Scarps.*

Examples of these features, which are due to erosion only, are the "breakaways" of the interior and the escarpments formed in the dissected plateaux of Pilbaraland and North Kimberley, where hard rocks overlie softer ones, and so tend to form precipitous faces. A possible



Figs. 122 and 123.—Diagrams to illustrate the formation of erosion scarps near Nullagine, Pilbaraland. Based on Maitland, Bull. 40, G.S.W.A., Pl. 8.

erosion scarp is at the Kennedy Range (in Murchisonia), which presents a great east-facing scarp—the "Kennedy Scarp"—of sedimentary rocks dipping slightly to the west. Hard rocks form the cap and softer ones occur below. The latter have apparently been cut into

by the Lyons River, which thus undermines the hard cap, and produces the scarp. The possibility of the scarp being due to faulting is referred to above under the heading "Fault Scarps."

In the Pilbara Goldfield of Pilbaraland, Maitland's mapping brings out a number of erosion scarps very distinctly. In this district, the soft rocks are granite, and the hard ones belong to the metamorphic series (greenstone schists, quartzites, etc.) and to the gabbro and other basic dykes. The usually nearly horizontal or gently inclined conglomerates, grits, sandstones, and volcanics of the Nullagine Series are also fairly hard. The granite has in places been reduced to low-lying plains,* and where that rock abuts the metamorphic rocks, the latter frequently form scarps rising from the granite plain. Those scarps are often clearly due to differential erosion. In the case of the rocks of the Nullagine Series, scarps often occur between them (the higher outcropping rocks), and the low-lying granite. The latter has in some localities no doubt been denuded more rapidly than the Nullagine beds, and as the latter possess very hard bands, they weather into steep escarpments. It is not always clear whether the Nullagine rocks have everywhere covered the granite and have been in part subsequently removed; or whether the granite outcrops have been on a level with the existing Nullagine† (the whole probably forming an uplifted peneplain), and the granite, by reason of its comparative softness, has been removed faster than the Nullagine. The writer believes from the distribution of the rocks as shown by the geological map, that both features have occurred.

Near Nullagine itself, the Nullagine Series overlies unconformably another sedimentary series, known as the Mosquito Creek Series. The former series forms a plateau with young streams, and the latter a low-lying plain with shallow valleys. An abrupt erosion scarp occurs between the two series, near Nullagine, due to the resistant nature of the Nullagine beds. (Figs. 122 and 123 illustrate this feature.)

A number of beautiful examples of erosion scarps occur in the Irwin and Greenough River districts of the northern portion of Swanland. The rocks are chiefly horizontal Jurassic sandstones, forming plateaux, which have been dissected by streams, the valleys of which contain the escarpments referred to.

Two plateaux, the Collier and Lofty Plateaux, which lie between the head waters of the Ashburton and Gascoyne Rivers are bounded

* Notice the east and west belt close to the coast between the Yule and De Grey Rivers which is spoken of as the coastal plain. This plain appears to be due to subaerial differential erosion of the soft granite or other soft overlying rocks leaving the harder masses (Cook's Hill, Mt. Goldsworthy, Ord Range, and others) standing above the plain as residuals.

† That this latter possibility is probably true in places is indicated by the number of trignometrical stations in the granite immediately to the east of the Yule River, and by the granite hills and tablelands near the Oakover River.

in part by scarps, which are evidently entirely due to erosion. (See figs. 23 and 124.) The plateaux are described in the chapter on the physiographic division of Pilbaraland.

(*b*) *Fault-line Scarps.*

Of scarps along old fault lines, but which are due to differential erosion, examples probably occur in Pilbaraland, where the metamorphic rocks (greenstone schists, quartzites, etc.) and the harder bands of the Nullagine Series may in places be separated from the wide plains of low-lying granite by an escarpment, the latter being along or close to the line of a fault, between the two rock series. If the

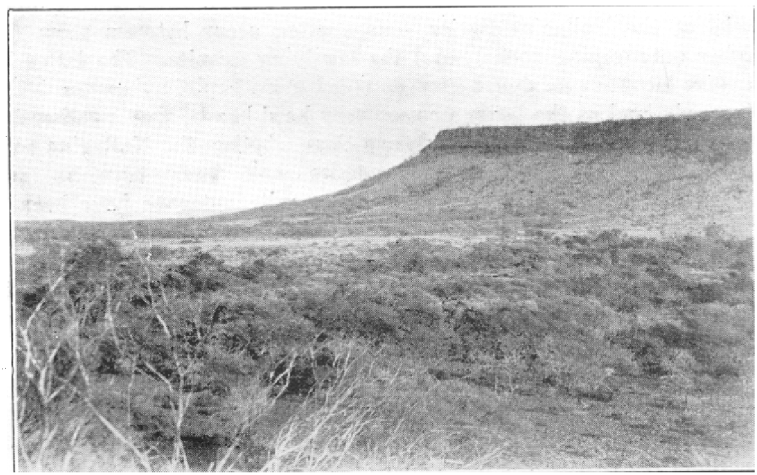
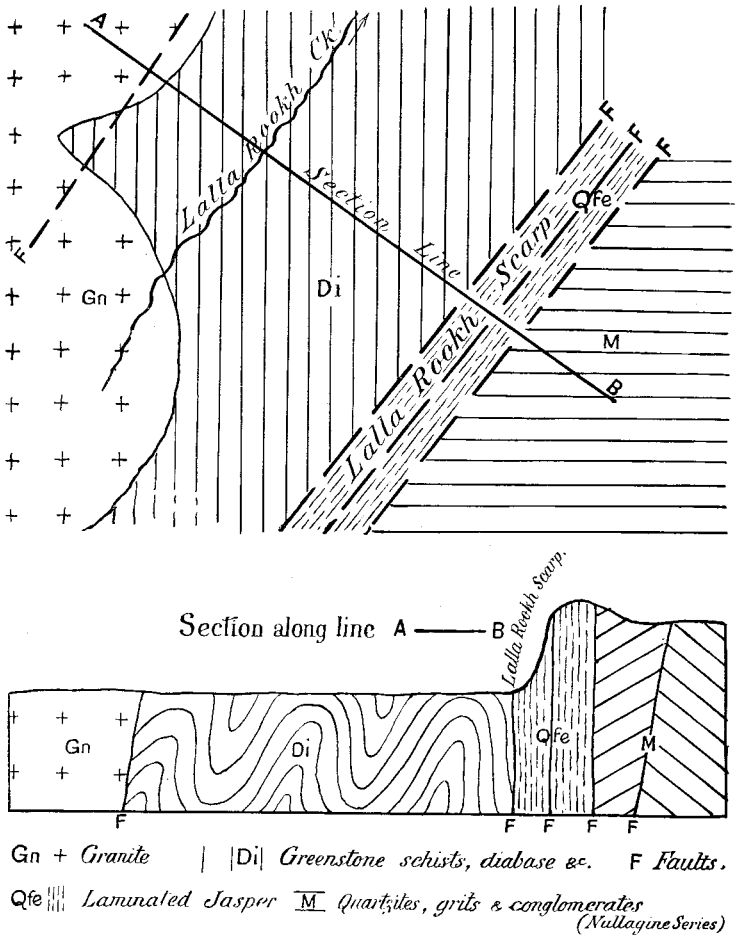


Fig. 124.—An erosion scarp, Collier Plateau, Pilbaraland. The indurated capping and the beautiful denudation curve of the scarp are well shown.

scarp be of the type indicated, the country after faulting was evidently reduced to a peneplain, thus obliterating the original inequalities produced by the faulting. Subsequently, uplift took place, and erosion commenced. The harder rocks resisted, but the comparatively soft granite yielded, so that a scarp was formed at the junction of the two, in this case a fault plane. The scarp is, therefore, due to differential erosion along a fault-line. Adopting Davis's terminology (*b*, 912), such a feature is termed a "fault-line scarp." The scarp running north-east and south-west at Lalla Rookh along a fault between some laminated jaspers and some greenstone schists, may be a fault-line scarp, the schists perhaps being eroded more rapidly than the jaspers. (See figs. 125 and 126.)



Figs. 125 and 126.—Diagrams to show the nature of the Lalla Rookh Scarp. It is not clear whether the scarp is a true fault scarp, or a fault-line scarp. *Note*: For simplicity two series of rocks have been grouped together under "Di," and various details have been omitted. (Based on Maitland, Bull. 40, G.S.W.A., Pl. 2.)

CHAPTER III.

THE SUNKLANDS.

CONTENTS.

The Collie Sunkland. The Moora Sunkland. The Perth Sunkland. The Marsh Sunkland. The Lake Disappointment Sunkland (?). The Lake Cowan Sunkland (?) The Fitzroy Sunkland (?). The Stirling Sunkland. Minor Sunklands of Salinaland. (a) The Coolgardie Sunkland. (b) The Waverley (Siberia) Sunkland. (c) The Yerilla Sunkland (?).

The information relating to the sunklands of Western Australia is scanty, and it is, therefore, hoped that the enumeration here of known and probable sunklands will lead to the acquisition of further knowledge concerning them as opportunity offers.

The sunklands are of various forms and areas, and the respective dates of their formation no doubt differ.

THE COLLIE SUNKLAND.

This comprises the Collie coal measures, in the southern portion of Swanland, which lie in a faulted basin of the igneous rocks of the Darling Peneplain. Reference to this basin has been made by Saint-Smith (*a*), and the earlier work of Jack (*b*, 6, and geological map attached) clearly shows the faulting that has taken place.

THE MOORA SUNKLAND.

This has been described (with plan and section) by Blatchford (*c*). It consists of the wide sunken area of sedimentary rocks between Moora and Dandaragan (the latter about 20 miles west of the former) apparently between two parallel faults. On the east, the sunkland is bounded by granite and gneiss and on the west by sediments different from those of the sunkland.

THE PERTH SUNKLAND.

This term has been applied to what is believed to be a great sinking area lying to the west of the Darling Fault Scarp and having an east and west axis somewhere in the vicinity of Perth. It has been alternatively termed the "Perth Syncline" (Jutson, *a*, 151). The following statement indicates the evidence on which the idea is based.

Maitland (*i*) has pointed out that the Darling Fault may be the eastern wall of a long rift valley, of which probably part of the western wall was the narrow ridge of crystalline rocks extending from Flinders Bay to Geographe Bay (that is to say, this part western wall is what is now known as the Dunsborough-Augusta Scarp, a probable fault-scarp), and that the fundamental rocks of the islands of Rottnest

and Houtman's Abrolhos possibly mark the northern extension of the crystalline rocks mentioned above. Maitland also remarked that the sedimentary rocks filling the rift valley become younger southwards from the Irwin River coalfield, and he believed that the Dunsborough-Augusta Fault may be of late or post-Tertiary age.

David points out that the deep indent between Cape Naturaliste and Bunbury is due to the rift valley, and he illustrates the latter by transverse and longitudinal sections (David, 9, figs. 1 and 2).

Saint-Smith (*a*, 73, *et seq.*) has indicated the increase in depth of the sedimentary rocks in a northerly direction from the Busselton district, the inference being drawn by him that the throw of the Darling Fault increases from south to north.

The present writer has noted (*a*) that the Darling Fault Scarp dies out some distance to the north of Perth, but that the fault itself continues, and that the movements which produced the Darling Fault Scarp* were probably along the line of a pre-existing fault (the Darling Fault). In the same publication, the occurrence of Carboniferous, Jurassic and Cretaceous rocks, a few hundred feet above sea-level, in the vicinity of the Irwin River and of Gingin; their non-occurrence at the surface in the Perth area; the great depth of sediments in the latter as proved by boring; the thinning of such sediments to the south, as also proved by boring; and the occurrence of granitic rocks in the south, were remarked on.

The throw of the Darling Fault appears to be greatest in the neighbourhood of Perth; there likewise the sediments appear to be deepest (that is from south to north and mainly on the Swan Coastal Plain); and the lower Swan valley has been drowned; these three features appear to be intimately connected, and no doubt result from one another.

The above statement makes out a reasonable case for the existence of the Perth Syncline or Sunkland. This feature may be treated as a great synclinal fold or down warp from north to south and from south to north, the axis trending east and west.

Maitland's suggestion of a north and south rift valley is also apparently true, although the phenomena do not indicate a typical rift valley, inasmuch as the central portion of the valley appears to have sagged so strongly in an east and west direction, that the synclinal structure masks the rift valley, except that portion lying to the east of the Leeuwin-Naturaliste Ridge, which is apparently a horst.

This central sagging of the rift valley explains the concave curve of the ocean between the Irwin River and Cape Naturaliste, as David has in effect stated. The accompanying plan and block diagram (figs. 38 and 39) illustrate the matter.

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* See, however, Chapter VII., of Part VI., for other possible explanations of the origin of the Darling Scarp.

THE MARSH SUNKLAND.

This occurs in the valley of the upper Fortescue River above the Coodiadarri Hills. "The Marsh" is a huge swampy area over which the river spreads in time of flood. "The Marsh" is regarded by Talbot (*d*, 54, 97, 99, 105 and 141) as the remnant of an extensive lake and as evidence of a sunkland, and he points out (*d*, 141) that bores sunk to a depth of 104 feet in the sunkland have not struck bed-rock.

The portion of the Fortescue valley in which the Marsh Sunkland occurs is a rift valley. It is not clear from Talbot's description whether the sunkland is identical with the rift valley, or whether the sunkland is a depression on the floor of the rift valley. (See figs. 23 and 24.) If the second alternative be true, then there is some similarity to the Perth Sunkland and possible rift valley.

THE LAKE DISAPPOINTMENT SUNKLAND (?)

Lake Disappointment is on the Canning Stock Route and occupies an extensive area through which the tropic of Capricorn passes. Talbot (*d*, 31 and 141) states that near the lake, bores passed through 60 feet of lake deposits without reaching bottom, and he regards the lake as an old filled river valley, after considering the possibility of the lake occupying a deformation basin. It appears, however, to the writer, that the evidence is not conclusive one way or the other, but that it points more to the existence of a sunkland than to the existence of a buried river valley, especially in view of the fact that sunklands do occur in Western Australia; hence the lake is included in this section, although with a query. Further evidence is, however, required.

THE LAKE COWAN SUNKLAND (?)

Talbot (*d*, 31 and 141) also refers to a bore put down [in and] about 1,100 feet from the edge of Lake Cowan, which proved a depth of 377 feet of silt, and he comes to the same conclusion as in the case of Lake Disappointment, that is to say, that it represents an old buried river valley rather than a deformation basin. Montgomery (*l*, 75) appears to incline towards the old buried valley idea, but he points out (75), that the bottom of the Princess Royal "deep lead," which runs towards Lake Cowan, is probably quite 100 feet below the *present* bottom of the lake. Silt in the lake is stated to be 377 feet deep, therefore if the *original* (bedrock) lake bottom does not vary in contour much, and if the "lead" does not suddenly become much deeper than the depth noted by Montgomery, the mouth of the "lead" at the lake is 277 feet approximately above the *original* lake bottom, and therefore is apparently a fine example of a very high hanging valley, a phenomenon understood if the Lake Cowan depression were either an old glacial valley or a rift valley, but not if it were an ordinary river valley. Campbell (*a*, 23) suggested the glacial valley idea, but as no evidence in support has been brought forward it has not been accepted.

The occurrence of a sunkland or a rift valley would meet the facts; and as the lake occupies a long and (by contrast with its length) narrow belt, running in a remarkably straight north and south line in its southern half, a buried rift valley is suggested; the lake basin as a tectonic feature is therefore here included, although again with a query.

THE FITZROY SUNKLAND (?)

In the chapter treating of the general characteristics of Sandland it was pointed out (p. 119) that the valley of the lower Fitzroy was bounded on the north by the Napier-Geikie Fault Scarp and on the south by the Great Desert Scarp, and that if the latter were a fault scarp, the lower Fitzroy valley formed a great sunkland. This idea is put forth by way of suggestion only, with a view to stimulating further investigation of the area generally, and particularly as to the origin of the Great Desert Scarp.

THE STIRLING SUNLKAND.

This sunkland has now been changed into a horst, the history of which is briefly told in the account of the Stirling Range under the heading of "Mountains" (p. 272). Nevertheless, it is fitting to record here the fact that a great sunkland, due to faulting, once existed where the noble pile of the Stirling Horst now stands. (See figs. 40 and 41.)

MINOR SUNKLANDS OF SALINALAND.

Probably a moderate number of the salt lakes represent deformation basins which have been filled by detritus, but the evidence to prove or disprove this idea can only be obtained by extensive boring, which is unlikely to take place unless there is a prospect of economic results of value. Nevertheless, some probable tectonic basins have been discovered, and they will now be described.

(*a*) *The Coolgardie Sunkland.*

Maitland (*a*, 22) refers to an extensive flat at Coolgardie, where several bores and shafts had been put down, by which the occurrence of deep alluvial deposits was proved. The greatest depth at which the bedrock was located was 400 feet. The results of the boring operations suggest that the depressed area is a tectonic basin rather than portion of an old river valley. Montgomery (*l*, 93) inclines to the same opinion, for he states that the deep ground "seems inexplicable unless it is a small sunken field or 'grave' where a wedge-shaped piece of ground has been faulted downwards." Eucalyptus leaves have been found at a depth of 380 feet, and are regarded as of late Tertiary age (Blatchford, *b*, 25).

(*b*) *The Waverley (Siberia) Sunkland.*

Larcombe (*c*) considers that the deep alluvial deposits examined by him at Waverley (Siberia) occupy a small sunkland or miniature rift valley, which is bounded along its western wall by a fault. Montgomery (*l*, 93) notes, in the same deep lead apparently, a small fault by which the old gutter has been thrown down some six or eight feet. Blatchford (*e*, 75), however, doubts the existence of this fault.

(*c*) *The Yerilla Sunkland* (?).

A deep lead occurs to the west of the township of Yerilla, and has been described by the writer (*p*, 27). The length of the lead traced is about eight or nine chains, and it has a width of from two to three chains, with a depth from the surface to bedrock of generally from 15 to 20 feet. The depth appeared to be uniform, there being no defined "gutter." The bedrock is both granite and greenstone.

The facts suggest that the "lead" occupies a closed basin. The bedrock comes right to the surface to the south, to the west, to the north (in parts), and perhaps to the east. In the last-mentioned direction, a covering of laterite prevents this point being actually determined; and on the northern side the surface falls away and a covering in places of recent wash prevents detection of the underlying rock. If the "lead" has an outlet it is probably to the north, but so much "live" rock can be traced around the "lead" that it is doubtful whether such an outlet exists, and if not, then there is a true rock hollow, which can only have been formed by earth movements.

PART XIV.—THE COAST LINE AND THE COASTAL PLAINS.

CHAPTER 1.

THE NATURE AND RECENT HISTORY OF THE COAST LINE.

CONTENTS.

Division of the Coasts. The South-East and North-North-West Coasts. The South-West Coast. The West Coast. The North-West Coast. The North Coast. Recent Elevation of the Coast. Summary.

DIVISION OF THE COASTS.

Except in the extreme north, north-west, and south-west, the coast line of Western Australia is remarkable for its smooth and generally unbroken character. (See fig. 7.) For convenience of reference, it may be divided into six parts, viz.:—The South-East Coast, extending from Israelite Bay eastwards to the South Australian border; the South-West Coast, extending westwards from Israelite Bay to Cape Leeuwin; the West Coast, extending north from Cape Leeuwin to North-West Cape at Exmouth Gulf; the North-West Coast extending from North-West Cape east-north-eastwards to Condon; the North-North-West Coast, extending from Condon to Cape Levêque at the western head of King Sound; and the North Coast, extending from Cape Levêque to the North Australian border.

THE SOUTH-EAST AND NORTH-NORTH-WEST COASTS.

The South-East and North-North-West Coasts have much in common; their outlines are featureless; the bordering country possesses no rivers; and in each country there is probably a wide uniformity of rocks and of geological structure, although both these features differ in the respective areas. They differ in that the South-East Coast is bounded either actually at the sea-border or a few miles inland, by high cliffs, which no doubt represent a fault scarp; whilst the North-North-West Coast has a low sandy shoreline, the Eighty-Mile Beach

The rocks bordering the South-East Coast consist of horizontally (or nearly so) bedded limestones rising sharply from the coast to a height of between 200 and 400 feet, and thence extending inland as a gradually rising plateau (fig. 70). The smoothness of the coast line is apparently due to recent faulting, and where the faulted cliffs are

away from the coast, to a low coastal plain, carrying sand dunes (fig. 127). But if the coast line had recently been submerged it would be featureless, provided rivers remained absent; for such absence prevents the development of a land surface of marked relief; and if subsidence took place there would be no valleys to drown.

Blatchford (*j*, 8) notes that 40 miles south of Esperance on the South-East Coast, the ocean soundings increase from 40 to 50 fathoms to 120 to 600 fathoms, and he makes the interesting suggestion that the sudden drop is probably due to a fault scarp.

The geological map (Pl. II.) shows that the rocks of the North-North-West Coast are mainly Jurassic sediments, bordered at the sea by a thin band of Tertiary sedimentary rocks which form a coastal plain. That hard rocks probably exist is shown by the small projecting headlands in the northern portion, but the coast, as a whole, is smooth, and would for similar reasons to those stated in connection with the South-East Coast, remain so if submerged.

Clapp (*a*, 63) records that in the country to the north of Broome dead cajiput trees indicate that the land is now sinking. He also notes (63) that recent raised beaches occur at frequent intervals from Port Hedland to Lagrange, that they in places rise 50 feet above tide level, and that the pivot between the sinking areas north of Broome and the raised beaches mentioned appears not to be far from Broome.

THE SOUTH-WEST COAST.

Along the South-West Coast (Pl. IV.) many small areas of granite occur, largely associated with recent sedimentary (aqueous or aeolian) rocks. It is a line of indentations and headlands, the irregularities being no doubt chiefly due to a recent submergence which drowned the valleys. A notable example of the latter is at Albany, where the valleys of the lower King and Kalgan rivers, which originally joined one another, have been drowned; as a result of which they are now betrunked streams and King George's Sound, Princess Royal Harbour and Oyster Harbour have been formed. (See Jutson and Simpson.) The building by the waves and the wind of bars and dunes may also account for some of the inlets.

The coast is being smoothed by the tying of islands to the mainland, and the filling of bays by the action of the waves and of the wind in building up bars and dunes of sand, and by rivers bringing down silt. This is well illustrated by the geological sketch map of Maitland (*e*) of the country around Princess Royal Harbour at Albany. (See also Jutson and Simpson.) Maitland has also remarked that there are very strong grounds for believing that Princess Royal Harbour and Torbay Inlet (the first prominent indentation to the west) were at one time connected, and this suggestion has been confirmed by Jutson and Simpson, who have named the old strait "Grassmere Strait."

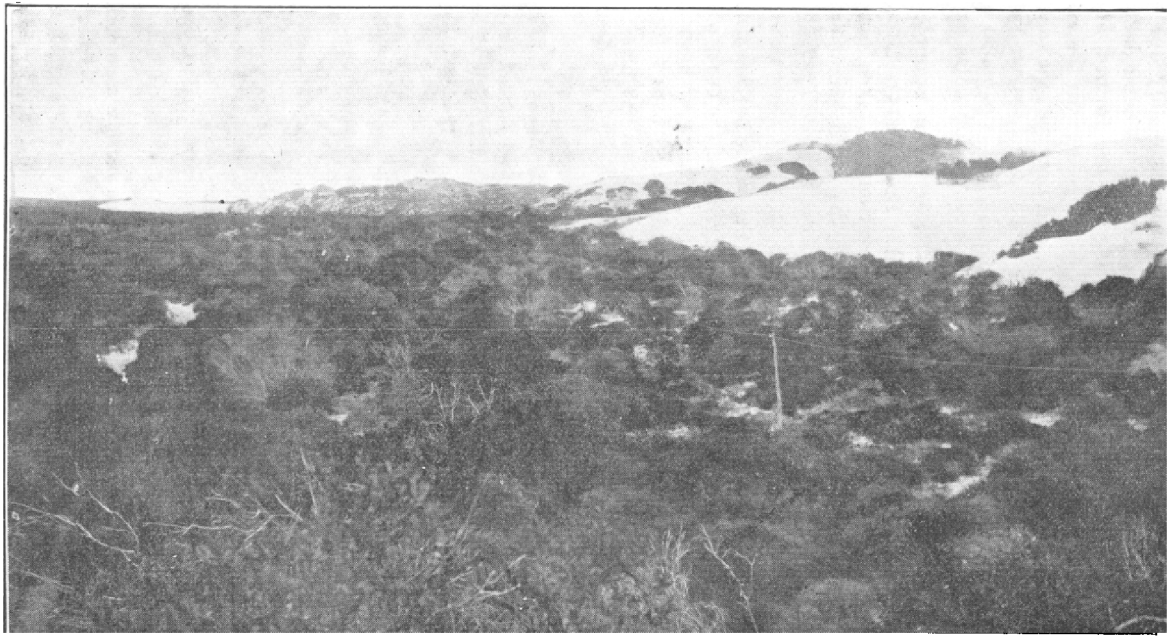


Fig. 127.—Drifting sand hills, Eyre, on the Euclonia coast.

THE WEST COAST.

The West Coast (Pl. IV. and figs. 30 and 31) is, with some exceptions, very smooth and unbroken. This feature is mainly due to the action of the winds and of the currents in building up sand dunes and bars parallel to the coast, behind which lagoons are formed, and the courses of rivers diverted to the direction of the coast. In the extreme southern portion between Capes Naturaliste and Leeuwin, the coast line is probably a fault-scarp which has been termed the "Leeuwin-Naturaliste Scarp." Not far from the coast the coastal plain is bounded by the great Darling Fault Scarp for a distance of about 200 miles at least.

In the vicinity of Perth, the Swan River is an example of a drowned valley (see figs. 37, 43 and 44). Brown (14) states that during a recent period geologically, a separation has taken place between Rottnest, Garden and other islands in the Perth neighbourhood, and the mainland. The Blackwood-Arthur River has also been drowned (Somerville, 13).

Other drowned valleys may exist along the coast, but have not yet been recorded. Whatever changes the submergence of the coast wrought at the time on the contour of the latter, its effect has now been almost destroyed by the building up of the sand dunes and bars referred to above. Since the submergence there has been a slight "uplift" in the Swan River area to a height of about 23 feet above sea-level, according to Somerville.

This idea of an uplift has been confirmed by Aurousseau and Budge, who, however, claim that it took place in stages, and caused rejuvenation of the Swan and Helena Rivers, resulting in four cycles of erosion which, they consider, can be correlated with other physiographic features indicative of the successive uplifts.

Aurousseau and Budge (34) also consider that Leschenault Inlet, Lake Preston, the Martin Tank line of lakes and swamps, and Lake Clifton (in the Bunbury-Mandurah district) which are long narrow sheets of water arranged *en echelon* parallel to the coast, are due to elevation, although the earth movements which produced them took place at different times. An interesting conclusion by these authors is, that when the Swan River area was being submerged, the Lake Clifton area was being uplifted (34 and 37). (See Pl. IV. and fig. 128.)

Nicolay (*b*, 41) has pointed out that along the West Coast the bays open mainly to the north. This fact may be merely a coincidence, but there may be some one cause acting over a wide area. If the rocks on the outer side of the more prominent bays are the comparatively recent aeolian limestones, they were apparently built up, by south to north winds and currents along the coast, to form north-pointing peninsulas. The rocks, however, in some parts are not the aeolian limestone and are of greater age than the latter. Thus the rocks of the Cape

Range to the west of Exmouth Gulf are of Oligocene age (Clapp, *a*) and those of the Shark Bay peninsulas and islands are also believed to be of Tertiary age. Evidently further research is required before any general conclusion can be arrived at.

THE NORTH-WEST COAST.

The North-West Coast (fig. 21) is indented and has numerous headlands and islands. Many of the headlands are composed of isolated patches of a very hard siliceous and ferruginous rock, known as "haematite-bearing quartzite," which resists erosion more effectually

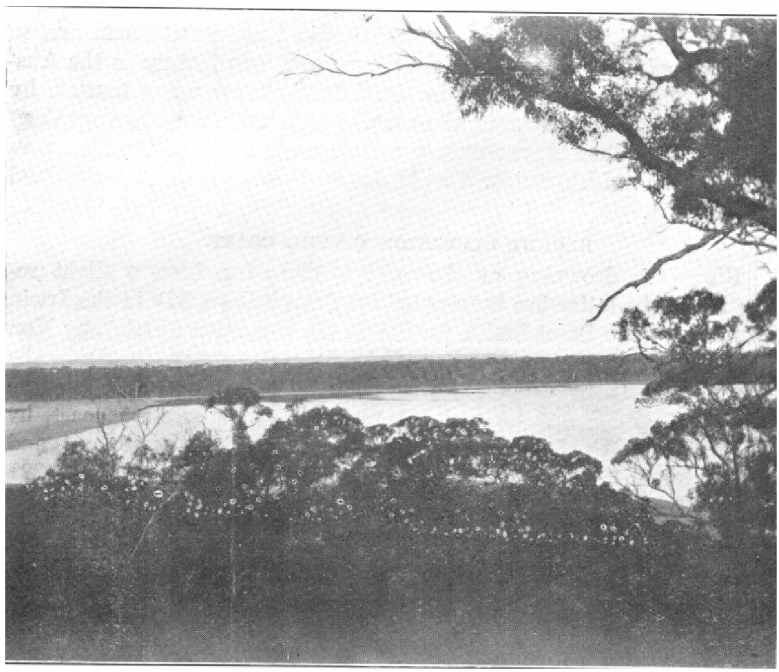


Fig. 128.—Lake Preston, one of the coastal lakes of Swanland.

than the surrounding softer rocks. It is probable that by normal erosion the country had obtained a moderate relief, and was then submerged, drowning the valleys and giving the present rough and broken coast. Since then the coast line is being smoothed by the tying of islands to the mainland, by deposits by wind and waves, by the growth of mangroves, and by rivers carrying silt to the sea.

The coast line, however, is not nearly so indented as the North Coast. The hinterland of the latter at the time of submergence was probably not so much worn down as that of the North-West Coast; hence the difference noted in the respective coast lines.

In some respects the features of the North-West Coast resemble those of the South-West Coast.

THE NORTH COAST.

The North Coast (Pl. V. and fig. 9) is the most broken in Western Australia. Deep sounds and bays (rias) run far into the land, and are manifestly the drowned continuations of the adjacent rivers. This region has been deeply dissected, probably to early maturity, and then submerged. It thus affords excellent illustrations of drowned valleys. A. C. Gregory (12) notes that Cambridge Gulf is of this nature.

The "Kimberley Sounds," as the writer has named them, are, in places, of great scenic interest; they form a unique feature in the Australian coast line, and should in the future attract many tourists by boat. As harbours, however, the sounds, although some are very deep and almost landlocked, are mostly useless on account of the high precipitous cliffs which render the harbours inaccessible from the land (Easton, 25).

RECENT ELEVATION OF THE COAST.

Since the drowning of the valleys, there has been a slight re-elevation. The latter has been noted by Campbell (*c*, 84) in the Irwin River district, by Saint-Smith (*a*, 74) in the Busselton district, by Von Sommer (52) in the Jurien Bay district, by Hardman (*a*, 7) in the Roebuck Bay (near Broome) district, by F. T. Gregory (482) in the Vasse (Busselton) district and (?) portions of the western coast, by Woodward (*f*, 21) along the southern portion of the western coast, and by Woodward (*f*, 32) at the Great Australian Bight. Victor (32) states that a recent upheaval of the coast line of the Great Australian Bight has occurred, cutting off the drainage of the interior. Helms (39) believes that the Abrolhos Islands were formerly connected with the mainland, and that there is also evidence of elevation.

As mentioned above, Somerville and Aurousseau and Budge have claimed that recent elevation has taken place in the Swan Estuary and in the Bunbury-Mandurah district. Woolnough and Somerville (103) record a small upraised coral reef at Point Leander, Dongara, at the mouth of the Irwin River, lifted at least 20 to 30 feet above sea-level.

SUMMARY.

Smooth and broken coasts alternate; fault, or perhaps in some instances, monoclinal scarps occur close to the South-East and West Coasts; valleys have been drowned on the South-West, West, North and probably on the North-West Coasts; and there are records of recent re-elevation in far-distant portions.

In connection, however, with re-elevation, it may be mentioned that since many of the records are comparatively old, judgment should be suspended pending a re-examination of the ground in the light of present-day knowledge concerning coastal physiography.

CHAPTER II.

THE COASTAL PLAINS.

The coastal plains of Western Australia form a narrow shelf along the West and in parts North-West and South-East Coasts. They are notably absent on the North and parts of the South-East and South-West Coasts.

The coastal plains are found at the foot of escarpments, and are, no doubt, partly true coastal plains. They are, however, largely covered with deposits other than marine, such as the detritus brought down by the rivers from the higher country and the consolidated and present-forming sand dunes. Both types of sand dunes and also the fluviatile deposits may be well seen in the neighbourhood of Perth, on the Swan Coastal Plain. Below these deposits, in the area now mentioned, the rocks are apparently of marine origin and of comparatively recent age.

In the neighbourhood of Perth, abundant artesian water has been obtained from the strata of the Swan Coastal Plain. This plain is separated from the Darling Peneplain by the sharp scarp known as the Darling Fault Scarp. Some details of the Swan Coastal Plain are given in Chapter VII. of Part VI.

The eastern half of the South-East Coast is a low coastal plain flanked by old sea-cliffs. Sand dunes now occupy the surface of the plain (see fig. 127). On the North-North-West Coast, between Broome and Wallal, Clapp (*a*, 49) notes that the coastal plain merges into the Interior Plateau [the Great Plateau] so gradually that no boundary can be pointed out.

Associated with the coastal plains are the numerous lagoons (Pl. IV. and fig. 128) along and parallel to the West Coast. They have been formed by the damming up of river waters and portions of the sea, by sand bars and sand dunes, which in turn are due to the action of the waves and of the wind.

The coastal plains are traversed by rivers, which are prematurely old (or to use W. M. Davis's expression have been "born mature") in the sense that they have had little youth, by reason of the low elevation of, and the "soft" rocks composing the plains.

PART XV.—SPRINGS, POOLS, ROCK-HOLES, GNAMMA HOLES AND SOAKS.

CHAPTER 1.

SPRINGS.

CONTENTS.

(1) Hot Springs. (2) Cold Springs. Origin of the Springs.

Numerous springs occur in different parts of the State. They form particularly valuable water supplies in the dry areas in the north. They have, however, not been systematically studied, so that the account here given is necessarily fragmentary.

A brief general description of the more important known springs will be given, together with references to localities where certain springs are stated to occur, but concerning which no particulars are given. Some remarks on their origin will then be made.

The Western Australian springs may be divided into hot and cold springs. The division is somewhat arbitrary, but as the hot springs are usually deep-seated, and the cold ones generally arise from close to the surface, it is not entirely so.

(1) HOT SPRINGS.

Blatchford (*g*, 11) records three hot springs in Fitzroyland and Ordland, viz.:—Mt. Wynne, Palm, and Texas Springs. The temperature of the spring (at the surface) at Mt. Wynne is 112° to 114° F. (29). From this spring "there is a flow of water at the surface of from 60,000 to 80,000 gallons per day. . . . . Large bubbles of gas pass up intermittently through the water in the basin" (Blatchford, *g*, 29). An analysis of this gas is given (29) and also (30) an analysis of the water, which shows the water to be fairly pure, the chief ingredients being sodium chloride and sodium carbonate.

Blatchford (*g*, 11 and 44) also notes that in the bed of the Ord River near Texas Homestead and flowing over the top of a basalt outcrop, is a series of brine springs, both hot and cold. He states that there is no noticeable gas in the hot springs, and suggests that the cause of the high temperature of the latter is depth of origin, *i.e.*, the source of the water is below the basalt. Salt deposited from the brine springs is collected from the rock floor for domestic use.

Wade (28) refers to the same hot brine springs, and states that they break out along joints in the upper part of the massive limestone at the base of the Upper Cambrian, and that the brine may originate in the beds which overlie the basalt. He also notes (25) the occurrence of a hot sulphur spring at Palm Creek (Ordland), and that the hot water probably escapes from depth along some line of fracture.

(2) COLD SPRINGS.

A series of cold springs extends from the hot spring at Mt. Wynne described above to past the south of Mt. McCallum. Associated with these springs are minor mud springs. In all the springs the water is fit to drink, though slightly alkaline and usually more or less charged with sulphuretted hydrogen and methane gas. With the exception of the hot spring, the flow of water is small.

It is suggested that the springs may be due to faulting (Blatchford, *g*, 29). Wade (12) states that the springs are roughly grouped along two lines, one north and south and the other east and west, and that the water is probably escaping along lines of fracture.

The cold brine springs associated with the hot brine springs in the bed of the Ord River have been referred to above under "hot springs". These cold springs probably come from the drainage of the Negri beds (Upper Cambrian) overlying the basalt, pseudomorphs of calcite after salt having been discovered in the Negri beds (Blatchford, *g*, 44). See also Wade (28).

The cold springs now to be described are usually suitable for man and beast, as their waters are not, as a rule, heavily mineralized. The water collects in rock-holes and pools as described below and in Chapters II. and III. of this Part.

Woodward (*p*, 52) remarks that one of the great features of the district of the upper Ashburton and Gascoyne Rivers, "is the springs, which break out at the base of the tableland or in the beds of streams where deep channels have been cut." Unfortunately, Woodward gives no further description than that quoted, although his report has some excellent illustrations (Farquharson's, Chalk, Mingah and Nicholl Springs) from which it would appear that considerable pools are formed by the flow of water from the springs. (See fig. 129.)

In the creeks at the head of the Ashburton River there are numerous permanent springs of good water (Talbot, *d*, 84). Permanent springs occur in the Punda Gorge and the Willy Wolly Spring in the Willy Wolly Gorge, the two gorges named occurring on the northern

side of the Hamersley-Ophthalmia Plateau (Talbot, *d*, 103). Referring to the head of the Oakover River and its numerous tributaries, Talbot states (*d*, 110) that there are many large and permanent springs, some of which yield an inexhaustible supply of fresh water. Carawine Pool, a notable sheet of water along the Oakover River, is fed by springs. (See Talbot, *d*, 110, and figs. 34-36.)

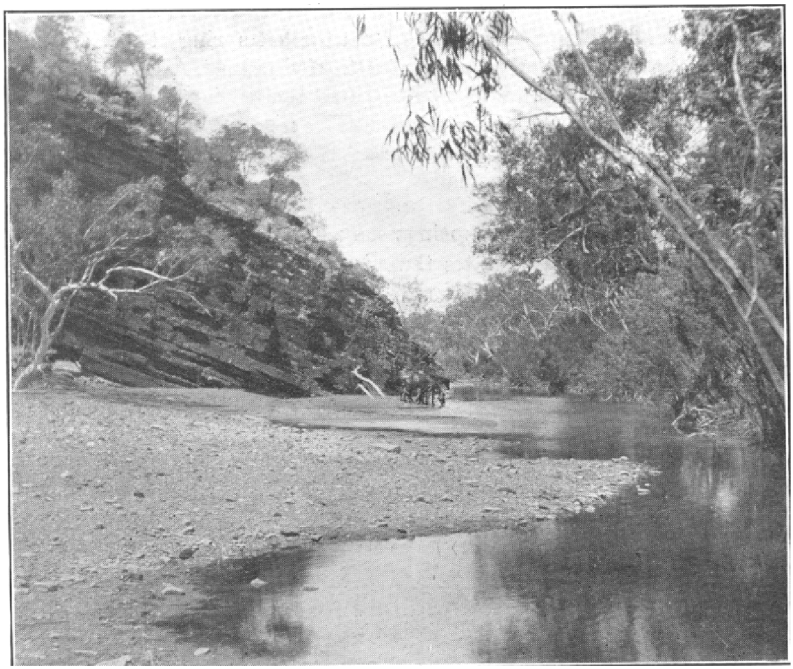


Fig. 129.—Nicholl Spring, Ethel River, a tributary of the Ashburton River, Pilbaraland. The pool is due to a spring in the valley bottom.

Horrigan Pool (on the Angelo River, a tributary of the Ashburton River), one of the finest pools in the State, is fed by permanent running springs which issue from a fault (Talbot, *e*, 19 and 20). Near the Pool the Angelo River runs along the line of a fault from which springs issue (Talbot, *e*, 20).

Many fine running springs occur in Bellary Creek, a tributary of Seven-Mile Creek, which is a tributary of the Ashburton River (Talbot, *e*, 28).

Fine springs and resulting pools, such as Murgurra or Illagie Pool (fig. 130), Killagurra Spring, Durba Spring, Diebil Spring and others are found along the Canning Stock Route and have been described and illustrated by Talbot (*a*, 17, 31-36). Some occur in rocky gorges. (See fig. 131.)

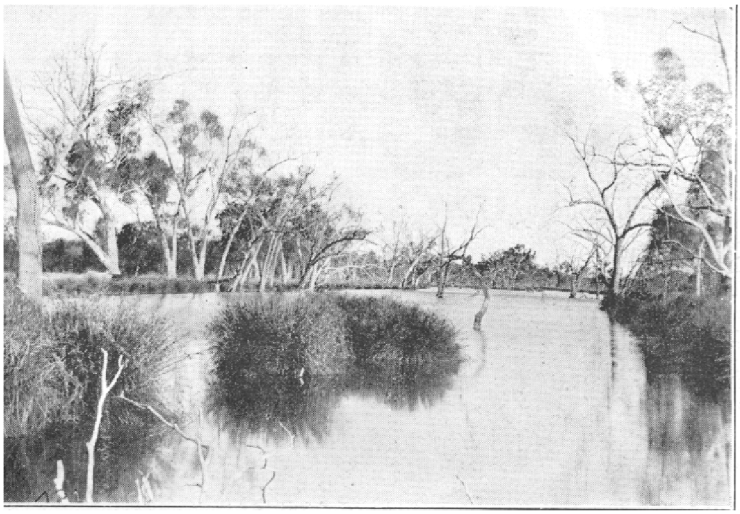


Fig. 130.—Illagie Pool, on a creek running into Lake Nabberu, Canning Stock Route, in the north of Salinaland. The pool is fed by a spring.

In the basin of the lower Ord River (Hobler, 6), and in North Kimberley (Easton, 39), springs are abundant.

In places along the North-North-West Coast between Lagrange Bay and King Sound clusters of springs occur (Despeissis, 21).

In valleys cutting an escarpment of horizontal Cretaceous rocks near Gingin, "heavy springs of water break out . . . . . at the base of the sandstone, which forms the upper portion of the plateau" (Maitland, *j*, 43).

In the country behind Geraldton and Dongara springs occur and are of great importance,

> . . . . . forming in many places the chief or only supply for farmers pastoralists and railways. (Simpson, *c*, 647).

The most famous springs in the State are those forming the group known as the Millstream, in Lat. 21° 35′, Long. 117° 6′, in the Fortescue valley just above Gregory Gorge. Within a radius of about 3 miles of Millstream homestead are four large overflowing pools, viz., Deep Reach, Crossing Pool, Millstream Pool and Palm Pool, of which the last named receives the overflows from the other three. The four pools, which are

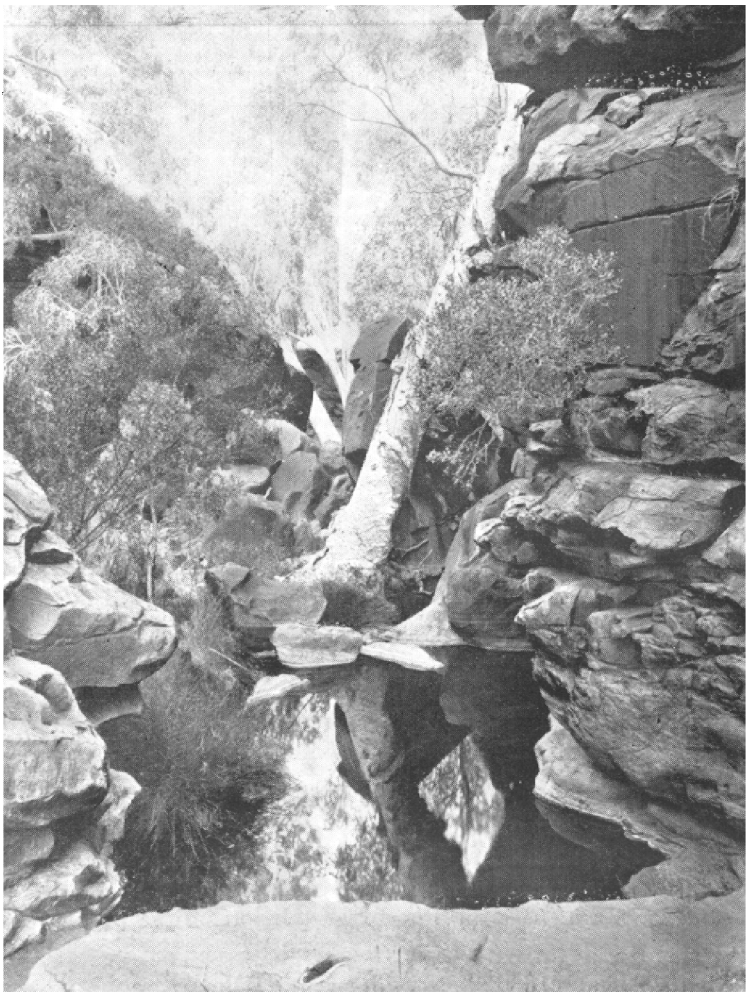


Fig. 131.—Killagurra Spring, Canning Stock Route, Sandland. The spring occurs in a gorge cut through sandstones.

fed by powerful springs, hold a permanent supply of no less than 1,300 million gallons of potable water, with a daily overflow all the year round of at least 22 million gallons, about 50 per cent. more than the maximum daily consumption of the metropolitan area. At present they are merely used by the owners of Millstream station for stock and domestic purposes, and to irrigate a tropical garden. The overflow disappears in a few miles in the otherwise usually dry bed of the Fortescue River. The water in Millstream pool remains constant in quality all the year round, samples at six months' interval showing 769 and 774 p.p.m. (53.8 and 54.2 g.p.g.) of total solids, of which 294 p.p.m. are NaCl, 200 $CaCO_3$ and 138 $MgSO_4$. The Palm Pool, being the final reservoir, shows the effects of evaporation on all the pools in the dry season, figures obtained at six months' interval being 791 and 1,092 p.p.m. (55 and 76 g.p.g.) of total solids, with a pH of 7.9 and 8.0.

The existence of these magnificent springs at the lower end of the upper Fortescue plain points to the possibility of that area being artesian water bearing. (Simpson, *c*, 648).

ORIGIN OF THE SPRINGS.

The origin of some of the springs is indicated in their descriptions. Thus the hot springs, the Millstream Springs and those along the North-North-West Coast are no doubt of deep-seated origin, and, as they also occur in sedimentary rocks, it has been suggested by Simpson (*c*, 647-648) that they are probably connected by faults to artesian supplies.

On the other hand, the Killagurra, Durba, Diebil, and others on the Canning Stock Route, and also those noted near Gingin and in the country behind Geraldton and Dongara, are due to surface waters penetrating approximately horizontal sedimentary rocks and finding an exit at the junction of a permeable bed with an underlying impermeable one.

The springs which feed the Horrigan Pool issue from a fault, but whether they are deep seated or not cannot at present be stated. Doubtless the springs found along stream beds are also due to faults, but those springs can be from shallow as well as from great depths. Where the springs break out above the level of the valley bed, they are probably due to surface waters finding their outlet along the top of an impermeable stratum as suggested above for some of the Canning Stock Route and other springs.

The writer suggests the advisability of detailed study and record of the geological conditions associated with springs whenever practicable.

CHAPTER II.

POOLS.

CONTENTS.

General Description. Origin of the Pools.

GENERAL DESCRIPTION.

Many large pools occur in the northern half of the State, and as they mostly remain fresh and most of them occur in some of the driest portions of the country, they are particularly valuable in human settlement. Pools also occur along the watercourses in Swanland, but as they become saline with evaporation they are scarcely of any value.

As in the case of springs with which some of the more valuable pools are genetically associated, a general description of their mode of occurrence will be given, which will be followed by a brief discussion of their origin.

Simpson (*c*, 642) notes the following pools:—Ima Ima Pool, in Sturt Creek (lat. 19deg. 18min., long. 127deg. 55min.); Yanneri Pool, in Ilgareri Creek (lat. 24deg. 25min., long. 119deg. 40min.); the two Jurell (Dural) Pools, in Wiluna West Creek (lat. 26deg. 10min., long. 119deg. 45min.); Illagie Pool (fig. 130), on a creek running into Lake Nabberu (lat. 25deg. 35min., long. 120deg. 25min.); and Mingul Pool on Brockman Creek (lat. 25deg. 50min., long. 122deg. 20min.). With the exception of Ima Ima Pool, the pools named are in the area where the physiographic divisions of Pilbaraland, Murchisonia, Salinaland, and Sandland come into contact.

The pools are up to a mile or more in length, and the water is of good quality for drinking. They show no signs of diminishing by evaporation, etc., except in the worst droughts. (Simpson, *c*, 642.)

Pools are also common, and some are large and practically premanent, along the upper Ashburton River and some of its tributaries (Talbot, *e*, Pl. III.); also along the lower Fortescue River (Woodward *n*, Pl. I.); and doubtless along the other great rivers of Pilbaraland and Murchisonia. The Horrigan Pool, which is one of the finest in the State, occurs on the Angelo River, a tributary of the Ashburton River (Talbot, *e*, 19, 70).

Carawine Pool, on the Oakover River, is a fine sheet of water (Talbot, *d*, 110, figs. 34-36).

Williambery Pool, on the main branch of the upper Minilya River, and Bilung Pool, at the head of the Wooramel River (the latter pool being a fine sheet of water formed by the stream falling over an almost horizontal bed of sandstone) have been noticed by Maitland (*j*, 35, 36).

In North Kimberley some of the rivers during the dry (winter) months of the year contract into large pools which are joined by small running streams. One pool is at least 12 miles long, six chains wide, and very deep (Easton, 39).

In small creeks in Salinaland, some pools occur, which, if shaded by vegetation and if resting on an impervious bottom, as often occurs, owing to the cementing of the detritus by oxide of iron, silica or travertine, may last for some time and form valuable supplies for stock and also for human beings.

In most of the rivers of the State during the dry season (summer in the south and winter in the north) chains of pools are formed as the rivers more or less dry up. Unless these pools are replenished by springs or by underground flow in the channels themselves, they become brackish and even highly saline as the dry season advances. Their value is consequently diminished. Such pools occur in the rivers of Swanland (see Simpson, *c*, 644 and 645).

"An important feature of the river pools is the stratification of the water according to density. The top water may be quite fresh during the rainy season whilst the deepest pockets in the beds of the pools still preserve their summer salinity with a graduation of salinity at intermediate depths." (Simpson, *c*, 645.)

The four large overflowing pools known collectively as the Millstream Pools in the basin of the upper Fortescue River have been described in the chapter on springs. To that description the following details may be added. Deep Reach, one of the pools, is two miles long, 200 yards wide and 68 feet deep.† Another one is described as a quarter of a mile long, 80 yards wide and 30 feet deep at its deepest part (Ibid., 15).

Pools occur in association with Farquharson's, Chalk, Mingah, and Nicholl Springs in the upper Ashburton and Gascoyne basins (Woodward, *p*, figs. 9, 11, 12, and 13), and with Banana and Mt. Brophy Springs, east of Sturt Creek (Talbot, *a*, 60, 61).

Windich Pool on Kennedy Creek, on the Canning Stock Route near long. 121° and lat. about 25° 30′, is a permanent pool nearly half a mile in length (Talbot, *a*, 11 and 12).

Rock-holes are described separately, although they may be regarded as small pools of an exceptional character.

ORIGIN OF THE POOLS.

Pools commonly arise along watercourses in the dry season owing to the shrinkage to the deepest portions of the stream beds, when the

† The North and North-West of Western Australia: its Wealth and Possibilities. Publication No. 4, Department of the North-West, Perth, 1924, p. 15.

streams are unable to maintain their flow. A river bed is usually gouged out into a series of holes of varying depth and extent; hence the basins are there when the streams begin to contract. A hard band of rock crossing a watercourse may result in a pool below it, as in the Bilung Pool already noted.

When such pools are not replenished by springs or by underground flows in the stream channels, the pools may gradually disappear by evaporation and soakage; but if they remain they become brackish or saline. Such are the streams particularly of Swanland.

Where the water remains fresh there is replenishment in one of the two ways mentioned.

The fine Horrigan Pool in the Angelo River is maintained by springs (Talbot, *e*, 19, 20); and the pools at Farquharson's, Chalk, Mingah, Nicholl, Banana, and Mt. Brophy Springs are similarly preserved. So also is Carawine Pool in the Oakover River (Talbot, *d*, 110, figs. 34-36).

Imat Ima, Yanneri, the two Jurell (Dural), Illagie, and Mingul Pools are believed by Simpson to be maintained by an almost continuous flow of fresh water through the porous beds of the stream channels, although he notes that Talbot considers that lateral springs play a part in keeping the pools full of water (Simpson, *c*, 642). Probably both causes operate together or separately, and if together, one is no doubt stronger than the other in different localities.

The Millstream Pools are fed by springs (Simpson, *c*, 648), from which enormous supplies of water issue.

Where pools are not in stream channels the origin of the holding basins is probably due to the action of the water issuing from the springs bringing about disintegration of the rocks, and to the overflow carrying away the detritus. If Deep Reach, one of the Millstream Pools, has been formed in this way, it is a remarkable example of a hitherto little noticed mode of erosion. If the rocks were wholly or in part calcareous, the removal of the rocks would of course be hastened by solution.

CHAPTER III.

ROCK-HOLES AND GNAMMA HOLES AND THEIR ORIGIN.

CONTENTS.

The Distinction between Rock-Holes and Gnamma Holes. Rock-Holes. Gnamma Holes.

THE DISTINCTION BETWEEN ROCK HOLES AND GNAMMA HOLES.

Rock-holes and gnamma holes are practically restricted to the arid portions of the State, Salinaland and Sandland. Talbot and Clarke (*a*, 52) point out that "rock-holes" are no doubt excavated by flood waters in the same way as pot-holes (*i.e.*, along the beds of watercourses), but that "gnamma-holes" cannot be thus explained. The distinction between rock-holes and gnamma-holes is thus based upon the difference of their mode of origin, and the division is therefore justified. The terminology, however, is unfortunate, as both classes are rock-holes, that is, holes that have been excavated in solid rocks. It is, however, too late to alter the names, and no confusion should arise if it be remembered exactly what the names stand for. These features will now be described.

ROCK-HOLES.

Rock-holes may be described as small holes formed by the action of water along the beds of watercourses, which are usually quite dry, in, as a rule, old sedimentary rocks in Salinaland and Sandland. Their mode of formation is essentially similar to the pot-holes that are formed in river channels in a normal climate.

They are usually circular or elliptical in horizontal outline, and are not more than a few feet in diameter and in depth. The water which brings about their formation is the occasional rushing stream that results from heavy downpours of rain. This water may be augmented by springs. The water in the rock-holes may remain for a considerable time after the creeks have ceased to flow.

The best known rock-holes are found in the beds of small creeks in sedimentary rocks at various points along the Canning Stock Route. Some of those creeks have cut gorges which may contain rock-holes. They have been described by Talbot (*a*). Examples are Breadon's Pool (fig. 68) and Godfrey's Tank near the Southesk Tableland, west of Gregory's Salt Sea (53-55); Wardabunna Rock-hole, at the side of which are several pot-holes up to five feet deep (49 and 50); Killagurra Rock-holes, which consist of a series of large holes in the creek channel, the holes being supplied with water from the Killagurra Spring (31-33); Carnarvon Rock-hole, in a creek running from the Carnarvon Range, near lat. 25° and long. 121° (15 and 16); Jellabra Rock-hole, east of Sturt Creek and near the North Australian border (62 and 63).



Fig. 132.—Large rock-hole in the horizontal sediments of the Hann Breakaways, Sandland.

Rock-holes were noted by Talbot and Clarke (*a*) on the expedition from Laverton to the South Australian border (near south lat. 26°). (See fig. 132.) Amongst them are the five large rock-holes named Carr Boyd Rock-holes, near long. 124° 30′ and lat. 28°, which occur in short creeks or gullies in "breakaways" (28 and 29); the Lily Rock-hole, which occurs in a gorge in the Wilkinson Range (28 and 29); the Point Lilian Rock-hole, which is a large hole in a deep gorge at long. 126° and near lat. 28° (31); Henning Rock-hole in a small rocky creek running west from the Hann "breakaways" south of Faulkiner Hill (32); and Mt. Eveline Rock-hole, in a gully in the mount near long. 127° and lat. 26° (36).

Rock-holes have been of the greatest value in the exploration and opening up of the country.

GNAMMA HOLES.

Gnamma holes are small holes in rocks which have, as a rule, not been formed by running water. For the holes formed by running water by pot-hole action which therefore occur in stream channels, the name "Rock-holes" is applied, although, as already noted, that term is used in too narrow a sense, but it has become fairly well established and so is used in this work in the above sense.

Gnamma holes are of two kinds. The typical and more common hole is that found at the base or on the sides of the bare rounded island hills or domes of granite, which occur in Sandland and Salinaland surrounded by vast plains. (See figs. 133 and 134.)

The second type is usually situated on or near the tops of "breakaways" in Sandland and Salinaland, and is sometimes called a rock-hole, although such use may lead to confusion.

The gnamma holes of the first type usually approach the circular in horizontal outline, are from a few inches to six or eight feet deep, and are from two to 10 or 12 feet in diameter; and vary in their holding capacity from a few pints to many thousands of gallons (Talbot, *b*, 39). They may widen as they deepen, a valuable condition for the preservation of the water from rapid evaporation.

They are formed by the irregular disintegration of the surface by the action of rain and insolation acting on portion of the rock which, owing to its texture or the nature of its component minerals, disintegrates more readily than other portions. In the rough shallow cavity formed water collects and dissolves out some of the constituents of the rock minerals, which are thereby weakened, and the rock further disintegrates. When the hole fills with water, the overflow washes out portion of the debris; and when dry and the hole is shallow, the wind assists by removing the finer particles. The processes are repeated, and so the hole gradually deepens. As the water increases in quantity

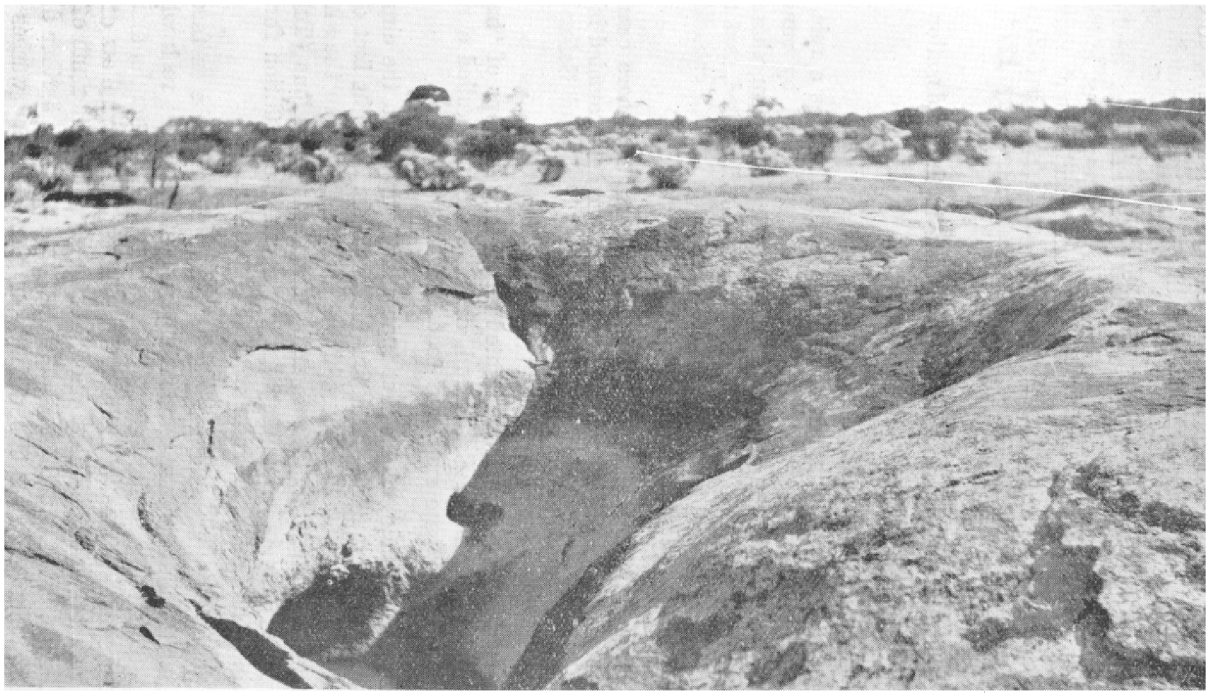


Fig. 133.—Gnamma hole in granite, Jumannia, in the south-eastern corner of Salinaland.

the hole becomes known to the animals and to aboriginal man, both of whom scratch debris or rotten rock from the bottom and sides in their efforts to get the last drop of water out, and in this way the hole becomes widened and deepened. That the holes are formed in the way

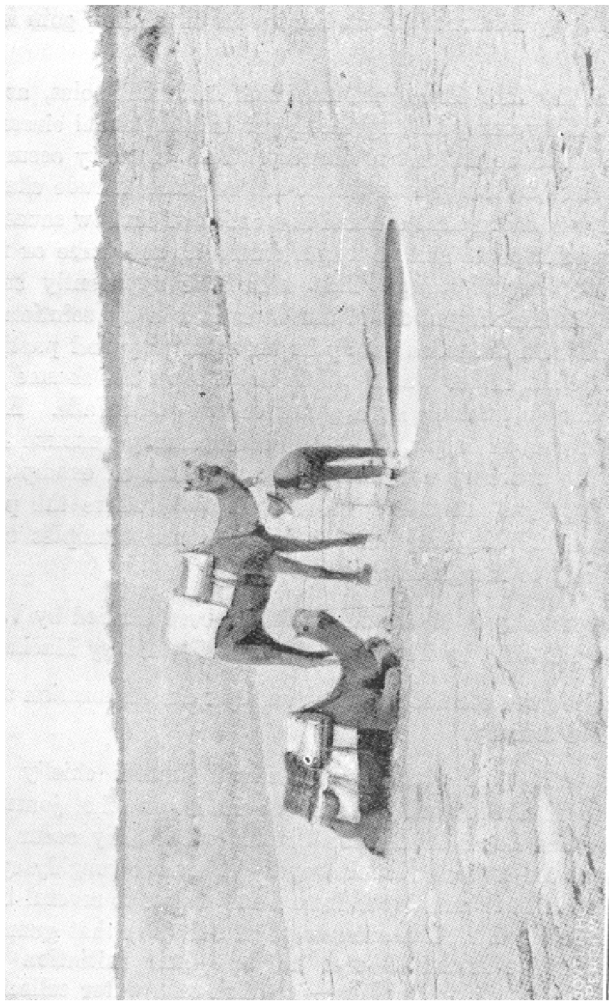


Fig. 134.—Gnamma hole in granite. Eudarie Rock, in the south-eastern corner of Salinaland.

stated appears to be certain, but the writer has a lingering doubt whether all the deeper holes have been formed with the active aid of animals and of man in the manner described, or whether some have not been formed independently by inorganic agents only. If so, then

solution and the subsequent washing out of the disintegrated material by overflow after rain are the ways, no doubt, in which such holes have been formed.

Joints in the rocks in some places play an important part in the development of the holes by providing channels leading to the hollow, and by providing fissures around or partly around the incipient gnamma hole, by means of which the agents of erosion gain increased activity.

Despite the fact that gnamma holes and rock-holes, as defined above, are usually easily distinguished, yet in exceptional circumstances some holes would be difficult to classify. This difficulty occurs where, on the slopes of a bare granite island-hill or dome, a rude channel has been scored, and along that channel is a series of shallow saucer-shaped holes up to perhaps 10 feet in longer diameter, and three or four feet deep at their deepest parts. The holes have apparently been commenced by the disintegration of the rock *in situ* by solution and insolation, and then deepened partly in the same way and partly by the mechanical action of the water, which flows down the channel, passing from one hole to another by a series of low waterfalls. Hence the holes in part are, in origin, similar to the ordinary gnamma hole, and in part to the ordinary rock-hole. For a record of examples of the composite type just described, see Jutson (*n*), where the process is referred to as a "dimpling" of the hills. Those examples appear to be due entirely to inorganic agencies.

The common type of gnamma hole has been studied by Woodward (*o*, 16 and *q*, 33-35), by Talbot (*b*, 38 and 39) and by Maclaren.

The holes have been of priceless value in the exploration and opening up of the country.

The second type of gnamma holes is known chiefly from the observations of Talbot and Clarke (*a*) made on the journey from Laverton to the South Australian border, where they occur chiefly in sandstones at the tops of "breakaways." They are roughly cylindrical, and vary in diameter and depth from a few inches to several feet, often enlarging below (51). The authors point out (53) that gnamma holes of the type now referred to owe all but their initiation as slight hollows on the lateritized surface—in which rain water collects—to the action of animals, including man, who, in scooping out the last drop of water, scoop out the material previously loosened by the chemical action of water, which contains dissolved organic matter. The position of the holes on the sides of gently shelving patches of bare rock close to the edge of the breakaways precludes the idea that they were once a watercourse (52 and 53).

Clapp (*a*, 53) also found rock-holes (gnamma holes) at the head of the "breakaways" in the Great Desert Scarp in the north-western portion of Sandland, and a few rock-holes in gorges near the base of the cliffs. Gnamma holes also occur on the Eucla Limestone Plateau (fig. 69).

It is the occurrence of gnamma holes on the tops of, and of rock-holes in the canyons of the "breakaways," which makes breakaway country of the type described so valuable for water supplies.

CHAPTER IV.

SOAKS.

At the foot of the island-hills or domes of granite, sand and grit accumulate. Water from those hills percolates downward into this material in which, if shallow holes be sunk, a good supply of water may be obtained.

These "soaks" were very valuable in the days of the exploration of the interior and "are still the source of some of the best domestic and stock waters in the 'wheat belt,' where homesteads are frequently found at the foot of the island hills because of the water supply." (Simpson, *c*, 640.)

Finally it is well to note that in certain parts of the dry interior, notably in the country now traversed by the Canning Stock Route, many shallow wells had been sunk by the aboriginals. These proved of great benefit to the early explorers.

PART XVI.—ROCK WEATHERING AND ITS TOPOGRAPHIC EFFECTS.

CONTENTS.

Granite. Greenstones and their Detritus. Quartz Porphyries. Haematite-Quartz Rocks. Huge Gabbro and Dolerite Dykes. Giant Quartz Reefs or "Blows" and their Detritus. Laterite and its Detritus. Chert and its Detritus. Limestones. (a) The Coastal or Dune Limestone. (b) Lower Carboniferous Limestones. Ancient Sandstones, Grits and Conglomerates. Lava Flows. (a) Lava Flows and Fragmental Rocks of Pilbaraland. (b) Lava Flows of Swanland. (c) Lava Flows of Ordland. Schists. Jurassic Sandstones. Other Features of Weathering. (a) Sand Plains. (b) Sand Ridges of Sandland. (c) Travertine. Rock Weathering Generally.

There is a variety of rocks in Western Australia, which, owing to their texture, structure, and chemical composition, receive the attacks of the weather in various ways.

An outline of the general geology of the State has already been given, and reference may be made to it and also to the geological map (Pl. II.) for the distribution of the rocks and their geological relationships.

The effects of weathering on the principal rock types will now be stated.

GRANITE.

Granite (which name here and throughout this work is used as a broad field term for granitic rocks generally) occupies vast areas in the south-central and south-western portions of the State, that is, in Salinaland and Swanland. It also occurs less abundantly in other parts of the country.

In Pilbaraland, Murchisonia and Salinaland, the granite is in many places associated with greenstones and haematite-quartz rocks. The granite weathers much more readily than the other rocks mentioned, with the result that extensive sandy plains occur, broken by occasional hills and ridges of the greenstones and haematite-quartz rocks, and also in places of the granite itself.

In Salinaland particularly, the areas of granite that resist this general planation are small, but they are of considerable interest. They form the fairly common island-hills or domes of granite, which rise to perhaps 100 feet above the general surface of the plains. The hills may occupy but a few square yards, or they may be a mile or more in their longer diameter (fig. 135). They are usually almost

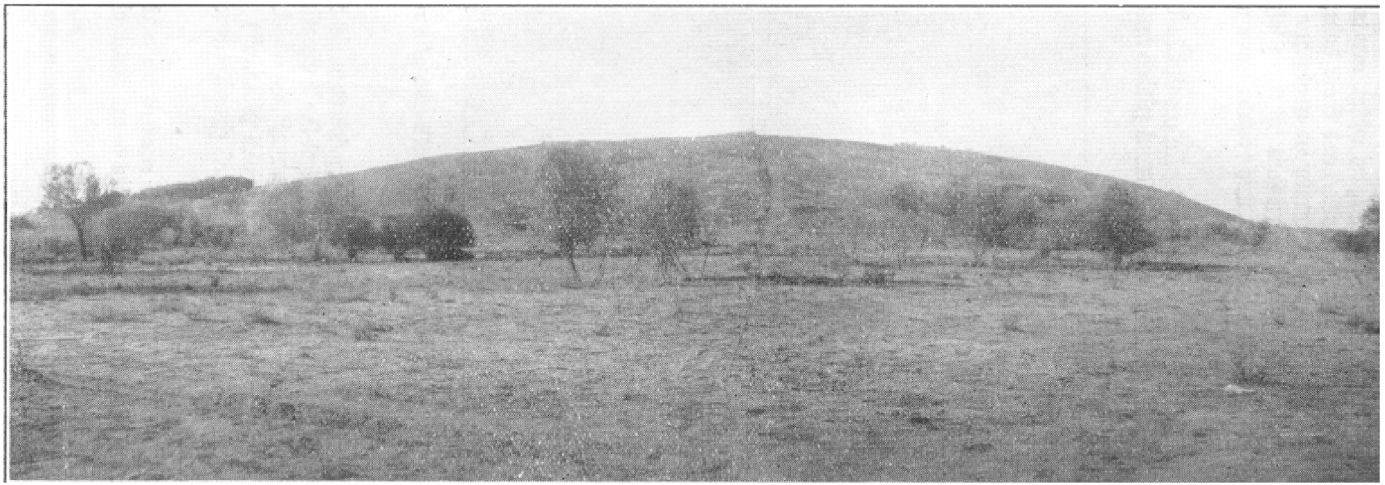


Fig. 135.—Pigeon Rock, Salinaland. An outcrop of granite, showing its bare, rounded form.

destitute of vegetation and present rounded flowing outlines, due to the exfoliation of the rock surface (fig. 108), on which are tors of various shape and size, some of which are hollowed out from below upwards in a remarkable manner, which often results in grotesque forms being produced. It is on the sides and at the foot of these island-hills that most of the valuable gnamma holes occur; "soaks" are also found at the foot

The widespread weathering of the granite results in the accumulation of a quartzose sand, which may form sand plains and sand ridges.

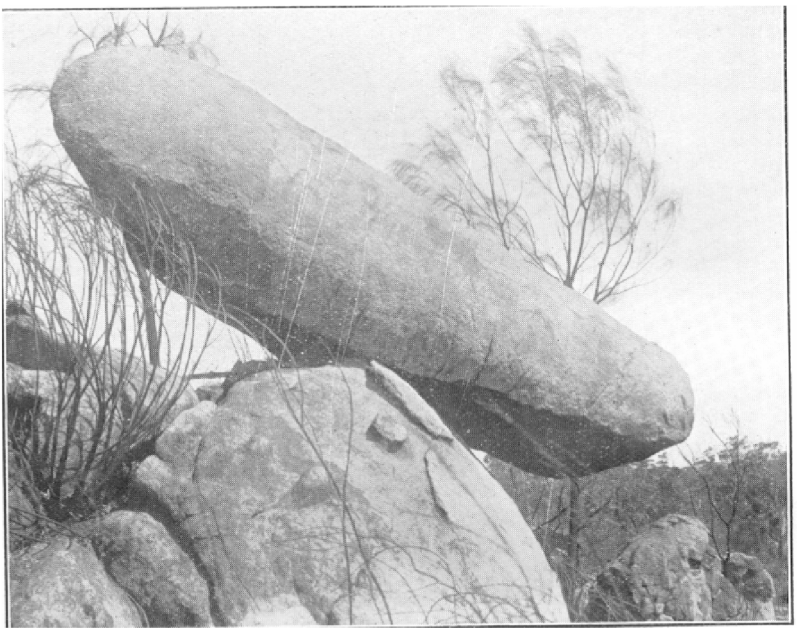


Fig. 136.—A granite tor. Yulgering district, north-east of Perth, Swanland.

Over wide areas the granite has become decomposed for some feet below the surface, a fact which has permitted the formation of laterite caps, which form the tops of the "breakaways," by which many mesas and buttes (which are remnants of the "old plateau") are bounded. When this cap is stripped off, the weathered granite develops a pitted surface (fig. 100).

In the coastal region of Swanland, an area of normal erosion, outcrops of granite as boulders, tors and floors occur similarly as in other lands. (See fig. 136.)

On the sea coast rounded flowing outlines occur in places, as at the entrance to Princess Royal Harbour, Albany; vertical faces or

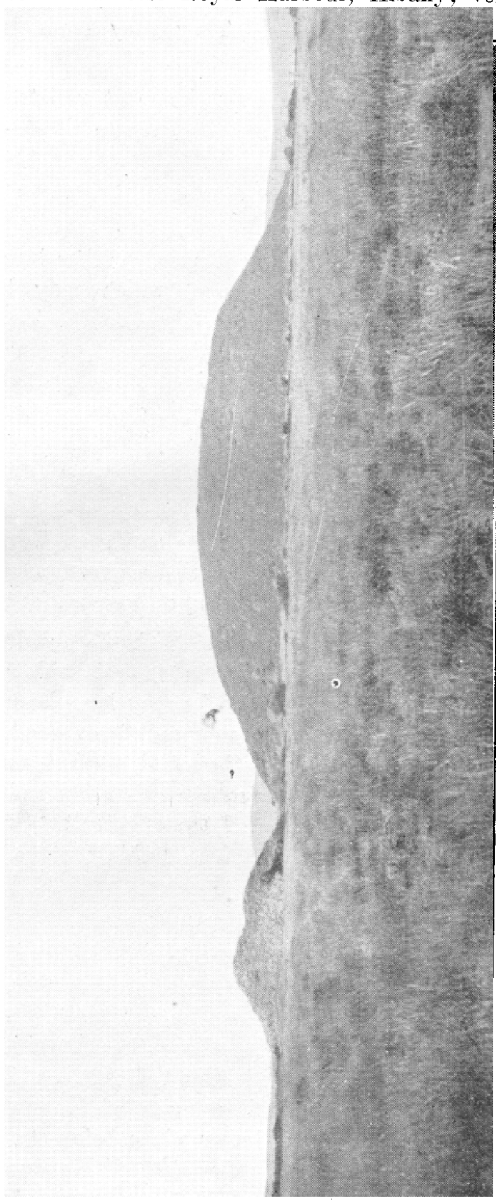


Fig. 137.—Peeawah Hill, West Pilbara, Pilbaraland. A residual of gabbro.

walls due to vertical joints are found in other places, as on the ocean coast south of Albany and on the Leeuwin-Naturaliste coast.

GREENSTONES AND THEIR DETRITUS.

Basic igneous rocks comprising gabbros, amphibolites, pyroxenites, hornblendites and others, for which the general field term "greenstones" is used, are common in Western Australia, and in many places are associated with granite and gneiss. They vary from fine to coarse-grained.

The greenstone rocks are amongst the most resistant to erosion. In many places they stand up above the granite plains as bold hills and ridges, thus often forming striking landmarks in the country, as, for example, Mt. Burgess near Coolgardie, and Peeawah Hill in Pilbaraland (fig. 137).

In places the coarse-grained greenstones weather into small knobs and fairly large boulders, examples of which may been seen at Goongarrie, Ora Banda and Yulgering (fig. 109). The fine-grained greenstones, however, break down into thousands of small fragments, averaging probably from two to four inches in size, owing to very close jointing. The fragments form creeping sheets of rock-waste on the sides and at the foot of the hills.

Decomposition *in situ* is a common feature of the greenstones, by means of which they may practically be transformed into clays. The alteration may extend to 300 feet from the surface. Very ferruginous laterite forms in places as a cap on these decomposed rocks, and "breakaways" may result, but they are not common.

A rather striking point in connection with the granites and greenstones is the formation of erosion scarps on old fault lines, between the two series of rocks. Both sets of rocks may have been planed down to a level surface, so as to obliterate any difference of surface level along the fault line. On uplift, differential erosion may reduce the granite to a plain, leaving the greenstone as an upland and the two separated by a scarp along the line of the old fault. Such a scarp is termed a "Fault-line Scarp." Examples of this feature occur in Pilbaraland.

QUARTZ PORPHYRIES.

These rocks are fairly widely distributed on the goldfields of Salinaland. They occur as dykes and small intrusive masses into the greenstones and old sediments. On account of their strong resistance to erosion they generally tend to rise above the surrounding rocks, in places as high prominent ridges and hills. Examples known to the writer are at Gordon, about 11 miles north of Kanowna, also at a point about five miles east of the latter place (close to the Kurnalpi Road), and at Kurnalpi, about 40 miles east of Kanowna.

In other localities (as at Ora Banda, a mining area about 40 miles north-west of Kalgoorlie, and at Niagara, 120 miles north of Kalgoorlie) the porphyries form long, thin dykes and the rocks outcrop in small low knobs (fig. 138).

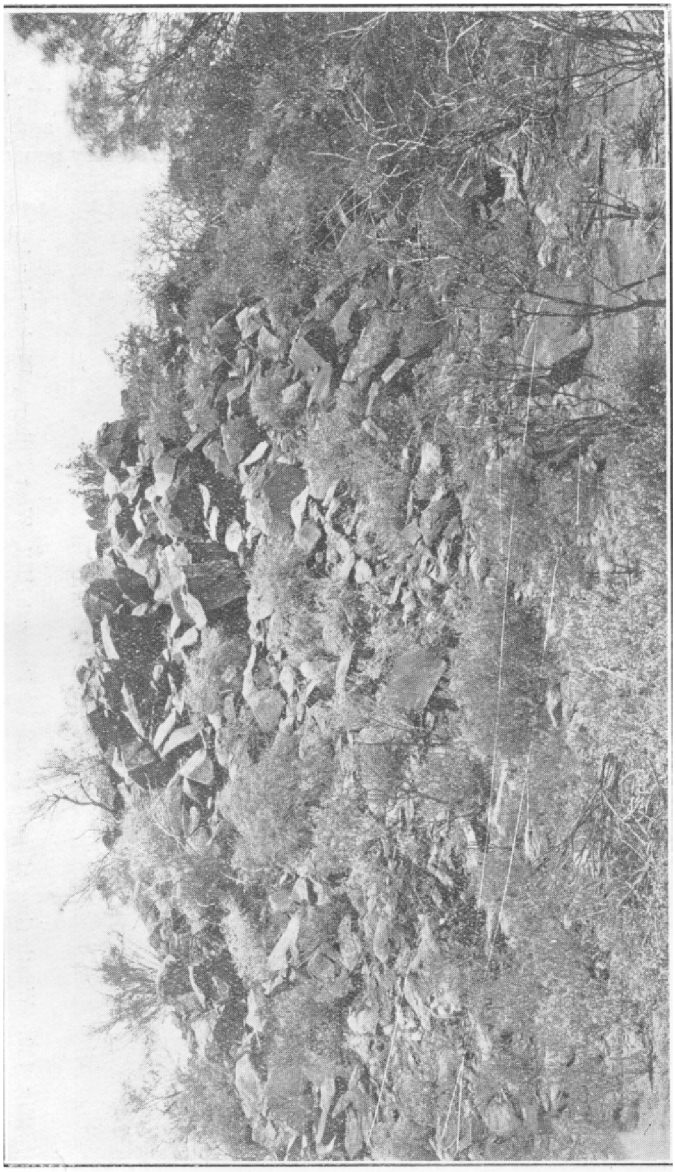


Fig. 138.—Weathering of quartz porphyry into low knobs at Niagara, about 120 miles north of Kalgoorlie, Salmaland.

HAEMATITE-QUARTZ ROCKS.

These rocks are usually laminated bands of igneous rocks that have become hardened by the introduction of secondary silica and iron. In places the miners term them "jasper bars." They

may carry gold or they may be associated with gold-bearing quartz, as at the famous "jasper bars" of Boogardie, near Mt. Magnet in Murchisonia.

The haematite-quartz rocks are of wide distribution in Western Australia, being found especially in Salinaland, Murchisonia, and Pilbaraland; and by reason of their very resistant character they generally

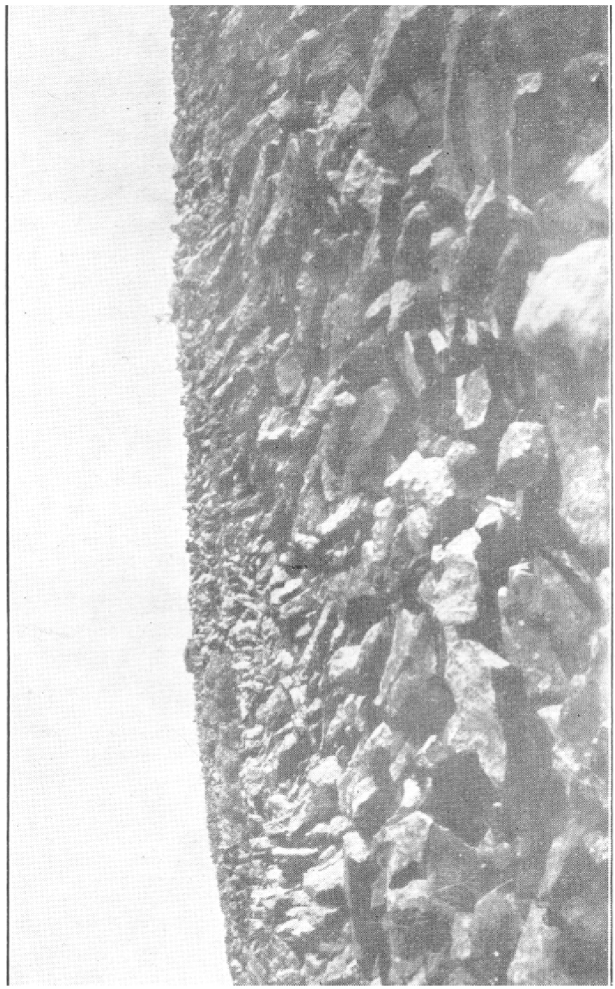


Fig. 139.—Weathering of gabbro, top of Peeawah Hill, West Pilbara, Pilbaraland.

project well above the surrounding country as long narrow ridges, which are usually parallel to the geographical "grain" of the country. In places in Pilbaraland, rivers cut right through them, but the streams are not antecedent. The haematite-quartz ridges have not been separately uplifted; the surrounding country has been denuded.

These outcrops present similar features to the haematite-quartz rocks of projection above the surrounding country and of rivers cutting through them, and the explanation of the projection of both groups is the same. Woodward (*n*, Pl. I.) shows an outstanding gabbro dyke about 50 miles long as occurring to the south of Roebourne in Pilbaraland. In the same physiographic division many dolerite dykes project above the granite plains. Thus Talbot notes (*d*, 131, 132) that in the granite area drained by the Shaw River, several dolerite dykes which rise from 100 to 200 feet above the adjacent country, constitute remarkable physical features in the landscape. One has been traced for 34 miles without its end being reached. Fig. 139 shows the mode of disintegration of a gabbro and fig. 140 the mode of occurrence of a dolerite dyke.

GIANT QUARTZ REEFS OR "BLOWS" AND THEIR DETRITUS.

Great quartz reefs or "blows" (fig. 141), which rise well above the country in the vicinity, are fairly numerous in Salinaland and in Pilbaraland. In the last-named division they may be broken by water gaps in the same way as the "jasper bars" and gabbro and dolerite dykes above described.

A rather interesting feature in connection with these reefs is the amount of detrital quartz that is sometimes shed from their outcrops. This detritus covers the ground, for perhaps a hundred yards or more from the outcrop, with angular fragments of white quartz, which constitute a slowly moving sheet of rock-waste. This surface accumulation must represent the wearing down of the reefs for a long period of time. The quartz detritus is practically all on the surface; below are the soil and subsoil; so that the quartz waste really constitutes a thin layer instead of the at first apparently thick one. The reason for this discrepancy is that the rain and the wind are constantly removing the soil between the fragments of the quartz; so that it is simply the latter that accumulates as a surface mass, not a comparatively thick deposit of quartz fragments and surface wash. Göczel (*a*, 25, 26) notes this feature and states that the fragments become somewhat rounded by the wind. Of course, in places there are layers of quartz with layers of soil and other detritus, but the above observations generally hold good.

Individual fragments may travel much more than 100 yards down a slope, and it is remarkable how little rounded (according to the writer's observations) they become in the course of their slow migration. The accumulations of detrital quartz just described form typical "Stone Fields." (See fig. 106.)



Fig. 140.—A dolerite dyke in granite. "Black Range," Shaw River, Pilbaraland. Note the worn down granite plain in front of the resistant dolerite ridge.

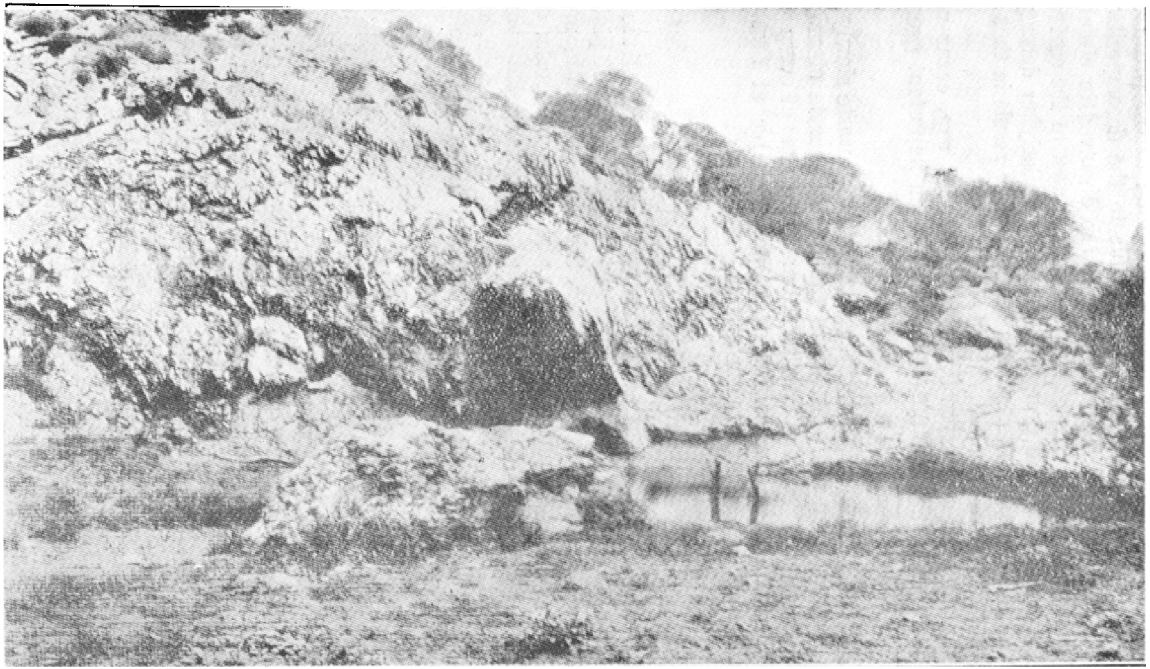


Fig. 141.—Quartz "Blow." Lawlers-Mt. Ida Road, Salinaland.

LATERITE AND ITS DETRITUS.

Laterite is extensively developed in Western Australia and may be ferruginous, siliceous, or aluminous, according to the predominant component. Its formation is essentially due to the decomposition of rocks by which iron, silica and aluminium are dissolved in circulating underground water. Portion of that water is drawn to the surface by capillarity, and laterite is precipitated on the underlying decomposed rocks, which it greatly protects from erosion. The result is that steep cliffs ("breakaways") are formed and they, together with the associated rock hollows and caves beneath the laterite cap, occur widely in the drier parts of the State, and constitute an important group of features in the landscape (figs. 102 and 103).

The detrital laterite forms a thin sheet of rock-waste slowly moving from the parent rock, similar to the detrital quartz already described. As some of the laterite takes the form of very small concretions, when the rock disintegrates, the detritus at first sight looks like a water-worn ironstone gravel.

CHERT AND ITS DETRITUS.

Chert is widely distributed in the country at the heads of the Fortescue, Ashburton and Gascoyne Rivers. It forms the caps of plateaux and is also found on the slopes of ridges, the underlying rocks usually being sediments of the Nullagine Series. As the chert breaks down, the angular detrital fragments form talus slopes and spread over the plains, forming "gibber plains." (See Simpson, *b*, 48 and 49, where references to Talbot's observations in Bulletin 83 of the Geological Survey of Western Australia are also given.)

LIMESTONES.

(a) *The Coastal or Dune Limestone.*

This rock is of very recent origin and borders the sea in narrow belts along various parts of the western and south-western coasts. The greater portion of it is essentially blown sand, which has been hardened into the present sandy limestone by the precipitation in the sand of calcium carbonate, the solution of which was obtained from the hard remains of mollusca and of other marine animals in the sand.

It has the usual characteristics of limestone country, such as abundant and large caves, often of great beauty, as in the south-western portion of the State, rapid run off of the surface water, and an underground circulation.

On the sea-coast, where the full effect of subaerial and marine erosion may be seen, the sea is cutting into it and forming marine

platforms. Above the action of the waves, the wind and rain fashion the rocks into fantastic forms, rough, ragged and fretted, forming a striking contrast with the smooth outlines of the bases of the cliffs, where the waves are abrading the rocks (fig. 142). The shapes as-

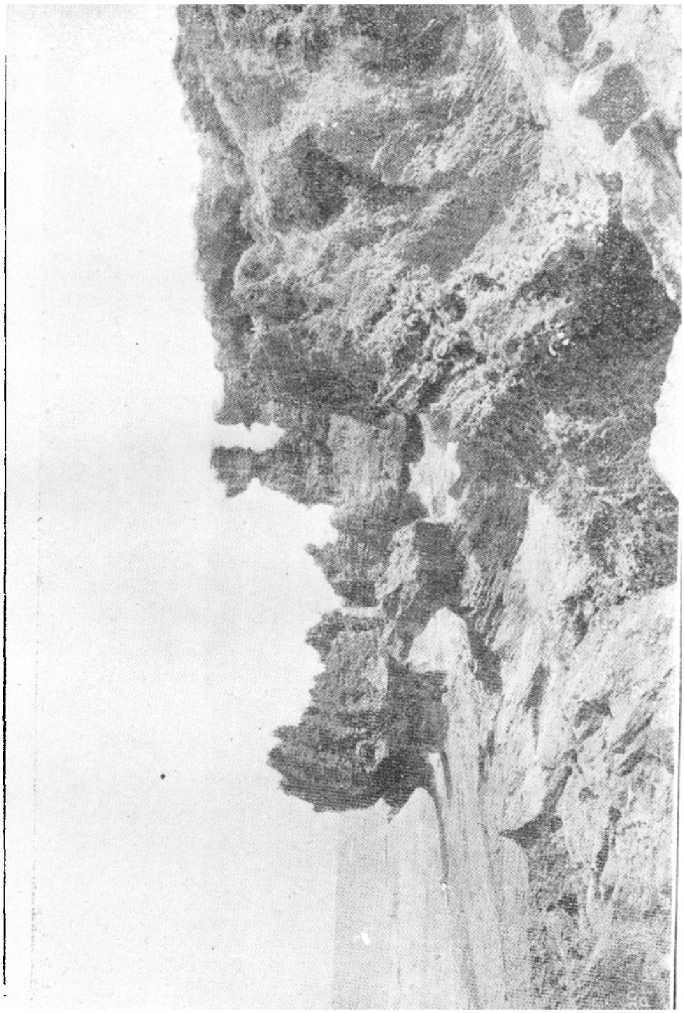


Fig. 142.—Coastal Limestone, showing the ragged atmospheric weathering, and the smooth surface and undercutting due to marine abrasion. Penguin Island, Warnbro' Sound, Swanland.

sumed above high-water mark are due to the unequal distribution of the calcium carbonate and of other substances through the rock. The cliffs along the estuary of the Swan River show examples of striking atmospheric erosion. (See fig. 143.)

(b) *Lower Carboniferous Limestones.*

These occur principally in Fitzroyland where they are massively-bedded and jointed rocks, generally with little dip, and, according to Hardman's description, weathering along the river valleys into huge

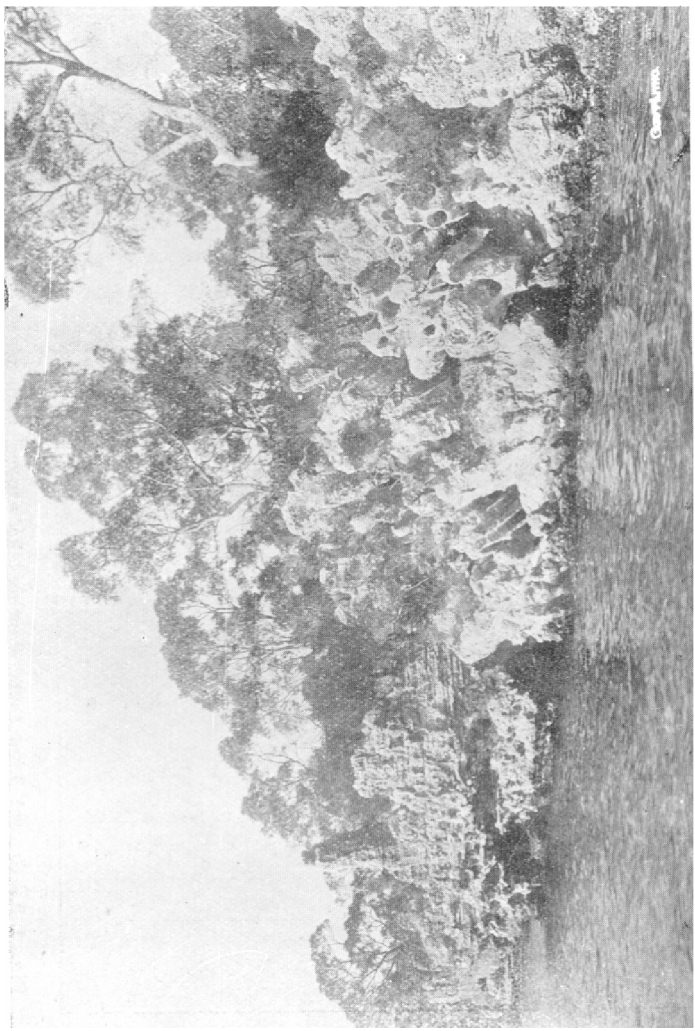


Fig. 143.—Coastal Limestone, showing its honeycombed and jagged appearance on exposure to the weather. Swan River, Perth.

cliffs and precipices (fig. 144). They are resistant to erosion, as they frequently form the rocks traversed by canyons in the river valleys, e.g., the Fitzroy in the Geikie Range (fig. 74) and the Lennard and the Barker in the Napier Range.

Jack (*a*, 11), states that the Oscar Range shows a rectilinear rampart of limestone, 47 miles in length. He also notes (13) two "walls"

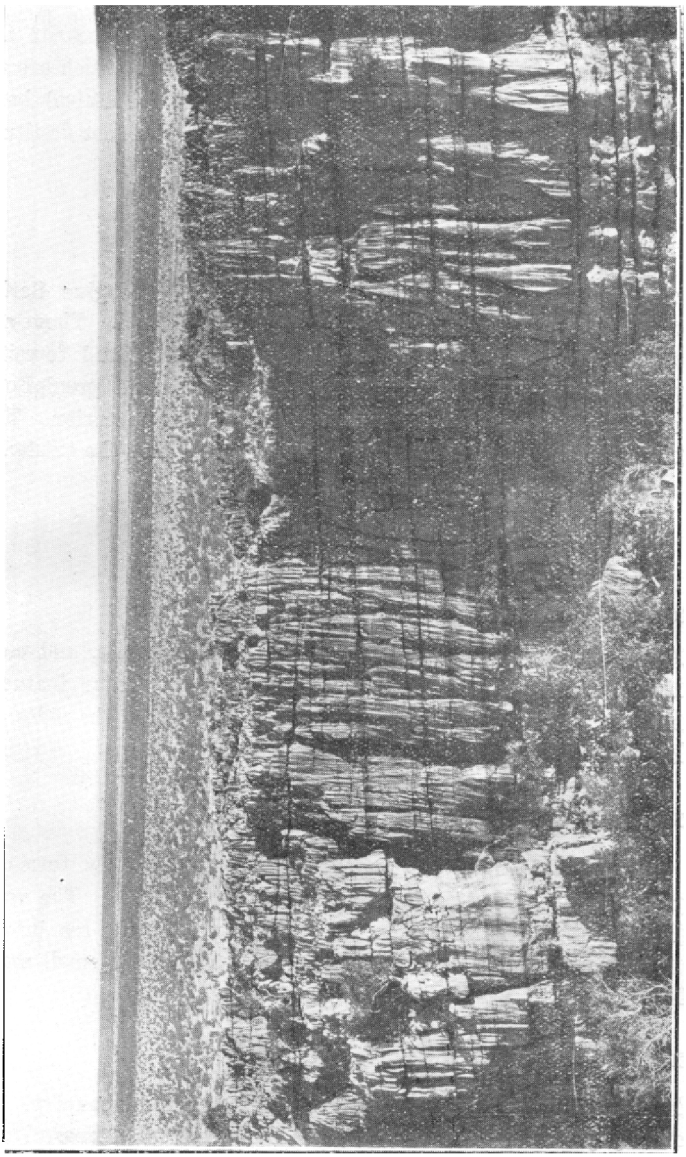


Fig. 144.—Carboniferous Limestone cliffs, showing the wall-like weathering, with the formation of "chimneys," and the great plateau beyond. Napier Range, Kimberley.

of limestone, one about 10 miles and the other possibly 45 miles in length, rising up in the midst of basaltic "downs." Hardman (*a*, 4) describes the Barrier Range (comprising the Napier, Oscar and Geikie

Ranges), as extending for miles like a vast wall, rising as it does, abruptly from the alluvial plains as a perpendicular cliff. This wall is, however, a fault scarp, the "Napier-Geikie Fault Scarp."

Woodward (*i*, 11), notes that the crystalline limestones of the Napier Range are riddled by numerous caverns, some of which are of very considerable dimensions. They have in the past (he states) been used by the natives as places of interment. They are almost destitute of stalactites.

ANCIENT SANDSTONES, GRITS AND CONGLOMERATES.

Rocks of this character forming part of the Nullagine Series occur extensively in North Kimberley and Pilbaraland. They are usually in nearly horizontal beds, and are in places found forming the caps of flat-topped hills and ridges, which are often precipitous on their sides, the result of the resistance of the rocks to erosion. The beds are seen to have been originally continuous, and thus the existence of old extensive plateaux is proved (fig. 145).

LAVA FLOWS.

(a) *Lava Flows and Fragmental Rocks of Pilbaraland.*

These rocks are interbedded with the sandstones, grits, and conglomerates just described, and they tend to present similar features of weathering, except that in the case of the lava flows, the sides of the hills are more precipitous.

(b) *Lava Flows of Swanland.*

A small outcrop of basalt on the coast near Bunbury forms a striking object by contrast with the adjacent sand dunes. The rock is roughly columnar in structure and is being worn by the sea into a wave-cut platform and into gulches, cliffs, and stacks on a small scale (fig. 146).

(*c*) *Lava Flows of Ordland.*

The Great Antrim Plateau occupies a wide extent of country. It is apparently yet little dissected, so that it is either a comparatively recent flow or an old peneplain, above the present surface of which much covering lava or other rocks have been removed,

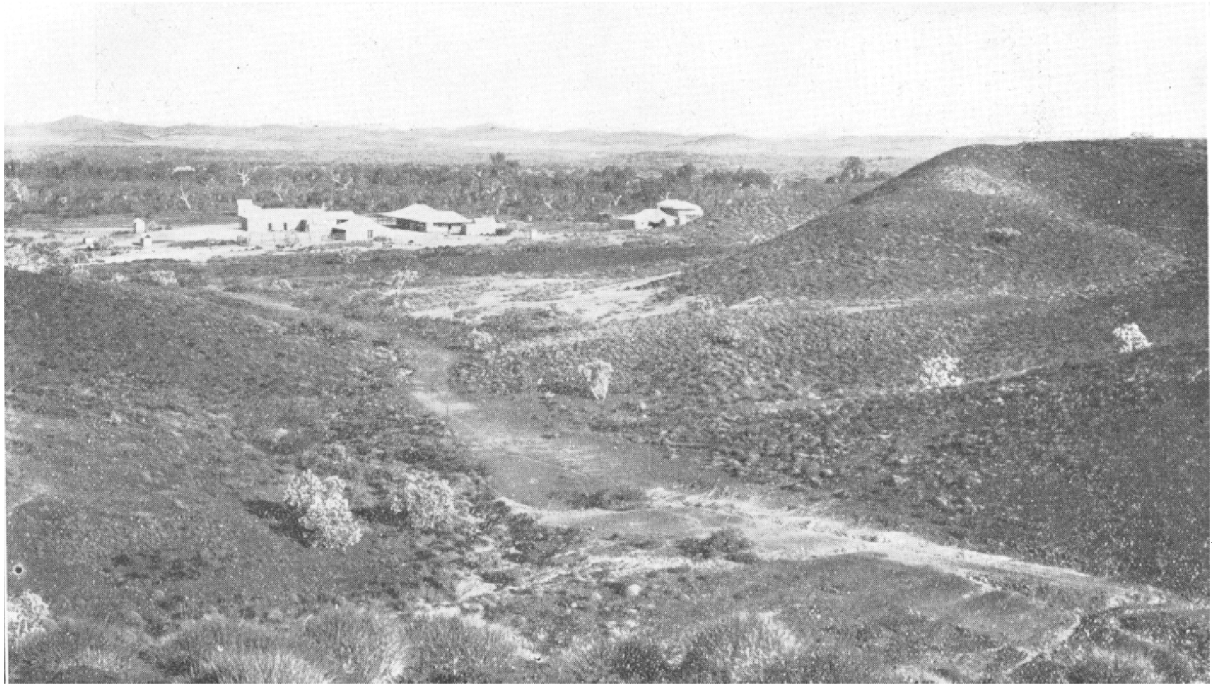


Fig. 145.—The dissected Nullagine Plateau, Nullagine, Pilbaraland.



Fig. 146.—A wave-cut platform in basalt. Bunbury, Swanland.

SCHISTS.

Extensive belts of these rocks occur throughout the country, but, as a rule, they do not make prominent surface features. They are frequently altered igneous rocks, and by reason of the abundant chan-



Fig. 147.—Weathering of chloritic schists. Goongarrie, Salinaland.

nels for circulating waters, they decompose rapidly. Where somewhat hardened by iron or silica, or both, they in places form low, rough, jagged outcrops (fig. 147).

JURASSIC SANDSTONES.

Around the Irwin, Greenough, and Chapman Rivers ferruginous, nearly horizontally-bedded sandstones of Jurassic age outcrop. They weather into flat-topped hills and steep (escarpment-like) slopes of very characteristic form.

OTHER FEATURES OF WEATHERING.

(*a*) *Sand Plains.*

These form one of the distinctive physical features of Western Australia. They occupy large areas of almost level country in the northern and eastern portions of Swanland, and in Salinaland and Sandland. They are comprised mainly of sand derived chiefly from the underlying rocks, which are either granite or sandstone. Near the coast they are usually covered only with a heathy vegetation, but inland, mallee eucalypts and spinifex are characteristic. In places the sand plains may be surrounded by well grown timber, which, however, is apparently growing on similar country. No explanation as to this anomaly has been given, except by Cleland, who suggests (119) in the case of the granite sand plains of the Cosmo-Newberry district (a locality north-east of Laverton), that such sand plains were at one time granite outcrops and that the places where the good timber grows represent the deeper and moister ground at the bases of such outcrops.

(*b*) *Sand Ridges of Sandland.*

These are due to the action of the wind in piling up the detritus (which is chiefly quartz) from the granites and sandstones of the area.

(*c*) *Travertine.*

Inland, this is often extensively developed. It is carried to the surface in solution, the water being drawn up by capillarity. On the evaporation of the water the travertine is deposited. It sometimes occurs in thin horizontal layers, making a deposit at times of several feet in thickness and of considerable hardness. This deposit seriously interferes with prospecting operations by the miners on the goldfields, and has, no doubt, prevented many rich auriferous lodes from being discovered. It is known as "cement" to the miners. It in places carries some secondary gold.

Travertine also coats hard rock pebbles, making them appear (until broken or scraped) as complete nodules of this substance. Along the Canning Stock Route extensive deposits of travertine occur, more or less associated with salt lakes. Talbot (*a*, 80) considers that the travertine has been derived from the mineralized waters of those lakes.

The mode of weathering in the areas of normal erosion calls for no special attention, but in the interior, where arid erosion prevails, and there are great diurnal changes of temperature, insolation is very pronounced. Also in spite of the very dry climate, chemical weathering is very strong, the rocks being decomposed in some cases, as already pointed out, for hundreds of feet vertically. Such an extent of deep chemical weathering is not common in arid lands, and consequently it may be evidence in support of a comparatively recent change of climate. The level of ground water below the surface of the ground varies from a few feet to hundreds.

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(*e*) A Report on the Country between Broomehill and the Dundas Hills, and the Mines in that neighbourhood. Appendix 3, *Ad Interim* Report of the Department of Mines for the half-year ending 30th June, 1894.

(*f*) Mining Handbook to the Colony of Western Australia, 2nd Edition, 1895.

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GLOSSARY.

Acid Rocks.
Igneous rocks containing a high percentage of silica.

Aggradation.
The raising of a land surface by the deposition upon it of material derived from the waste of the land. Its converse is degradation.

Air Gap.
Equivalent of Wind Gap, q.v.

Alluvial Plains.
Plains which are composed of the waste from the higher country brought down by rain and rivers.

Aluminous.
Containing alumina.

Amphibolite.
A metamorphic, in places schistose rock, with hornblende as the chief constituent and with subordinate felspar.

Antecedent River.
A river which existed prior or " antecedent " to the uplift of a portion of its valley, but which notwithstanding such uplift has been able to maintain its course. The uplift must therefore be regarded as very gradual.

Anticline.
An arch-like fold of strata having a long axis so as to form a ridge instead of a dome.

Archaeozoic.
The term is used to indicate the oldest known group of rocks, and means the oldest or primal life, although no direct evidence of life in those rocks is yet available.

Areic.
An area in which there is no run-off and therefore no drainage system.

Arid Erosion.
The erosion produced in arid countries, such erosion being due mainly to the action of wind, sun and rain in varying degrees, as contrasted with the predominant erosion by rain and rivers in countries with normal climates.

Artesian.
A term to describe water which when tapped by a bore, usually at considerable depths in the earth's crust, will rise to the surface.

Atmospheric Erosion.
A phase of normal erosion restricted to the breaking down of rocks by the chemical and mechanical agencies of rain, frost and changes of temperature.

Basalt.
Usually a fine-grained basic igneous rock which has been cooled on the surface of the earth as a lava flow. A basalt may, however, never reach the surface before cooling.

Base-Level.
As generally understood the term means the lowest level that the bed of a river can reach by normal erosion without further uplift of the land. This level tends towards that of the sea.

Base-Levelling.
The reduction by normal erosion of a portion of the earth's surface to base-level.

Basic rocks.
Igneous rocks containing a comparatively low percentage of silica.

Batholith or Bathylith.
A large irregularly shaped mass of igneous rock (usually coarse-grained) which has intruded other rocks at great depths.

Beach Conglomerate or Breccia.
A mass of waterworn or angular rock fragments formed at the shoreline of a lake or the sea, and subsequently hardened into a compact rock.

Beach Platform.
A narrow approximately level belt of marine deposits : (a) which have been formed below and subsequently have been uplifted above sea-level, or (b) which have been thrown up above sea-level by the waves, thus prograding the land.

Bedrock.
The rock of any particular area of the earth's crust below which to moderate depths no older rock is likely to be found.

Beheaded River.
A river, the upper portion of which has been cut off or " captured " by another river.

Betrunked River.
A river, some of the tributaries of which have been changed into separate rivers by the drowning of the lower part of the main trunk stream.

Billiard-Table Rock Floors.
Extremely level rock floors of " dry " lakes.

Block Faulting.
The breaking and movement of large portions of the earth's crust, by which distinct blocks of varying height are formed.

Blowholes.
Holes of various sizes, descending more or less vertically from the surface of the land and then extending approximately horizontally to the sea. They occur in the limestone of the Nullarbor Plains, and also are occasionally found in the immediate vicinity of the sea coast. The term is also used for more or less circular openings in the laterite cap of a rock hollow, passing downwards from the surface of the cap through the roof of the rock hollow.

" Blows."
A vernacular term applied to the prominent hills of quartz and ironstone in Western Australia and elsewhere.

Boathook Bends.
A sudden bend back of a tributary stream just before it joins the main river, often indicating river capture.

"Born Mature" Valley.
A term used by W. M. Davis to indicate a valley that has never had the features of a normal young valley.

Boss.
An amorphous mass of igneous rocks, mainly coarse-textured, which have disrupted the rocks through which they rise.

Braided.
A term applied to a stream which has a network of small channels in its own alluvium.

Breakaways.
A local term applied to the steep cliffs connecting the old and new plateaux. The top of the cliffs is usually capped by laterite, below which the rocks are decomposed.

Breccia.
A rock composed of angular fragments of pre-existing rocks, consolidated by some cementing material, such as silica, carbonate of lime, etc. The constituent rock fragments may be formed by the ordinary agents of weathering or by the crushing force exerted by great earth movements.

Butte.
A small mesa, q.v.

Cainozoic.
See Tertiary.

Calcareous.
Containing carbonate of lime.

Calcite.
Calcium carbonate.

Cambrian.
The oldest system of the Palaeozoic division of the geological record.

Canyon.
A Spanish name for a valley with steep and relatively high sides.

Carboniferous.
The second youngest system of the Palaeozoic division of the geological record.

Cement.
A local term indicating a tough rock which, in some places, is "wash" cemented together with silicia or other material, and in other places is decomposed bedrock hardened by the same material.

Chert.
A common type of chalcedony, which is a form of oxide of silicon.

Clay.
A general name for the fine aluminous sediments that are plastic.

Clay-pans.
Shallow depressions, generally circular in outline, and varying in diameter from a few to several hundred yards. They are floored with clay, and are bare of vegetation. After rain they hold fresh water for a time.

Coastal Plain.
A plain abutting the coast, usually composed of unconsolidated materials, such as gravels, sands and clays.

Conformable.
When two series of rocks are recognized as succeeding each other without a distinct break they are said to be conformable to each other. When such a break occurs, they are said to be " unconformable " to each other.

Conglomerate.
A rock composed of pebbles rounded by water action or by earth movements, and cemented by ferruginous, calcareous, siliceous or other material.

Conoplain.
A plain which is slightly raised in its central part above the remainder, so as to form a flat dome.

Consequent Stream.
A stream the course of which is determined by the contour of the land on its uplift.

Contorted Rocks.
Rocks which have been bent into folds.

Corrasion.
The action of a stream in cutting its channel. Corrasion may be downward, whereby the channel is deepened, when it is termed vertical corrasion ; or sideways, whereby the channel is widened, when it is termed lateral corrasion. Corrasion is one of the phases of erosion.

Cretaceous.
The third or youngest system of the Mesozoic division of the geological record.

Cross Faults.
Subsidiary faults which cross the main faults more or less at right angles to one another.

Crustal Deformation.
The bending or breaking of portion of the earth's crust. The term is generally applied to those earth movements which affect wide areas.

Crystalline Rocks.
Those rocks which are wholly or largely composed of minerals in a crystalline form. They are usually of deep-seated origin.

Cuesta.
A hill of gently inclined stratified rocks, having a steep gradient on one side, and a gentle one, which accords more or less closely with the angle of inclination of the rocks, on the other.

Cycle of Normal Erosion.
The sequence of events following the uplift of an area of land and ending in the formation of a peneplain.

Cyclic Salts.
Soluble salts which have been carried into the air in sea spray, and subsequently brought to the surface of the land by rain.

Deep Leads.
As used in Western Australia, this term means old stream channels which have become so buried beneath the waste of the land that the channels no longer act as drainage lines.

Deflation.
The transportation by the wind of sand and dust.

Deformation.
The folding, fracturing, faulting or warping of the earth's crust by earth movements.

Deformation Basins.
Basins on the surface of the earth formed by movements of the earth's crust.

Deformation Lakes.
Lakes in deformation basins, q.v.

Degradation.
The wearing down of a land surface by any of the agents of erosion.

Denudation.
A term equivalent to erosion, q.v.

Desert Erosion.
Equivalent to " Arid Erosion," q.v.

Desert Pavement.
Angular fragments of rock, e.g., quartz, so closely and evenly arranged that they form a pavement of rock in a mosaic.

Detritus.
The material derived from the waste of the land by erosion.

Devonian.
The fourth oldest system in the Palaeozoic division of the geological record. It follows the Silurian.

Diabase.
A basic igneous rock frequently occurring in sheets or dykes. Broadly speaking, it may be called an altered dolerite.

Differential Erosion.
The more rapid erosion of one portion of the earth's surface than another.

Dip.
The inclination from the horizontal of a stratified rock or of a lode. The angle formed by such inclination is termed the amount of such dip.

Dip Faults.
Faults in sedimentary rocks which run parallel to the dip of the rocks.

Dissected.
When a belt of country has been cut into hills and valleys by erosion it is said to be " dissected." There are degrees of dissection according to the stage of erosion reached.

Divide.
The belt of land (usually narrow) which separates one drainage system from another.

Dolerite.
A dark-coloured basic igneous rock consisting largely of augite and felspar. One of the " greenstones."

Dolomite.
A rock or mineral consisting of carbonate of lime and magnesia.

Dongas.
Shallow circular depressions of varying size in the surface of the limestone of the Nullarbor Plains, due to the falling in of the roofs of subterranean chambers.

Dreikanter.
A German term applied to rock fragments which have been facetted by the action of the natural sand blast. Strictly speaking, the term should be applied to those with three facets only.

Drowned Valleys.
Valleys the lower ends of which have been submerged beneath the sea. They frequently form deep winding gulfs or sounds.

Dune or Coastal Limestone.
The limestone found in places on the coasts of Swanland. It is due mainly to the hardening of old sand dunes by the precipitation of calcium carbonate.

Dykes.
Bands of generally vertical or nearly vertical igneous rocks, which traverse other rocks and which are thin in proportion to their length and depth.

Endoreic Area.
An area the drainage of which flows towards the interior and has no outlet to the sea. See " Exoreic " and " Areic " areas.

Eocene.
The oldest system of the Tertiary division of the geological record.

Epidiorite.
An altered " greenstone " rock now consisting essentially of hornblende and felspar.

Erosion Scarp.
A scarp (q.v.) produced by the agents of erosion.

Escarpment.
Equivalent to " scarp," q.v.

Estuarine Deposits.
Layers of mud, sand and gravel deposited in estuaries, and generally characterized by the remains of the fauna peculiar to such localities.

Exfoliation.
The scaling off of surface layers of rock due to changes of temperature.

Exoreic Area.
An area the drainage of which flows to the sea. See " Endoreic " and " Areic " areas.

" Exportation " of Detritus.
The removal by the wind of waste material on the earth's surface to another land area or to the sea.

Exsudation.
A term which indicates the splitting off of small rock fragments from the parent mass by crystallization of the salts contained in the water which rises by capillarity to the rock surface.

Exterior Drainage.
The drainage of a country which finds its way to the sea.

Fault.
A fracture in the earth's crust, along which one or both of the adjacent rock-masses has or have moved.

Fault Plane.
The surface along which the rock masses have moved during the formation of a fault.

Fault-Line Scarp.
A scarp which has been produced by differential erosion along an old fault.

Fault Scarp.
A steep face along a comparatively long straight line which has been produced by faulting.

Ferruginous.
Containing usually an oxide of iron.

Fiord or Fjord.
A deep narrow valley now forming an inlet of the sea, but which has its bottom deeper within the inlet than at its mouth. See Ria.

Flexure.
The bending of the rocks of the earth's crust.

Flood Plain.
A plain composed of alluvium which has been brought by a river from higher to lower ground, and spread over the surface of the latter.

Fluviatile.
Pertaining to rivers.

Folded Rocks.
Rocks which by movements within the crust of the earth have been thrown into a series of arches and troughs of a widely varying character.

Foliation Planes.
A series of approximately parallel close-set planes in a rock mass, by which minerals are arranged in distinct lines, and the rock acquires an appearance somewhat like the edges of a book.

Fracture.
The actual breaking or dislocation by natural agents of rocks of the earth's crust.

Fragmental Rocks.
Rocks, such as sandstones and conglomerates, composed of the fragments of other rocks.

Gabbro.
A basic igneous rock generally of deep-seated origin, and composed chiefly of augite and felspar.

Geological Record.
A general history of the succession in time of the rocks forming the earth's crust, together with the succession of animal and vegetable life as revealed by the rocks, and the physical changes on the surface of the earth and in the earth's crust.

Geological Structure.
The mode of arrangement of the different rock masses which form the crust of the earth.

Geomorphology.
The science which treats of the origin and history of land forms.

Glacial Conglomerate.
A rock composed of rounded pebbles, such rounding being mainly the work of ice.

Gnamma Holes.
Small holes of varying shape, diameter and depth, found on hard granite outcrops and in the decomposed granite of the " breakaways."

Gneiss.
A rock generally similar in composition to a granite, but having its component minerals arranged in definite layers or " folia." A gneiss is a metamorphic rock and may result from either a sedimentary or an igneous rock.

Grade.
When a river has reached the condition that it is neither cutting down nor building up, it is said to be " at grade."

Granite.
A typical coarsely crystalline acid igneous rock of deep-seated origin composed usually of quartz, felspar and mica or hornblende.

Greenstone.
A broad field term to include various altered igneous basic rocks, such as gabbros and dolerites.

Grit.
Coarse sandstone composed mostly of angular quartz fragments cemented together.

Ground Water Table.
See Water Table.

Gypsum.
Hydrous calcium sulphate.

Haematite.
An anhydrous oxide of iron.

Haematite-quartz rock or Haematite-quartzite.
A metamorphic rock commonly occurring on the goldfields of the State, composed chiefly of haematite and quartz.

Halophytic.
A term applied to plants which live in soils rich in common salt.

Hanging Valley.
A term usually applied to a tributary glacial valley, the mouth of which is perched well up the side of the main valley. It is also used to indicate any valley the mouth of which is above the beach in a cliff of the sea coast, or upon the side of a normal river main valley.

Hornblendite.
A rock consisting almost wholly of hornblende plates or prisms and containing no felspar.

Horst.
A great earth block from which the originally continuous adjacent rock masses have subsided along powerful fractures of the earth's crust.

Igneous Rocks.
Rocks which have originally been in a molten condition and have cooled either on or within the earth's crust. Those which have reached the surface in a molten state are termed volcanic or effusive, and those cooled far below the surface are termed plutonic or intrusive.

Immature.
A term applied to certain land forms such as river valleys, to indicate that erosion is still vigorously proceeding.

Inselberge.
Isolated hills or ridges, the result of long-continued arid erosion. The anglicized form is " island hills."

Insequent River.
A river, the position and direction of which are not clearly determined by geological structure or initial contour of the land surface, in these respects differing from consequent, subsequent and obsequent streams.

Insolation.
Exposure to the sun's rays. Rocks so exposed are thereby subject to many changes of temperature, which are powerful factors in the disintegration of the rocks.

Interior Drainage.
Drainage that does not reach the sea but runs towards the interior of the land.

Island Hills.
Isolated hills or ridges, the result of long continued arid erosion. The anglicized form of " Inselberge."

Isohyets.
Lines along which an equal average quantity of rain falls annually.

Jasper.
Opaque chalcedony of red, brown, yellow or green colour.

Jasperoid Rock.
A metamorphic rock resembling jasper or largely composed of that mineral.

Joints.
Cracks or partings in a rock distinct from bedding or cleavage planes.

Jurassic.
The middle division of the Mesozoic division of the geological record.

Kainozoic.
See Tertiary.

Lacustrine.
A term applied to deposits which have been laid down in fresh water lakes or marshes.

Lateral Erosion.
The wearing away of the sides of a valley in contrast to vertical erosion which deepens it.

Laterite.
A term used in Western Australia to indicate the hard cap on granite and other rocks, such cap having resulted from the decomposition of those rocks. Laterite may be predominantly ferruginous, aluminous or siliceous.

Lava.
A rock which has issued in a molten state from vents or fissures and which solidifies on or close to the surface of the earth.

Leucitite.
A basic volcanic rock in which the mineral leucite occurs as an important constituent.

Lignite.
A brown coal showing a woody structure.

Limestone.
A rock composed mainly of carbonate of lime. Most limestones have been formed in the sea by the accumulation of the hard parts of marine animals and plants.

Lithology.
The character of a rock due to the nature of its component minerals broadly considered.

Longitudinal Stream or Valley.
A stream or valley which runs parallel to the strike of the rocks traversed by it.

Marginal Drainage.
Drainage, the principal lines or line of which run or runs parallel and comparatively close to the coast.

Marine Abrasion.
The erosive action of the sea.

Marl.
An earthy and usually soft form of limestone.

Mature River.
A river possessing a valley with graded slopes and a broadened floor on which the river may meander freely.

Meander System.
A river which has a series of swinging bends or meanders may be said to have a meander system.

Mesa.
A flat-topped remnant, due to subaerial erosion, of a plateau.

Mesozoic.
The great division of the geological record between the Palaeozoic and the Tertiary division.

Metamorphic Rocks.
Rocks which have suffered such great chemical or mechanical changes that the original characters of the rocks are largely obliterated.

Migration of Lakes.
A term applied to the slow lateral movement of the " dry " or salt lakes of Western Australia by erosion and deposition.

Miniature Soil Terraces.
Tiny approximately parallel terraces cut in the surface soil by rain on a gentle slope.

Miocene.
The third oldest and second youngest system of the Tertiary or Kainozoic division of the geological record.

Monadnock.
Equivalent to " Residual, " q.v.

Monoclinal Fold.
A great bend by which (usually) horizontal strata curve downwards and then regain their horizontal position.

Mud Spring.
A spring which brings much fine rock material in the form of mud to the surface of the ground.

Natural Bridge.
A natural arch in a projecting narrow mass of rock, the top of which, in th interior of Western Australia, may be harder than the lower parts, which fa facilitates the formation of the arch.

Natural Quarry.
An excavation, resembling an artificial quarry, made by natural agents, the chief of which is the rain, on a hillside or on a lake cliff in the interior of Western Australia.

Natural Region.
A particular area of the earth's surface having a generally similar climate, topography, vegetation and human occupation.

Negative Displacement of the Strand Line.
The apparent rising of any portion of the land above sea-level.

Normal Dissection.
The formation of hills and valleys by the ordinary or normal agents of erosion, *i.e.*, rivers, rain, frost, changes of temperature, etc.

Normal Erosion.
The wearing down of the surface of the land above sea-level by the agents operating in a normal climate. Such agents are chiefly rain, and rivers. Other kinds of erosion are distinguished as marine, glacial and arid.

Normal Erosion Scarp.
A scarp produced by the ordinary agents of erosion.

Normal Fault Scarp.
A scarp due to the ordinary process of faulting.

Obsequent Stream.
A stream which flows in the opposite direction to a consequent river, of which it at one time formed a part, but the direction of which part has been reversed by capture by a subsequent river.

Old River.
A river possessing a comparatively wide valley with faint slopes forming its sides.

Oligocene.
The second oldest system of the Tertiary division of the geological record.

Ordovician.
The second oldest system of the Palaeozoic division of the geological record.

Overthrusting.
The movement of one mass of rock over another, which, in places, has resulted in older rocks overlying younger ones.

Ox-Bow Lake.
A lake which has been formed by the cutting off of a river meander, with subsequent silting up of the latter at its cut-off ends.

Palaeontology.
The science which treats of the ancient remains of animals and plants embedded in sedimentary rocks.

Palaeozoic.
The great division of the geological record which succeeds the Pre-Cambrian and which contains the first abundant evidence of ancient life upon the earth.

Pediment.
A gently sloping rock surface of erosion at the foot of hills or mountains, usually in arid or semi-arid country.

Peneplain.
As used in this work, a gently rolling lowland, forming an " almost plain " surface, which is due to long-continued fluvial erosion. Sometimes spelt " peneplane."

Peneplanation.
The reduction or wearing down by normal erosion (q.v.) of a portion of the earth's surface to a featureless lowland or peneplain.

Permian.
The youngest system of the Palaeozoic division of the geological record.

Permo-Carboniferous.
A term applied to a rock series which possesses characters pertaining both to the Carboniferous and to the Permian systems of the geological record.

Physiography.
The science which treats of the origin and history of land forms.

Piedmont Plain.
When a series of rivers passes from the highland to a plain, the rivers build alluvial fans or flat cones at the foot of the highland. When the fans or cones coalesce they form a piedmont plain.

Plain of Erosion.
A plain or nearly plain surface of a portion of the earth's crust, which has been produced by erosion. Such plains may be normal, marine or arid.

Plain of Marine Abrasion.
A plain formed beneath the sea by the erosive powers of the latter.

Plain of Marine Denudation.
Equivalent to a " plain of marine abrasion," but now obsolescent.

Planation.
The reduction to a level or nearly level surface of a portion of the earth's exterior by erosion.

Playa.
An extensive bare level area in an arid country, the surface materials of which are usually fine silts which may be impregnated with salts. Its surface is occasionally covered with thin sheets of water which rapidly evaporate.

Pleistocene.
The great geological period immediately preceding the present epoch, which is known as the Recent Period, the two periods often being referred to as the Post-Tertiary.

Pliocene.
The youngest system of the Kainozoic or Tertiary division of the geological record.

Positive Displacement of the Strand Line.
The apparent sinking of a portion of the land beneath the sea.

Post-Pliocene.
Equivalent to Post-Tertiary or Quaternary.

Post-Tertiary or Quaternary.
Later than the Pliocene. It includes the Pleistocene and Recent periods.

Pre-Cambrian.
A term applied to all rocks older than the oldest system of the Palaeozoic division. The Pre-Cambrian rocks are divided into the Archaeozoic and the Proterozoic.

Primary Breakaway.
The original breakaway (q.v.) without change in its general level. *Cf.* " Secondary Breakaway."

Proterozoic.
The term is used to indicate a group of rocks older than the Cambrian and younger than the Archæozoic, and means the time of first known life.

Pseudomorph.
The taking by a mineral of a form which does not really belong to it.

Pyroxenite.
A granitoid, non-felspathic rock, the chief mineral of which is pyroxene. It contains no olivine.

Quartz.
A common oxide of silicon. There are many varieties. Rock crystal is the purest form.

Quartzites.
Rocks composed almost wholly of silica. They are of various origin.

Quartz Porphyry.
An acid igneous rock closely related to granite, but generally found in dykes and small masses.

Quaternary or Post-Tertiary.
Later than the Pliocene. It includes the Pleistocene and Recent periods.

Radial Drainage.
Drainage which tends to run or " radiate " towards the coast or inland basins.

Raised Beach.
An old sea beach which has been relatively raised above present sea-level.

Rejuvenated River.
Equivalent to " Revived River," q.v.

Residual.
A hill which projects above the general surface of a peneplain, the residual having escaped the erosion which formed the peneplain. Equivalent to "Monadnock."

Revived Fault Scarp.
A scarp which has been formed by renewed faulting along an old fault line.

Revived River.
A river which has gained new erosional activity, usually by an uplift of the land.

Ria.
A partially submerged normal valley.

Rift Valley.
A comparatively narrow valley due to faulting, and bounded by more or less parallel fault scarps.

River Capture.
The term applied to the process by which one river may " capture " or divert a portion of the water of another river to itself.

River Piracy.
Equivalent to " river capture," q.v.

Rock-hole.
A hole excavated in solid rock in the arid portions of the State by the flood waters of occasional streams. Such a hole is different in origin from a gnamma hole, q.v.

Rock Hollow or Shelter.
A hollow or cave cut more or less horizontally beneath a hard rock cap or at the foot of a lake cliff of hard rocks.

Rock Weathering.
The general term applied to all natural methods by which a rock is broken up and decays.

Salina.
An extensive level area in an arid country which is occasionally covered with thin sheets of water. The surface of such an area is covered with sheets of salt of varying thickness. See " Playa."

Sand Glacier.
A stream-like tongue of sand formed by the sand having been blown from one side of a ridge to the other.

Sandstones.
Rocks composed essentially of compacted, usually quartz, sand. The character of the rock may vary according to the nature of the cementing material, such as iron, lime, etc.

Scarp.
The face forming a sharp transition from a higher to a lower belt of country. It may be due either to erosion or to faulting.

Schists.
Metamorphic rocks (with a predominant mineral such as mica, hornblende, etc.), which split along approximately parallel lines.

Sclerophyllous.
A term applied to plants in which the epidermis of the leaves is composed of thick-walled (scelerenchyma) cells with a very heavy cuticle.

Secondary Breakaway.
A breakaway (q.v.) which has been cut into or below the base of a primary breakaway.

Sedimentary Rocks.
Rocks which have been formed as " sediments " or deposits under water. Wind-blown deposits (aeolian rocks) are generally included in this series, notwithstanding their inability to fit the definition.

Shale.
A sedimentary clayey rock, which splits along the original planes of deposition.

Sheet Flood or Sheet Flow.
A wide body of water, usually very thin, which spreads over the surface of the ground in the dry interior after heavy rain.

Siliceous.
Containing silica.

Sill.
A sheet of volcanic rock injected between layers of other rocks.

Silurian.
The third oldest system in the Palaeozoic division of the geological record. It follows the Ordovician.

Slate.
An argillaceous rock which splits into thin plates at various angles to the bedding.

Sparselands.
A term applied by Griffith Taylor to the very sparsely inhabited and stocked pastoral lands of the interior of Australia.

Spit.
A narrow belt of sand and other fragmental material projecting from the mainland or an island into the sea or a lake, and built up by waves or currents.

Spur.
A prominent projection in a valley sloping from the top of the valley downwards and due to the winding course of a stream.

Stanniferous.
Tin-bearing.

Step Faults.
A series of approximately parallel faults along which blocks of the earth's crust have been lowered or raised to different levels.

Stone Field.
An area so littered with the fragments of hard rocks, e.g., quartz and ironstone, as to cover, practically completely, the surface of the ground.

Strata.
The series of successive deposits one above the other which compose a sedimentary rock.

Stratification Planes.
The planes between the strata or layers of sedimentary rocks.

Stratigraphy.
That branch of geology which treats of the age and succession of (mainly) the great sedimentary rock masses.

Strike.
The general trend or direction in a horizontal line of a lode, stratum or fault.

Subaerial.
A term applied to the form of erosion which takes place " under the air," i.e., on the surface of the land as distinct from that beneath the waters of the ocean.

Sub-artesian.
A term having the same application as " artesian " except that the water in the bore does not actually reach the surface.

Subsequent Stream.
A stream, the course of which is usually parallel to the strike of the rocks, but which is a tributary to a consequent stream.

Sunkland.
An earth block which has been sunk relatively to the surrounding area.

Superimposed Stream.
A stream which has cut through a more or less thin cover of rocks into underlying rocks of different age and structure, the course of the stream being primarily determined irrespective of the character of such underlying rocks.

Syncline.
A trough-shaped curve of strata, having one long axis, which distinguishes it from a basin.

Tectonic.
A term indicating that a particular land form or the geological structure of a district is due to earth movements.

Tertiary.
The great division of the geological record immediately preceding the Post-Tertiary or Quaternary period.

Thalweg.
The lowest line in and along the course of a valley.

Tilted.
Used to describe an earth block which has been raised or " tilted " unequally.

Transverse Stream.
A stream which cuts across the strike of the rocks.

Travertine.
As used in Western Australia the term indicates a deposit composed of carbonate of lime, laid down on or close to the surface of the ground from evaporating water containing the substance in solution.

Trough Faulting.
The lowering of a block of rocks deeper into the earth's crust along fault lines.

Truncated Upland.
An elevated belt of country, the component rocks of which have been worn down or " levelled " by erosion.

Unconformable.
See " Conformable."

Volcanic Ash.
A rock consisting of small fragments of rock ejected from a volcano.

Volcanic Breccia.
Rock fragments of various sizes, ejected from a volcano and subsequently cemented together.

Volcanic Neck.
A plug of volcanic rock in the old funnel of a volcano.

Volcanic Rocks.
Rocks which have reached the earth's surface or close to that surface in a molten state, from which they have since solidified.

Warping.
The gentle bending of the earth's crust without forming pronounced folds or dislocations.

Water Gap.
A gap or notch cut by a river through a ridge of hard rocks.

Watershed.
Synonymous with " Divide," q.v.

Water Table.
The top of the layer of water beneath the surface of the earth's crust.

Wave-cut Platform.
A rock bench which has been cut by marine abrasion on a coast line.

Weathering.
The decomposition, disintegration and breaking up of the surface of the earth's crust by the action of changes of temperature, and of wind, rain and frost.

Willi Willies.
Violent circular dust whirls of varying diameter and height which traverse the interior of Western Australia on calm summer days. Also known as dust whirls.

Wind Brush.
A term used by W. M. Davis to indicate the removal of dust and fine sand from the surface of the ground by the wind.

Wind Gap.
A water gap not now occupied by a stream in consequence of the capture and reversal of flow of the upper portion of the latter.

Young River.
A stream which usually possesses a valley having steep and little dissected sides.

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By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

VEGETATION
MAP OF
WESTERN AUSTRALIA

Scale of English statute miles.
30 40 30 20 10 0 50 100 150 200

— REFERENCE —

Sclerophyllous types
(undergrowth harsh leaved shrubs).

- **Low rainfall tropical woodlands.*
- **Low rainfall temperate forests and woodlands with belts of sand heaths and mallee*
  (Vernacular: Salmon gum forest and sandplains).
- **Sclerophyllous forest*
  (Vernacular: Jarrah forest).
- **Temperate Eucalyptus rain forest*
  (Vernacular: Karri forest).

Savannah types
(undergrowth herbaceous, principally grasses).

- **Savannah forests and woodlands.*
- *Savannah.*
- *Mulga (Acacia) bush.*

**Denotes forests and woodland where Eucalypts are the dominant species.*

Treeless regions.

- *Saltbush plains*
  (Vernacular: Nullabor plains).
- *Desert with spinifex and belts of low shrubs.*

Fringing Forests.
Throughout the savannah woodland region of the Kimberley Division tropical rain forests occur in narrow belts fringing the principal water courses.

Mangrove formation.
Mangroves occur from Carnarvon Northwards along the coast but only develop as distinct forest formations in the estuaries Northwards from Derby.

Isohyets shown thus 10"

TIMOR SEA
BONAPARTE ARCHIPELAGO
ADMIRALTY GULF
Cape Bougainville
Cape Londonderry
JOSEPH BONAPARTE GULF
CAMBRIDGE GULF
PRYSDALE R.
FORREST R.
DURACK R.
WYNDHAM
BUCCANEER ARCHIPELAGO
YAMPI SOUND
COLLIER BAY
Mt. HANN
CHARNLEY R.
Cape Leveque
CARNOT BAY
KING SOUND
DERBY
KING LEOPOLD RANGE
NORTHERN HIGHWAY
ORD RIVER
BROOME
ROEBUCK BAY
FITZROY CROSSING
FITZROY RIVER
GREAT NORTHERN HIGHWAY
HALLS CREEK
TO DARWIN & WAVE HILL
EIGHTY MILE BEACH
DAMPIER ARCHIPELAGO
PORT SAMSON
PORT HEDLAND
PROBOURNE
BARROW I.
DE GREY RIVER
MARBLE BAR
NORTH WEST COASTAL HIGHWAY
ONSLOW
FORTESCUE RIVER
NULLAGINE
North West Cape
EXMOUTH GULF
ASHBURTON RIVER
HAMERSLEY RANGE
WITTENOOM GORGE
Mt. BRUCE
LAKE DORA
LAKE MACKAY
STOCK ROUTE
Pt Cloates
TROPIC OF CAPRICORN
LAKE DISAPPOINTMENT
LAKE MACDONALD
INDIAN OCEAN
Mt. EGERTON
GASCOYNE RIVER
CARNARVON
BERNIER I.
DORRE I.
SHARK BAY
Cape Inscription
West Pt
DIRK HARTOGS I.
Steep Pt
WOORAMEL RIVER
GLADSTONE
HAMELIN POOL
ROBINSON RANGE
PEAK HILL
GREAT NORTHERN HIGHWAY
RABBIT PROOF FENCE
The Weld Spring
LAKE NABBERU
RAWLINSON RANGE
LAKE CARNEGIE
MEEKATHARRA
WILUNA
LAKE WAY
NANNINE
MURCHISON RIVER
BIG BELL
CUE
LAKE AUSTIN
MT. MAGNET
SANDSTONE
LAWLERS
AJANA
NORTHAMPTON
YUNA
YALGOO
GREENOUGH R.
MULLEWA
HOUTMAN ABROLHOS
CHAMPION BAY
GERALDTON
WALKAWAY
PELSART I.
YOUANMI
LAKE BARLEE
LAKE LEONORA
GWALIA
LAVERTON
MALCOLM
LAKE CAREY
RAESIDE
MENZIES
DONGARA
MORAWA
MINGENEW
THREE SPRINGS
PERENJORI
CARNAMAH
MAYNES FIND
MONGERS LAKE
LAKE MOORE
JURIEN BAY
WUBIN
DALWALLINU
PITHARA
MILING
KALANNIE
KULJA
BONNIE ROCK
BROAD ARROW
KANOWNA
KALGOORLIE
COOLGARDIE
BOULDER
ZANTHUS
RAWLINNA
FORREST
DEAKIN
TO ADELAIDE
NULLARBOR PLAIN
MOORA
PIAWANING
NEW NORCIA
DOWERIN
WONGAN HILLS
ROORDA
BENCUBBIN
CHANDLER
LAKE BROWN
CAMPION
BULLFINCH
SOUTHERN CROSS
WYALKATCHEM
NUNGARIN
GOOMALLING
MERREDIN
NORTHAM
MECKERING
CUNDERDIN
GREAT EASTERN HIGHWAY
BOLGART
GINGIN
AVON R.
YORK
QUAIRADING
BRUCE ROCK
NAREMBEEN
LAKE COWAN
NORSEMAN
LAKE LEFROY
EYRE HIGHWAY
EYRE
EUCLA
10" TO ADELAIDE
PERTH
FREMANTLE
SWAN R.
SPENCERS BK.
KELLERBERRIN
CORRIGIN
KONDININ
HYDEN
MANDURAH
PINJARRA
NORTH DANDALUP R.
SERPENTINE R.
PINGELLY
BROOKTON
WICKEPIN
WILLIAMS
WAROONA
YARLOOP
HARVEY
BRUNSWICK
COLLIE
BUNBURY
GEOGRAPHE BAY
BUSSELTON
Cape Naturaliste
CAPEL R.
BALINGUP
GREEN BUSHES
BRIDGETOWN
TAMBELLUP
NEWDEGATE
LAKE GRACE
PINGRUP
RAVENSTHORPE
KATANNING
CHOWANGERUP
ONGERUP
MARGARET R.
BLACKWOOD R.
NANNUP
MANJIMUP
AUGUSTA
Cape Leeuwin
NORTH CLIFFE
WARREN R.
DENMARK R.
ALBANY HIGHWAY
STIRLING RANGE
PALLINUP R.
MT. BARKER
Cape Riche
Cape Knob
BREMER BAY
Cape Vancouver
KING GEORGE SOUND
ECLIPSE I.
D'Entrecasteaux Pt
WALPOLE
NORNALUP INLET
FLINDERS BAY
HOPETOUN
ESPERANCE BAY
ESPERANCE
MIDDLE I.
Cape Le Grand
ARCHIPELAGO OF THE RECHERCHE
ISRAELITE BAY
GREAT AUSTRALIAN BIGHT
SOUTHERN OCEAN
SALMON GUMS
LAKE EWANRELLA
LAKE MACLEOD
LAKE MACKAY
LAKE DORA
LAKE DISAPPOINTMENT
LAKE MACDONALD
LAKE CAREY
LAKE BARLEE
LAKE AUSTIN
LAKE MOORE
LAKE NABBERU
LAKE CARNEGIE
LAKE WAY
LAKE LEFROY
LAKE COWAN
NORTHERN TERRITORY
SOUTH AUSTRALIA

Data Supplied by Forests Department.

Longitude 121° East of Greenwich

By Authority: WILLIAM H. WYATT, Government Printer, Perth.

HON. C.H. SIMPSON, M.L.C.
MINISTER FOR MINES

GEOLOGICAL SKETCH MAP
OF
WESTERN AUSTRALIA

1950

Scale 40 Miles to 1 Inch

40 20 0 40 80 120 160 200

1 : 2,534,400

Compiled from information obtained by the Geological Survey of Western Australia, Oil Exploration Companies, Department of Geology of the University of Western Australia, Commonwealth Bureau of Mineral Resources and various Mining Companies.

Collated by J. H. Lord, B.Sc., F.G.S., and N. M. Gray, B.Sc., Geological Survey of Western Australia, August, 1949.

H. A. ELLIS, B.Sc., A.O.S.M., Government Geologist.

VERTICAL SCALE.

Feet 4,000 3,000 2,000 1,000 0

Inch 1 Mile 40

HORIZONTAL SCALE.

SEA LEVEL

JOSEPH BONAPARTE GULF

BONAPARTE GULF BASIN

ONSLOW HILLS

ORD RIVER

WYNDHAM

KING RIVER

PENTECOST RIVER

DURACK RIVER

PHILLIPS RANGE

KING LEOPOLD RANGE

OSCAR RANGE

TERTIARY VOLCANIC PLUGS

FITZROY RIVER

NERRIMA BORE

1,000 FEET BELOW SEA LEVEL

Permian sediments, probably up to 2,000 feet in thickness, dip at less than 5 degrees. Devonian sediments may be up to 10,000 feet thick.

Carboniferous up to 5,000 feet thick, overlying basal lava flows of a similar thickness.

Little detailed reconnaissance has been carried out in this area.

Low folds plotted, principal anticlines (no lines drawn, crests along the northern limbs, have the appearance of synclines). Faults, where they are known to be of considerable extent, are indicated. Salt domes were discovered recently (1948) in the Canning Basin.

INDIAN DESERT BASIN

KIMBERLEY DIVISION

WEST KIMBERLEY

KIMBERLEY

PILBARA

WEST PILBARA

NORTH WEST

ASHBURTON

GASCOYNE

PEAK HILL

DIVISION

EASTERN DIVISION

NORTHERN TERRITORY

JOSEPH BONAPARTE GULF

BONAPARTE ARCHIPELAGO

ROWLEY SHOALS

LINE

SECTION

TROPIC OF CAPRICORN

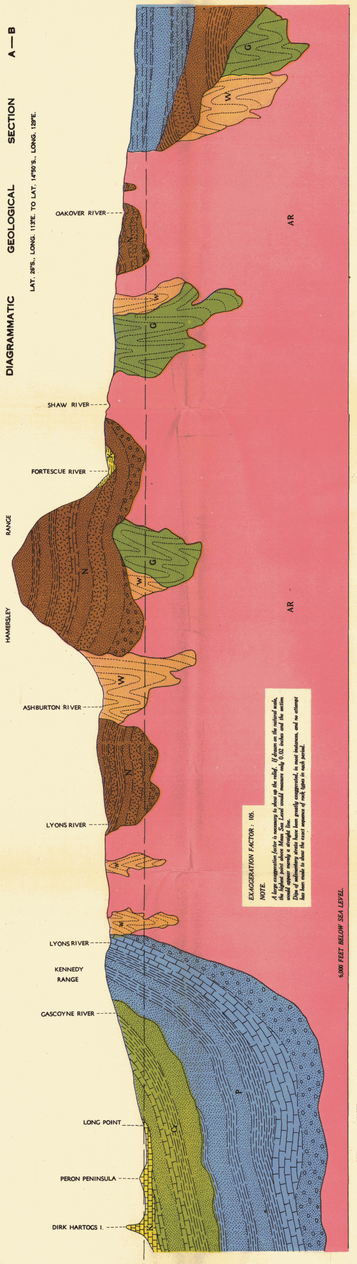
MERIDIAN 129°

109° 112° 115° 118° 121° 124° 127°

14° 17° 20° 23° 26°

DIAGRAMMATIC GEOLOGICAL SECTION A—B

LAT. 28°S., LONG. 113°E. TO LAT. 14°30'S., LONG. 128°E.



EXAGGERATION FACTOR : 105.

NOTE.

A large exaggeration factor is necessary to show up the relief. If drawn on the natural scale, the highest point above Mean Sea Level would measure only 0.02 inches and the section would appear merely a straight line.

Dips of sedimentary strata have been greatly exaggerated, in most instances, and no attempt has been made to show the exact sequence of rock types in each period.

Inches 1 2 3 4 4,000 Feet 1,000 1,000 1,000 1,000

VERTICAL SCALE.

Inch 1 40 Miles 20 0

HORIZONTAL SCALE.

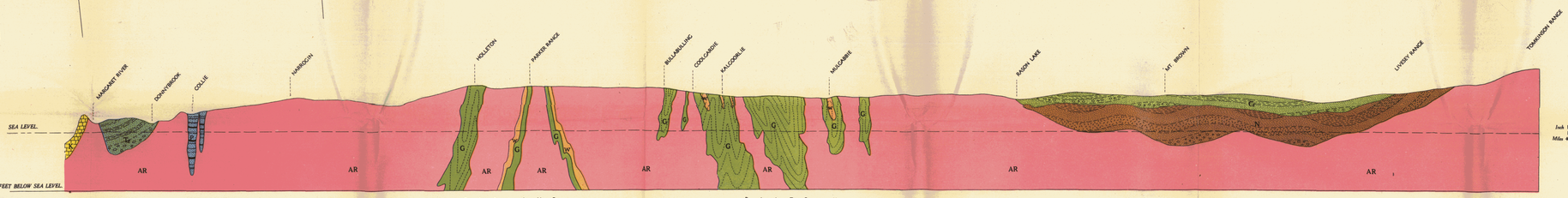
4,000 FEET BELOW SEA LEVEL.

Palaeozoic Scale has been classified as Ordovician, Devonian, Carboniferous, Permian, with further examination proving to be Palaeozoic in many areas. Mesozoic Scale has been classified as Triassic, Jurassic, Cretaceous, Tertiary and Quaternary. Precambrian Continuous and after to the Palaeozoic System, the unconformity is not an easily distinguishable.

Permian sediments occupy from 5,000 feet to 14,000 feet in thickness, outcropping from the Fitzroy River to the Irwin River, and underlying the Permian in this area. Jurassic deposits occur occasionally. There are Cretaceous deposits along the coast. 1,000 feet of Cretaceous and Quaternary sediments were discovered recently (1954), underlying the Permian in this area.

DIAGRAMMATIC GEOLOGICAL SECTION C—D

LAT. 34°S., LONG. 115°E. TO LAT. 26°S., LONG. 129°E.



BLACKWOOD BASIN

Variable thickness of sediments up to at least 1,700 feet to the south. Assigned to Triassic but more detailed geological investigation is required to prove exact age.

COLLIE COAL BASIN

At least 2,500 feet of gently-dipping sediments, with coal seams, in larger basin and probably 1,500 feet of sediments, with coal seams, in the smaller, or north-eastern basin.

Slope of sides is greatly exaggerated, maximum slope estimated to be 40 degrees.

EXAGGERATION FACTOR : 105.

Consisting of mainly acid rocks (evidence of much granitisation) with patches of Greenstones and Whitestones. No attempt has been made to estimate the depth to which the Greenstones and Whitestones extend.

D A R L I N G P L A T E A U

This area has been reconnoitred twice by the Geological Survey of Western Australia. The extent of the Nullagine System below the surface is supposition, while Granostones, of no economic importance, have been found at the eastern end of the section.

Prepared by the Geological Section, Chief Draftsman's Branch, Mines Department, Perth, W.A.

Government Print

KAINOZOIC

TERTIARY AND QUATERNARY

K — SEDIMENTARY AND VOLCANIC ROCKS

Occurrence : Principal deposits forms the Nullarbor Plains. Coastal deposits along south, west and north-west coasts. Isolated deposits inland, e.g., Fortescue River Beds.

Volcanic : Some small basalt flows on west south of Bunbury and basalts plugs in West Kimberley Area.

MESOZOIC

CRETACEOUS — Cr — SEDIMENTARY ROCKS

Occurrence : Best known in the North-West Basin between Murchison River and Exmouth Gulf, up to 2,000 feet in thickness. Underlies the Nullarbor Plains and a large area to the north (Wyloo to Range Series) has been assigned to this period on lithology only. North of Perth near Bullsbrook and Gingin.

JURASSIC — J — SEDIMENTARY ROCKS

Occurrence : Coastal Plain between Perth and Geraldton. Smaller deposits further northwards along coast to vicinity of Broome.

TRIASSIC — Tr — SEDIMENTARY ROCKS

Occurrence : Blackwood Basin, in far south-west including Donnybrook Sandstone. Assigned to this period on limited geological evidence.

PALAEOZOIC

PERMIAN — P — SEDIMENTARY ROCKS

Occurrence : 1, East Kimberley Area including the Bonaparte Gulf Basin (2,000 feet ?) ; 2, Desert Basin (thickness in doubt) ; 3, North-West Basin (10,000 feet) ; 4, Small Basins of South-West Division, (a) Ecrade (1,500 feet ?), (b) Irwin River (2,000 feet), (c) Collie (2,500 feet), (d) Wilga (700 feet).

CARBONIFEROUS — C — SEDIMENTARY ROCKS

Occurrence : Only known localities are in the East Kimberley Area. 1, Burt Range ; 2, Mt. Septimus ; 3, Sandy Creek Crossing (28 miles W. of Laguna).

DEVONIAN — D — SEDIMENTARY ROCKS

Occurrence : 1, East Kimberley Area, including Burt Range Basin (7,000 feet) ; 2, West Kimberley Area, including Napier, Oscar, Gibbs, Rough and Hugh Ranges. Thickness and southerly extension below Permian in doubt.

SILURIAN — S

No occurrence yet known.

ORDOVICIAN — O

Occurrence : Extension of the Lasapatina System of Central Australia into Western Australia, based on lithological evidence.

CAMBRIAN — Cm — SEDIMENTARY ROCKS

Occurrence : West Kimberley Area up to 2,000 feet thick.

CAMBRIAN — Cl — LAVAS

Underlying the Cambrian sediments, variable up to 2,000 feet in thickness.

PRE-CAMBRIAN

PROTEROZOIC — N — NULLAGINE SYSTEM

Consisting of unfossiliferous sediments and lavas invaded by basic dykes but not by granite or anatic rock. Only gently disturbed.

Detailed study may show some of the sediments to be Lower Palaeozoic. Includes Kiaraweng Series and Stirling Range Series.

ARCHAEOZOIC

AR — MAINLY ACID ROCKS

Granite, granite-gneiss and allied rocks. Includes much granitised sedimentary and volcanic rock, also unmapped areas of Greenstones and Whitestones.

W — WHITESTONE SERIES

Mainly metamorphosed sedimentary rocks. Includes Mosquito Creek Series, Black Flag Series, White Flag Series, Kanowna Series, Jimperding-Caralup Series and Mt. Barren Series.

G — GREENSTONE SERIES

Mainly metamorphosed igneous rocks. Includes Kalgoorlie Series (Older Greenstone Series), Warrawoona Series, Younger Greenstone Series.

MAP OF

Part of the

SOUTH-WEST DIVISION

of

WESTERN AUSTRALIA

SHOWING FOREST ZONES

Red hatching indicates approximately the position of prime merchantable forest.

Isohyets shown thus : 30"

Scale 15 Miles to an Inch

10 5 0 10 20 30 40 50 60

JARRAH ZONE.

JARRAH	(Eucalyptus marginata)
MARRI	(Eucalyptus calophylla)
BLACKBUTT	(Eucalyptus patens)
FLOODED GUM	(Eucalyptus rudis)
WANDOO	(Eucalyptus redunca, var. elata)
POWDER-BARK WANDOO	(Eucalyptus accedens)
RIVER BANKSIA	(Banksia verticillata)
BULL BANKSIA	(Banksia grandis)
SHEOAK	(Casuarina Fraseriana)
BULLICH	(Eucalyptus megacarpa)

KARRI ZONE.

KARRI	(Eucalyptus diversicolor)
MARRI	(Eucalyptus calophylla)
RED TINGLE	(Eucalyptus Jacksoni)
YELLOW TINGLE	(Eucalyptus Guilfoylei)
JARRAH	(Eucalyptus marginata)
BULLICH	(Eucalyptus megacarpa)
RED FLOWERING GUM	(Eucalyptus ficifolia)
KARRI SHEOAK	(Casuarina decussata)
CEDAR	(Agonis juniperina)
RIVER BANKSIA	(Banksia verticillata)

TUART ZONE.

TUART	(Eucalyptus gomphocephala)
COASTAL WHITE GUM	(Eucalyptus decipiens)
PEPPERMINT	(Agonis flexuosa)
YATE	(Eucalyptus cornuta)

WANDOO ZONE.

WANDOO	(Eucalyptus redunca, var. elata)
POWDER-BARK WANDOO	(Eucalyptus accedens)
JARRAH	(Eucalyptus marginata)
MARRI	(Eucalyptus calophylla)
SALMON GUM	(Eucalyptus salmonophloia)
RED MORREL	(Eucalyptus longicornis)
YORK GUM	(Eucalyptus foecunda, var. loxophleba)
JAM	(Acacia acuminata)
SHEOAK	(Casuarina Huegeliana)
SANDALWOOD	(Santalum spicatum)

WANDOO AND SWAMP YATE ZONE.

WANDOO	(Eucalyptus redunca, var. elata)
SWAMP YATE	(Eucalyptus occidentalis)
YATE	(Eucalyptus cornuta)
SALMON GUM	(Eucalyptus salmonophloia)
RED MORREL	(Eucalyptus longicornis)
JAM	(Acacia acuminata)
SWAMP OAK	(Casuarina glauca)
SWAMP MALLET	(Eucalyptus spathulata)
SANDALWOOD	(Santalum spicatum)

SALMON GUM ZONE.

SALMON GUM	(Eucalyptus salmonophloia)
RED MORREL	(Eucalyptus longicornis)
YORRELL	(Eucalyptus gracilis)
GIMLET	(Eucalyptus salubris)
YORK GUM	(Eucalyptus foecunda, var. loxophleba)
WANDOO	(Eucalyptus redunca, var. elata)
JAM	(Acacia acuminata)
BROWN MALLET	(Eucalyptus astringens)
BLUE MALLET	(Eucalyptus Gardneri)
MERRIT	(Eucalyptus Flocktoniae)
SANDALWOOD	(Santalum spicatum)

SAND PLAIN BANKSIAS.

HOLLY-LEAVED BANKSIA	(Banksia ilicifolia)
NARROW-LEAVED BANKSIA	(Banksia attenuata)
FIREWOOD BANKSIA	(Banksia Menziesii)
SWAMP BANKSIA	(Banksia littoralis)
COASTAL BLACKBUTT	(Eucalyptus Todtiana)

SAND PLAIN ZONE.

Various small shrubs of several families. All of low stature.

5 15 25 35 45 55 65 75 85 95 105

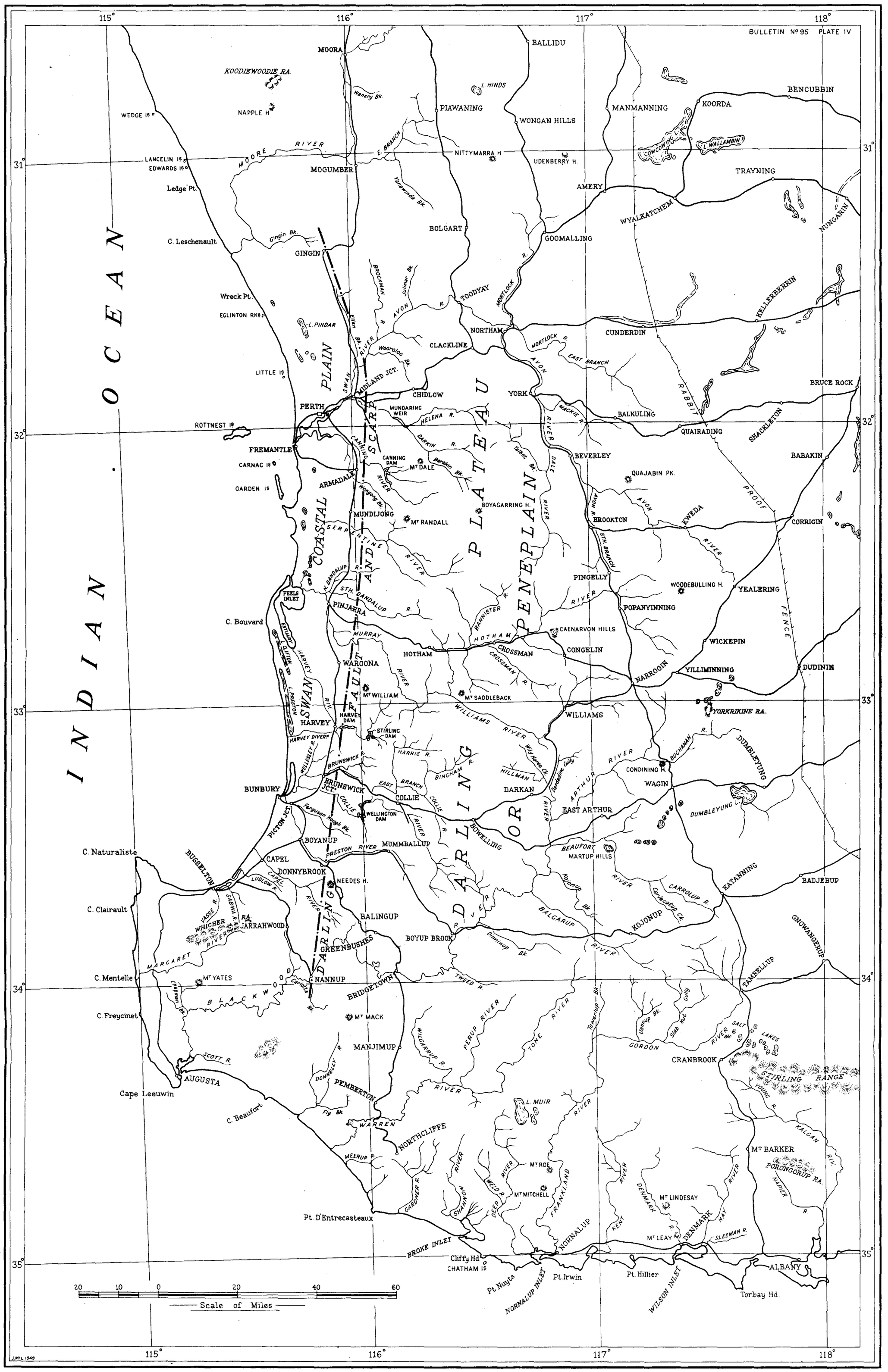
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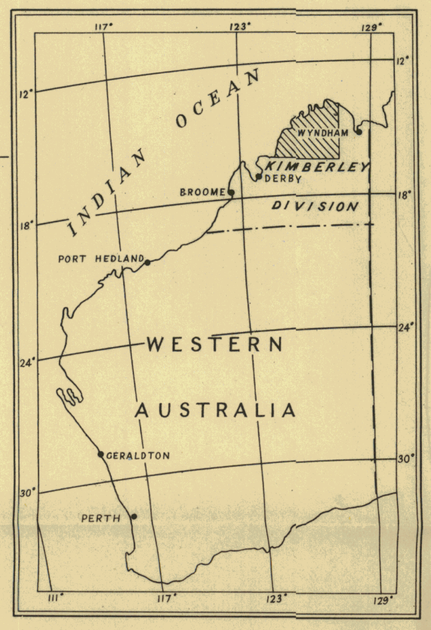
32°0′ 35°0′

RED & YELLOW TINGLE — RED FLOWERING GUMS

Information concerning Forest Zones by courtesy of the Forests Department

TOPOGRAPHICAL MAP
OF THE
SOUTH WEST PORTION OF WESTERN AUSTRALIA





125° 126° 127°

14° 15° 16°

C. Londonderry
C. Talbot
Long Reef
Long I.
Mary I.
NAPIER BROOME BAY
VANSITTART BAY
Encounter Cove
ADMIRALTY GULF
Crystal Hd.
Port Warrender
Bigge I.
MUDGE BAY
SWIFT BAY
MITCHELL RIVER
EDWARD RIVER
Mt CONNOR (500')
Mt LEEMING (800')
SIR FREDERICK HILLS
DRYSDALE MISSION
RIVER
CARSON RIVER
KING RIVER
MORAN RIVER
ROE RIVER
PRINCE REGENT RIVER
CALDER RIVER
CHARNLEY RIVER
SALE RIVER
OLENELG RIVER
HUNTER R.
DONKINS H.
MANNING Pk
Coronation Islands
Port Nelson
PRINCE FREDERICK HARBOUR
CAREENING B.
BRUNSWICK BAY
ROTHSAY WATER
Mt TRAFALGAR
Augustus Island
Port George IV
Camden Harbour
PORT GEORGE MISSION
Mt TREVOR (650')
Mt LYELL (700')
Mt KING
Mt GREY
Mt METHUEN (1400')
Mt FRENCH
Mt DEBORAH (1350')
Mt YORK
Mt BRADSHAW
WALCOTT INLET
KING LEOPOLD RANGES
SYNNOTT RANGE
ISDELL RIVER
GIBB RIVER
DRYSDALE RIVER

ironstone & basalt tableland; well grassed soft spinifex; boxwood messmate
Sandstone country small patches basalt
soft spinifex; fair grass
wattle woollybutt soft spinifex; sandstone tableland woollybutt pine; soft spinifex & grassy flats
soft spinifex low sandstone hills & sandy flats
magnificently grassed basaltic plain; sandstone tableland country; soft spinifex & grass; boxwood; rich red loam
well grassed; basaltic hills & valleys boxwood etc.
rough sandstone small pockets of basalt; soft spinifex; fair grasses for feed
sandstone tableland country small pockets of basalt; soft spinifex & fair grass
splendidly grassed basaltic country; basaltic tableland boxwood messmate
very rugged sandstone; very rough sandstone; fair tableland country soft spinifex fair grassy flats messmate woollybutt
good basalt country; well grassed basalt & ironstone well grassed boxwood & messmate
basaltic hills & valleys; sandstone messmate soft spinifex, fair grassed fair top feed
very rough sandstone hills fair grassy flats & valleys soft spinifex & fair top feed
basaltic & ironstone tableland messmate & boxwood splendidly grassed with fine grasses & soft spinifex
very rough sandstone; fine river flats splendidly grassed; soft spinifex; grassy flats; boxwood; splendidly grassed
basaltic & ironstone tableland splendidly grassed with fine grasses soft spinifex
messmate woollybutt boxwood
rough sandstone (1100')
rough sandstone country; soft spinifex & grass; woollybutt messmate & pine
basaltic hills & valleys; good sandy tableland; boxwood
splendidly grassed basaltic hills & valleys; splendidly grassed basaltic hills & valleys
messmate pine etc.; soft spinifex; basaltic & ironstone well grassed; good tableland sandy soft spinifex; boxwood; rough sandstone
good sandstone tableland; soft spinifex; good grassy flats; good top feed; good tableland country
basaltic & ironstone hills; splendidly grassed
sandstone country
basaltic hills & valleys; soft spinifex & fair grasses
boxwood; splendidly grassed
good tableland country; soft spinifex & fair grasses; woollybutt messmate pine etc; basalt
undulating basalt country; splendidly grassed
good tableland country; sandy soil; soft spinifex & grassy flats; messmate woollybutt & pine
basaltic hills & valleys
sandstone tableland country; messmate woollybutt pine etc.; tableland country woollybutt & pine
basaltic hills & valleys splendidly grassed
good sandstone tableland country soft spinifex & grassy flats good top feed throughout.
basaltic hills & valleys
woollybutt (900') messmate pine etc.
basaltic & ironstone hills & valleys
boxwood; splendidly grassed; well grassed
basaltic & ironstone hills & valleys splendidly grassed
rough sandstone country; woollybutt messmate & pine; soft spinifex & grass; basaltic hills & valleys
messmate & pine; soft spinifex; basaltic & ironstone well grassed; good tableland sandy soft spinifex; boxwood; rough sandstone
basaltic & ironstone hills; splendidly grassed
soft spinifex; good grassy flats; good top feed; good tableland country
basaltic hills & valleys; soft spinifex & grass; boxwood
sandstone country
soft spinifex & fair grasses
splendidly grassed
good tableland country; soft spinifex & fair grasses; woollybutt messmate pine etc; basalt
fine basalt country; basalt plain
rough basalt hills
very rugged sandstone country
fine basalt soil heavily grassed
rough sandstone woollybutt soft spinifex
sandstone tableland country woollybutt messmate & pine
small grassy flats seamed with gorges
rough sandstone; woollybutt messmate & pine tableland country; fine flats; fair grasses
very rough sandstone; woollybutt messmate & pine; sandstone spinifex & fine grass gullies
very rough sandstone; soft spinifex; fair grassy flats; woollybutt pine etc; soft spinifex & woollybutt grassy gullies; messmate pine etc
rough sandstone country; good top feed
very rough sandstone; woollybutt soft spinifex & grass gullies; soft spinifex; seamed with gorges
very rough sandstone country; woollybutt messmate & pine
soft spinifex & fair grassy gullies
very rough sandstone hills good grassy valleys soft spinifex & top feed; woollybutt messmate & pine
soft spinifex & good grassy gullies
splendidly grassed basaltic hills & valleys; splendidly grassed basaltic hills & valleys
basaltic hills & valleys; boxwood
rough sandstone ranges; good grassy flats & valleys; rough sandstone country; messmate woollybutt pine etc; soft spinifex; rough sandstone soft spinifex grassy gullies; messmate & woollybutt & pine; very rough sandstone country; rugged sandstone; fine basalt country; rough basalt hills
good tableland sandy soil ironstone gravel; messmate soft spinifex grass; good tableland country rough; fine basalt country
very rough sandstone; soft spinifex & grass; basaltic; rough sandstone; messmate & woollybutt & pine; good tableland; soft spinifex; good grassy flats & gullies; rough sandstone; very rugged sandstone country; fine flats; fair grasses; woollybutt messmate & pine
very rough sandstone; soft spinifex valley; wattles; good tableland soft spinifex; messmate pine & woollybutt; good sandstone tableland; wattle & top feed
very rough sandstone hills & grassy valleys; soft spinifex & fair grasses; sandstone hills & valleys
very rough sandstone country; good sandy flats & grassy gullies; woollybutt pine quinine soft spinifex; fair top feed
very rough sandstone; good grassy flats & gullies; soft spinifex; very rough sandstone country; good sandy flats & grassy gullies; woollybutt pine quinine soft spinifex; fair top feed
very rough sandstone; fine grassy; basaltic
rough sandstone; messmate woollybutt pine etc; soft spinifex; soft spinifex grass; good tableland country rough; fine basalt country
rough sandstone; soft spinifex & fair grassy gullies; messmate & woollybutt & pine; very rough sandstone country; soft spinifex; rough sandstone
very rough sandstone; soft spinifex & grass flat; basaltic; basalt plain; rich black soil plain; undulating basaltic stony rises well grassed; Mt DEBORAH (1350'); basaltic country; stony well grassed country; box timber well grassed; rough basalt hills; open undulating basalt country; very rough sandstone woollybutt pine etc soft spinifex & grassy gullies; woollybutt messmate pine etc; rough sandstone country good top feed; woollybutt soft spinifex & grass gullies; soft spinifex; seamed with gorges
very rugged sandstone spinifex, fair grasses; woollybutt quinine pine etc fair top feed; very rugged sandstone country; stony basaltic country small black soil plains; soft spinifex & small grassy gullies; very rugged sandstone woollybutt pine etc soft spinifex; sandstone tableland country very rough in places; rough sandstone country very broken; woollybutt, quinine & pine soft spinifex & small grassy gullies; very broken sandstone country woollybutt · quinine & few pines soft spinifex; soft spinifex small grass flats; strong basaltic; undulating basaltic country bare marsh small patches salt-grass; very rough sandstone with fair grassy flats soft spinifex & top feed seamed with gorges; very rough sandstone soft spinifex grassy valleys; woollybutt few pines; messmate soft spinifex; very rough sandstone; very rough sandstone; boxwood; very stony basalt; very rough stony basalt; CALDER; CHARNLEY RIVER; SYNNOTT RANGE; KING LEOPOLD RANGES; WALCOTT INLET

MAP OF

NORTH WEST KIMBERLEY

SHOWING CLASSIFICATION BY SURVEYOR W.R.EASTON

1921

Scale: 10 miles to an inch

10 5 0 10 20 30

REFERENCE

- Sandstone Country
- Basaltic Country (Abt 4,000,000 ac)
- Agricultural Land (Basaltic - Abt 800,000 ac)
- Agricultural Land (Sandstone - Abt 1,000,000 ac)
- Good Routes for Stock

W.R.M.