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THE GEOLOGY OF THE YILGARN GOLDFIELD, SOUTH OF THE GREAT EASTERN RAILWAY

BY

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WITH AN APPENDIX BY DOROTHY CARROLL, Ph.D., D.I.C.

ON

“Sand-Plain Soils from the Yilgarn Goldfield.”

*Issued under the authority of the Hon. A. H.
Panton, Minister for Mines.*

WITH 7 PLATES AND 15 FIGURES.



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PREFATORY NOTE.

This Bulletin deals with the regional geology of all that portion of The Yilgarn Goldfield situated south of The Great Eastern Railway, an area covering some 5,500 square miles, or approximately one third of the total area of the whole of the Yilgarn Goldfield.

The field-work was carried out during the period July 1935 to February 1937 with some unavoidable delays when the author was withdrawn for duty elsewhere.

Geological Survey publications covering previous geological work in this area are now out of print, and in the re-survey, designed to again make available to the mining community information which has been shown to be in great demand, the object was to investigate the general and economic geology as fully as possible. With this object in view the work was divided, Messrs. Hobson and Matheson, Departmental geologists who were associated with the author in the field-work undertaking the examination of the Mining Groups while the regional geology was investigated by Mr. Ellis.

The volume of data accumulated made it impracticable to publish the results as one bulletin, and the importance of the results achieved in the investigations of the regional geology rendered it necessary to publish the results of the re-survey as three separate bulletins, one being confined to the general geology (Bull. 97) and two others (Bulls. 98 and 99) compiled under the joint authorship of Messrs. Hobson and Matheson dealing with the various mines of the area.

Bulletins 98 and 99 have been prepared and are awaiting publication. Their titles are:—

Bull. 98: "The Mining Groups of the Yilgarn Goldfield South of the Great Eastern Railway," Part I., From Southern Cross Southwards to Marvel Loch, by R. S. Matheson and R. A. Hobson.

Bull 99: "The Mining Groups of The Yilgarn Goldfield South of the Great Eastern Railway," Part II., South of Marvel Loch, by R. A. Hobson and R. S. Matheson.

A convenient digest of the contents of the present publication will be obtained by perusing the following sections of the text:—

- (1) General Description of The Area Investigated, page 10.
- (2) Resumé of Regional Geology, page 62.
- (3) Summary of Results of Re-survey, page 13.

It has been found necessary as a result of the geological mapping to greatly alter the original conception of the general geology of this part of the Yilgarn Goldfield, and the present interpretation of the rock sequence which places the metamorphic sedimentary rocks above

the metamorphic Greenstone Series in the stratigraphic succession, is in keeping with a similar sequence now known to exist in other goldfields of the State.

The broad relation between regional geological structure and the localisation of mining groups has not previously been established in publications of the Geological Survey, and it is to be hoped that some of the principles found to apply in the Yilgarn Goldfield will subsequently be established for other goldfields of the State when regional geological work similar to that carried out in the Yilgarn Goldfield is undertaken in them.

A correlation of the major geological structure of the remnants of the Pre-Cambrian rocks of the goldfields of Western Australia with the known gold-bearing localities, offers perhaps the best prospects for the successful application of geological science to the search for new auriferous localities.

The section of this publication contributed by Dr. Dorothy Carroll is of particular interest and of considerable economic importance, establishing as it does the nature of the underlying rock over those portions of the goldfield occupied by sand-plains. Of primary importance is the fact that these sand-plain areas in which the geology is obscured have been found to overlie rocks which consist partly of metamorphosed erosion sediments. This is important from the point of view of possible gold occurrence, since, irrespective of the age of these metamorphosed sediments, whether they represent the series below the Greenstone Series or the Whitestone Series, evidence exists which shows that they have been intruded by a granitic magma, hence possibly carry auriferous quartz reefs.

The results of Dr. Carroll's work enable a wider application to be given to the suggestion made by Mr. Ellis in the section of his report dealing with Prospecting Recommendations, where it was suggested that drainage channels in the sand-plain country should be examined for detrital gold.

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Perth, 18th November, 1938.

CONTENTS.

	Page
Prefatory Note	2
CHAPTER I.—GENERAL INFORMATION.	
Introduction : The Yilgarn Goldfield South of the Great Eastern Railway	8
General Description of the Area Investigated	10
Summary of Results of Resurvey	13
Field Work	15
Acknowledgments	16
The Geological Maps	17
Previous Geological Work	19
History of Mining in the Area	20
Mineral Production	22
Climate : Temperature and Rainfall	24
Flora	32
Fauna	35
Agricultural Pursuits	36
Soils	36
Mining Timber, Fuel and Water Supplies (Mining)	43
Roads, Tracks and Water Supplies (Dams, Wells, etc.)	45
Literature	47
CHAPTER II.—PHYSIOGRAPHY.	
The General Land Form	50
The Drainage System	53
The Ridges and Hills	54
The Sand Plains	58
The Depressions and Salinas	59
CHAPTER III.—GENERAL GEOLOGY.	
Resumé of Regional Geology	62
Classification and Correlation	64
The Yilgarn System	66
(a) The Whitestone Series	68
(b) The Greenstone Series	74
The Basic Intrusive Rocks	83
The Granite, Gneiss, Acid Dykes and Quartz Reefs	85
Petrological Report on a Suite of Granitic, Gneissic and Pegmatitic Rocks from the Area	93
The Recent Deposits	113
Soil	113
Alluvium	113
Sand Dunes	113
“Cement”	114
The Grits	114
The Ferruginous Laterite	114
CHAPTER IV.—STRUCTURAL GEOLOGY.	
The Broad Geological Structure	116
Nature of Folding	127
Faulting	131
Shearing	132
Jointing	134
The Broad Relation between Geological Structure and Gold Deposition	134

CHAPTER V.—ECONOMIC GEOLOGY.

Introduction	148
The Gold Deposits	148
(a) Nature and Mode of Occurrence of the Auriferous Deposits	149
(b) The Mineral Associations of the Auriferous Quartz	154
Minerals Other than Gold	158
Prospecting Recommendations	158

TEXT FIGURES.

Figure.	Page
1 The south-eastern end of the township of Southern Cross, looking east from Reservoir Hill. Showing the flat to gently undulating nature of the granitic and gneissic country	11
2 Looking south from Mt. Caudan, Parker's Range. Showing low rises of the metamorphosed sedimentary series covered with dense scrub and forest growth	12
3 Looking west from Mt. Caudan, Parker's Range. Showing broadly undulating scrub and forest covered areas, including some high-level sand plain underlain by rocks of the metamorphosed sedimentary series	12
4 Looking south-east from Mt. Caudan, Parker's Range. Showing flat to undulating areas of heavily timbered country on rocks of the Greenstone Series and soil-covered flats	13
5 Yilgarn Goldfield, area south of the Great Eastern Railway. Graph for the period 1897-1936 showing:— (a) Annual Production of Gold (b) Tonnage of Ore Treated (c) Grade of Ore Treated	24
6 Graph showing annual rainfall curve for Southern Cross, Yilgarn Goldfield, for period 1891-1936, inclusive	28
7 Graph showing total monthly rainfall for January, a typical summer month, and for July, a typical winter month at Southern Cross, Yilgarn Goldfield, over the period 1891-1936, inclusive	29
8 Plan of portion of Yilgarn Goldfield showing some heights and surface profiles	52
9 Map showing localities of granitic, gneissic, and pegmatitic rocks referred to in petrological report	98
10 Geological section through Mt. Rankin, Kennyville and lake 1½ miles east of Yellowdine Railway Siding, Yilgarn Goldfield	122
11 Geological Map of south central portion of Yilgarn Goldfield, showing approximate distribution of sand plains and positions of soil samples examined	161
12 Mechanical analyses of some soils from the Yilgarn Goldfield. A dune and a beach sand from Cottesloe are added for comparison	165
13 Representation of Percentage Composition of the Heavy Mineral Assemblages of Soils from the Yilgarn Goldfield	175
14 Range Table showing Variation in Percentage Composition of Heavy Mineral Assemblages	176
15 Microphotographs of Heavy Mineral Assemblages of Typical Sand-plain Soils, Yilgarn Goldfield	178

MAPS.

Plate.		Scale.
I.	Map of Portion of the Yilgarn Goldfield (South of the Great Eastern Railway) Showing Mining Groups, Water Supplies, Main Roads and Tracks	6 miles = 1 inch.
II.	Geological Map of Portion of the Yilgarn Goldfield (South of the Great Eastern Railway)	4 miles = 1 inch.
III.	Geological Map of Country in Vicinity of Southern Cross, Yilgarn Goldfield	40 chains = 1 inch.
IV.	Geological Map of Country in Vicinity of Gledower, Lenneberg, Xantippe and Marvel Loch Groups, Yilgarn Goldfield	40 chains = 1 inch.
V.	Geological Map of Country in Vicinity of Nevoria, Burbidge and Parker's Range, Yilgarn Goldfield	40 chains = 1 inch.
VI.	Geological Map of Country in Vicinity of Mt. Palmer, Yilgarn Goldfield	40 chains = 1 inch.
VII.	Geological Map of Country in Vicinity of Olga, Dulcie and Cheriton's Groups, South end of Parker's Range, Yilgarn Goldfield	40 chains = 1 inch.

APPENDIX.

SAND-PLAIN SOILS FROM THE YILGARN GOLDFIELD.

	Page
Introduction	161
Topography and Geology—	
Topography	162
Geology :	
Basement Rocks	163
Superficial Deposits and Soils	164
Examination of the Sand-plain Soils—	
Mechanical Analysis	164
Mineralogical Examination	166
Mineralogy of the Soils	166
Description of the Individual Minerals—	
A. Heavy Fraction	167
B. Light Fraction	171
Source of the Heavy Residues	173
Significance of Results of Investigation	175
Acknowledgments	180

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of page numbering

CHAPTER I.

GENERAL INFORMATION.

	Page
Introduction : The Yilgarn Goldfield South of the Great Eastern Railway	8
General Description of the Area Investigated	10
Summary of Results of Resurvey	13
Field Work	15
Acknowledgments	16
The Geological Maps	17
Previous Geological Work	19
History of Mining in the Area	20
Mineral Production	22
Climate : Temperature and Rainfall	24
Flora	32
Fauna	35
Agricultural Pursuits	36
Soils	36
Mining Timber, Fuel and Water Supplies (Mining)	43
Roads, Tracks and Water Supplies (Dams, Wells, etc.)	45
Literature	47

INTRODUCTION: THE YILGARN GOLDFIELD SOUTH OF THE GREAT EASTERN RAILWAY.

In the West Australian Government Gazette of January 28th, 1916, the following boundaries were fixed for the Yilgarn Goldfield:—

Bounded by lines starting from a point north of Cairn H26 on Koorarawalyee rock and west of Cairn NB1 at Wangine Soak, and extending south along the west boundary of the Coolgardie and Dundas Goldfields, and passing through Cairn H26 at Koorarawalyee rock to a point east of the summit of Mount South Ironcap; thence west, passing through the summit of Mount South Ironcap to a point on the southern section of the No. 1 Rabbit-Proof Fence near the 113-mile post; thence north-westerly and northerly along the fence to the 14-mile post on the northern section of the fence; thence east 20,833 links, north 24,000 links, and west 20,833 links to the 17-mile post on the fence; thence northerly along the fence to the 158-mile post; thence easterly about 75 miles to a Cairn marked AN11 on an island at the eastern end of Lake Barlee; thence southerly about 11 miles to a Cairn marked GDR40 on Mount Elvire; thence south-south-easterly about 41 miles to Johnston's rocks; thence south-easterly about 26 miles to starting point.

The Great Eastern Railway from Perth to Kalgoorlie enters this area at the town of Burraoppin on the western boundary, and passes through it in a general easterly direction, ultimately leaving it near Koorarawalyee Railway Siding on the eastern boundary.

The area dealt with in this Bulletin embraces all that portion of the goldfield situated south of this railway line, and covers an area of approximately 5,500 square miles, or roughly about one-third of the total area of the Yilgarn Goldfield.

The map on Plate I. indicates the locality and boundaries of the area geologically surveyed, and in subsequent paragraphs in this report this area will be referred to as the Area.

GENERAL DESCRIPTION OF THE AREA INVESTIGATED.

The Area forms a portion of the great inland plateau of Western Australia and is, like that plateau, characterised by a low relief and the existence of vast areas of broadly undulating to flat country. The elevations of railway stations situated along the northern boundary at approximately the western, central and eastern points are 1133, 1149 and 1522 feet respectively above sea-level.

The rainfall is low, being about 10 inches and 11 inches per annum respectively in the northern and southern portions, and "salinas," or dry salt lakes are characteristic of the physiographic division, namely, "The Salt Lake Division or Salinaland," into which this part of Western Australia falls. There are no permanent streams, or even large dry watercourses, and except in localities possessing special topographical and geological conditions the ground water is extremely saline. The drainage is entirely internal.

The whole of the Area with the exception of a relatively small proportion cleared for agricultural purposes and the floors of the "salinas," is covered with either a thick growth of eucalypt forest or a dense stunted growth of shrubs, while about 95 per cent. of the land surface is covered with soil, the remaining 5 per cent. being represented by rock outcrops.

The entire rock series with the exception of some recent laterites is probably of Pre-Cambrian age, and represents a highly folded series of ancient sediments, pyroclastics, lava flows and basic intrusives which have been invaded by one or more granitic magmas with the formation of gold-bearing quartz reefs, mostly parallel with the planes of schistosity of the folded series, in the remaining recognisable folded rocks near their margins.

The manner of ore occurrence can be regarded as typical of most of the goldfields of Western Australia, and from a perusal of the available literature appears to be similar in type to that in similar rocks of a presumed similar age in Canada.

The folded remnants of the intruded rocks form the main topographic relief in an otherwise almost flat surface, and are represented by low rounded ridges seldom exceeding 200 feet in height, usually running in a north-north-west and south-south-east direction. Not infrequently these ridges are composed of greenstones (metamorphosed lavas and pyroclastics).

The forest-covered country consists mostly of areas of greenstone and soil-filled depressions, while the shrub-covered country or sand-plain overlies areas of granite, gneiss or granitised rocks and extends over

by far the larger part of the Area. In the mid-western section there are numerous large bare granite masses which form hills and are known as "Rocks," and which are regarded by the writer as representing bosses of granite intruded into a gneiss complex.

Gold-mining on a comparatively small scale only has been carried on in the Area since about the year 1888, and up to the end of 1936, 544,033 ozs. of fine gold have been produced from 1,309,636 tons of ore treated.

Southern Cross, situated on the main railway line between Perth and Kalgoorlie at 237 miles east of the capital (Perth) is a small town which is the administrative and business centre of the mining and small wheat-farming community of the district.



Fig. 1.—The south-eastern end of the township of Southern Cross, looking east from Reservoir Hill. Showing the flat to gently undulating nature of the granitic and gneissic country.

The mines are confined to a narrow strip of greenstone country extending south-easterly for a distance of about 40 miles from Southern Cross and are arranged in a number of groups more or less separated from each other by stretches of country not carrying gold-bearing quartz reefs. The deepest shaft of which any record is available does not exceed 480 feet, and much of the mining activity has been confined to depths seldom exceeding or even reaching 200 feet below the ground surface.

An attempt has been made to establish wheat-growing in the country immediately to the south of Southern Cross, but the unsuitable climatic conditions have rendered this a failure.

The mining and farming community is almost entirely dependent on the Goldfields Water Supply Pipe-line, which brings water from

Mundaring Dam near Perth, a distance of some 211 miles, for water supplies for both mining and farming pursuits, and natural supplies of potable water do not exist except for a short period after heavy thunderstorms.

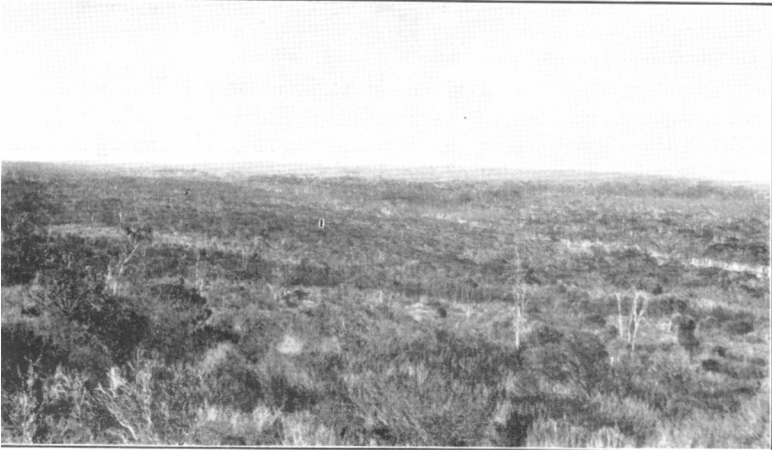


Fig. 2.—Looking south from Mt. Caudan, Parker's Range. Showing low rises of the metamorphosed sedimentary series covered with dense scrub and forest growth.

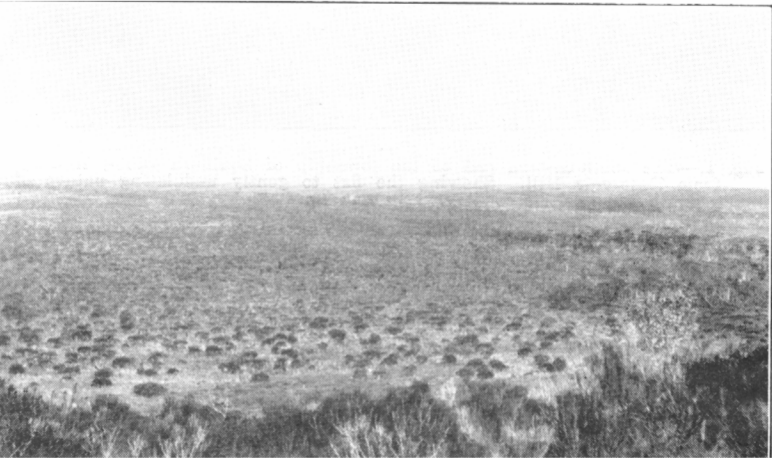


Fig. 3.—Looking west from Mt. Caudan, Parker's Range. Showing broadly undulating scrub and forest covered areas, including some high-level sand plain, underlain by rocks of the metamorphosed sedimentary series.

In the photograph in Fig. 1, the flat and gently undulating nature of the topography is illustrated by the even nature of the horizon some

8 miles distant from the camera. The forest and scrub growth has been cleared from most of this area in the course of mining and farming operations.

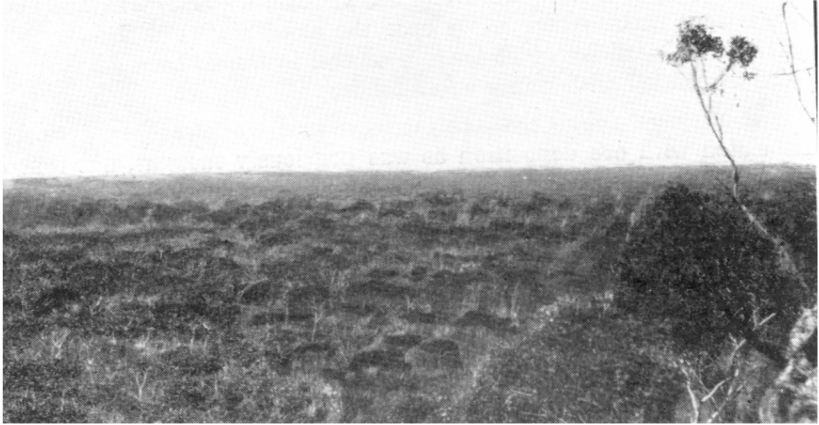


Fig. 4.—Looking south-east from Mt. Caudan, Parker's Range. Showing flat to undulating areas of heavily timbered country on rocks of the Greenstone Series and soil-covered flats.

The photographs in Figs. 2, 3, and 4 on pages 12 and 13 respectively, are illustrative of typical topographical and vegetational features of portions of the Area still in their natural state. In Figs. 2 and 3 the horizon is distant about 3 miles and in fig. 4 about 10 miles.

SUMMARY OF RESULTS OF RESURVEY.

In this section a brief statement of the geological facts not previously known for this part of the Yilgarn Goldfield but brought to light as the result of the resurvey will be given.

The folded Pre-Cambrian rocks of the Area have been found to consist of two gold-bearing series, namely, the Whitestone Series and the Greenstone Series of which the former is the younger. The Whitestone Series is composed predominantly of metamorphosed erosion sediments with interbedded greenstone bands of igneous origin, and the Greenstone Series comprises mainly metamorphosed basic lavas and pyroclastics with a minor amount of interbedded metamorphosed erosion sediments.

The two series have taken part in regional folding movements resulting in their broad distribution as a series of tightly folded pitching anticlines and synclines. Reversals in pitch of the major structures have been recognised, and the cause of such reversals has been

attributed to cross-folding. A localisation of gold deposition has taken place in the vicinity of the axes of these cross folds in the Nevoria-Burbidge area, and in the vicinity of Southern Cross.

The distribution of the gold-lines within the Greenstone Series is intimately associated with an incompetent zone of which one or more bands of jaspilite of sedimentary origin form a part. The ore bodies in this zone occur either on or near the axial planes of tightly folded synclines at localities which have in several instances been demonstrated to be associated with minor cross-folding.

It has been found that the intrusive basic rocks are not intimately associated with ore deposition as was previously thought, but that ore bodies occur in both the Whitestone and Greenstone Series when these rocks are situated in favourable structural positions. Some of the basic intrusive rocks have been intruded after the main period of folding but prior to the intrusion of the granite, while others appear to have taken part in the folding.

The extent of the granite shown on previous geological maps has been considerably reduced, and some of the gneissic rocks of granitic composition have been recognised as migmatites and replacement gneisses; these latter resulting from the process of regional granitisation.

The intrusive granite which has been assumed to have provided the gold-bearing solutions is a medium grained usually non-porphyrific biotite granite, probably intruded during two periods of intrusion, but having its origin in a common magma. The granite "rocks" of the Area are, in all probability, the apices of these batholithic intrusions.

The area of metamorphosed sedimentary rocks has been greatly extended with a consequent reduction in the areas previously shown as greenstone, but several new belts of greenstone rocks have been located and mapped. The exact order of occurrence of gold deposition and regional granitisation has not been established for the whole of the Area, but gold deposition has taken place in one instance in granitised rocks, and the area of potential auriferous country can therefore be extended into the gneissic rocks flanking the greenstones. This makes the sand-plain country potentially gold bearing at least where it adjoins the metamorphosed sediments and greenstones.

A broad classification of the various types of ore-bodies according to their manner of occurrence has been made, and in the lode formations thin lenses and veinlets of quartz have been found to be so universally present that "no quartz, no gold" seems to be a statement having an application throughout the Area.

One of the results of the recognition of the fact that ore deposition in this part of the Yilgarn Goldfield has been primarily controlled by the principles of folding, is that lateral prospecting from known ore-

bodies both on the surface and from underground workings is advisable in the search for new ore-bodies.

An extensive distribution of anthophyllite schist not previously recorded from this district has been mapped, and from the occurrence of chromite as an accessory mineral in this schist, the existence of ultra-basic igneous rocks in the Yilgarn System has been established. A nepheline bearing intrusive rock (phonolite) found as a dyke cutting the schistose greenstone rocks at the Olga Group south of Parker's Range is an unusual type for the Eastern Goldfields and has not been previously noted. The metamorphic mineral staurolite, found in some beds of the Whitestone Series west of the Mountain Queen mine at Marvel Loch, is also the first recorded occurrence of this mineral from the Yilgarn Goldfield.

A number of recommendations for the further prospecting of the gold belts south of Southern Cross have been able to be made, and in the reports by Messrs. Hobson and Matheson on the mines, contained in G.S.W.A. Bulletins Nos. 98 and 99, suggestions are made which should be found helpful in the search for continuations or repetitions of ore bodies in the various mines examined.

FIELD WORK.

In the course of the geological resurvey of this portion of the Yilgarn Goldfield, three departmental geologists, namely, Messrs. R. A. Hobson, R. S. Matheson and the writer, were in the field as one party from July 1935 to the middle of December 1935, and from February 1936 to the end of March 1936 when the writer was withdrawn for duty elsewhere. Messrs. Hobson and Matheson remained in the field until October 1936, and the writer returned to complete the broad field work during November and December 1936, and for two weeks towards the latter end of January and early in February 1937.

The object of the survey was to investigate the general and economic geology of the Area as fully as possible, and with this object in view, the work was divided, Messrs. Hobson and Matheson undertaking the examination of the Mining Groups and Gold Mining Leases while the regional geology fell to the author.

Reports on the work done by my colleagues on the geology and ore bodies of the various gold-mines of the Area have been prepared under their joint authorship, and comprise Bulletins Nos. 98 and 99 of the Geological Survey Bulletin Series. Bulletin No. 98 deals with the mines as far south as and including Marvel Loch, while Bulletin No. 99 embraces the mining centres south of Marvel Loch.

In addition to their detailed work on the mining centres, my colleagues rendered valuable assistance to the regional work by carrying out several extensive compass and chain and plane-table traverses of beds whose outcrop lines ultimately helped to unravel the geological structure.

Throughout the course of the survey the process of geological surveying was considerably hampered by the extremely poor outcrop conditions and the ever present mantle of soil and vegetation. Coupled with this was the highly weathered condition of much of the rock which did outcrop, and the general very low relief of the entire Area prevented that visual reconnaissance of fairly extensive areas so necessary to a proper perception of the topographic features and their probable geological significance.

Through the courtesy of the Western Mining Corporation some aerial photographs of portions of the Area in the vicinity of Southern Cross and Nevoria were made available for perusal by the writer, but the low relief, paucity of outcrops and the dense vegetation rendered these photographs valueless from a structural point of view.

When working in areas such as this one, the geologist feels that he cannot see enough of the country at the one time on account of its broadly undulating nature, low relief, and thick forest growth. It is almost certain that the mental picture he would retain as the result of an aeroplane flight (a visual reconnaissance) over the area to be investigated would very greatly help him in the work of correlating geological structure and topography.

An estimate of five per cent. of rock outcrop in the Area of 5,500 square miles is probably not too low, and naturally, under such circumstances, a very large portion of the country has had to be mapped on soil types, distribution of vegetation and occasional rock fragments found in the soil.

ACKNOWLEDGMENTS.

The subject matter of this report is largely the result of a resurvey of an area in which a considerable amount of geological research has already been done by other investigators, chief among whom are Messrs. T. Blatchford and E. St. Smith, sometime members of the Geological Survey of Western Australia. These two geologists were the pioneers of the detailed geological knowledge we already possess of this part of the Yilgarn Goldfield, and although differences of interpretation of geological fact and inference have been made by the writer in this report, it is desired to acknowledge the great value of their work to the present investigations.

In 1913, when Mr. Blatchford carried out the geological survey of the southern portion of the Yilgarn Goldfield, the results of which are incorporated in G.S.W.A. Bulletin 63, there were few roads in the district and practically no agricultural settlement, and he was working single-handed with horse-transport. The district is now well provided with usable motor roads and tracks, and considerable areas of it have been cleared of the thick eucalypt forest which still covers extensive areas.

The use of motor transport and the division of the work as explained under the heading of Field Work, combined with the advance in geological science, have enabled full use to be made of the ground work carried out by Mr. Blatchford.

Suitable reference to the sources of any information obtained from the writings of other investigators will be made in the text as occasion demands.

In compiling this report extensive use has been made of the information gained by Messrs. Hobson and Matheson in the course of their detailed examinations of the Mining Centres. Considerable help to the regional geological work has also been given by my colleagues in the way of lengthy traverses of outcrop lines and valuable suggestions as to possible geological structures during many camp and office discussions on this all important matter. The writer is particularly indebted to Mr. R. S. Matheson in this latter respect.

The valuable help of the Government Mineralogist and Analyst and his staff in carrying out many mineral determinations and assays on material collected by us during the course of the resurvey is gratefully acknowledged. Several minerals not previously recorded from this district have been identified by Dr. E. S. Simpson, Government Mineralogist and Analyst, and details of these will be found in the text.

THE GEOLOGICAL MAPS.

The geology has been represented on maps of two scales, namely, 4 miles to one inch in the case of the general geological map (Plate II), and 40 chains to the inch for the gold-bearing greenstone belt from Southern Cross south-eastwards to Cheriton's Find at the southern end of Parker's Range (Plates III, IV., V., VI., and VII.).

Portions of Lands Department Lithographs Nos. 24/300, 10/300, 19/300 and 20/300 on a scale of $3\frac{3}{4}$ miles to the inch were used as base maps for the regional geology (subsequently reduced to 4 miles to the inch to conform to the existing series of 4 miles to the inch Geological Survey maps covering large areas of the State), while Mines Department Lithographs Nos. L. 53A, L. 53B, L. 55A and L. 54A/54 formed the base maps for the 40 chains to the inch maps of the more important mining centres.

The 40 chains to the inch geological map of the country in the vicinity of Mt. Palmer is compiled mainly from a 20 chains to the inch geological plan of that area made by Mr. R. A. Hobson during 1936. Much of the information on the 40 chain maps has been obtained from the 5 chains to the inch plane table maps made by Messrs. Hobson and Matheson during their examination of the mining centres.

It will be noted that all of the geological boundaries are represented in the legend as being doubtful or assumed, and it may seem strange to the reader not conversant with the topographic and outcrop

conditions of the Western Australian goldfields that in the many miles of boundaries indicated on the maps, no definite geological boundary is indicated. With the exception of a few chains of gneiss-greenstone contact in Southern Cross, no definite geological boundary was observed, and to represent the boundaries of the various rock types on the map as being doubtful or assumed is in strict keeping with the field conditions.

It is very necessary for any person examining these maps to bear this fact constantly in mind, particularly when interpreting structure. The location of structural axes as shown on the plan must not be regarded as being strictly accurate, since outcrop conditions and available facts concerning them prevent anything more than the indication of their presence being attempted.

A large part of the Area is represented as being soil-covered. To be strictly accurate about 95 per cent. should be thus represented, but it has been found possible to infer with a reasonable amount of accuracy the nature of the underlying rock over most of the soil-covered areas, and only in cases where this could not be done with any feeling of certainty has the colour for soil-covered areas been used.

Rocks of granitic and gneissic nature are shown as forming by far the greater portion of the land surface represented in the map on Plate II. Where granite could be definitely recognised, chiefly in the numerous bare "rocks" or isolated bare granite hills of the Area, it has been mapped as such. Over those portions of the map bearing the symbol Gr/Gn. and nearly always forming the sand-plain country, what few outcrops there are generally have a gneissic appearance and are very decomposed. This gneiss may be either a gneissic granite (orthogneiss) a paragneiss (gneiss of sedimentary origin), or metamorphosed sedimentary and igneous rocks changed to gneisses by regional granitisation. There may also be some areas of normal granite underlying this sand-plain country.

The exact nature of this type of country could not be determined, and it is accordingly shown as granite and/or gneiss undifferentiated.

It will be noticed that in the general description of the Greenstone Series in the various legends of the maps, mention is made of the presence of basic intrusive rocks in that series. On the 40 chain maps it has been possible to indicate the areas of proved basic intrusive rock, but they are so small in extent that they could not be shown on the 4 mile to the inch map. The degree of metamorphism has been so high that unless an actual intrusive contact could be discerned a rock has not been mapped as intrusive, although often an accessory mineral such as chromite or a peculiar mineral species indicates the presence of a probable basic intrusive type.

In the southern portion of the goldfield there are very few tracks suitable for motor vehicles, and it was not found possible to make the

number of traverses across the general trend of the formations which would have been desirable. The outcrops in this part of the Area are very few and the scrub is very thick and vine-entangled. The regional mapping here is therefore of a very broad nature, and much reliance has been placed on topographic expression and distribution of vegetation and soil types in sketching in the approximate positions of the geological boundaries. To do geological reconnaissance of a more detailed nature than that attempted, would entail the use of animal transport and would occupy much time. As it is, the probable limits of the metamorphosed sedimentary and igneous rocks are believed to have been reasonably accurately delineated, although even the broad structure of this part of the Area cannot be confidently indicated.

In conclusion it is desirable to again draw attention to the nature of the geological boundaries, and to emphasise that they are mainly controlled by the principles of folding, and that not even in the case of the granitic or gneissic areas (those marked Gr./Gn. on the maps) can it be definitely decided that principles of igneous intrusion determine the boundaries of that rock type. When a rock type can be proved to be of intrusive habit and its boundaries cannot be observed easily, it does not greatly affect the structural interpretation of the geological map if its boundaries as represented on the map are not as they actually are in nature. If, on the other hand, the boundaries of rock types are known to be fixed by the principles of folding it becomes an all important matter to be able to represent on the geological maps as near as possible the exact position of the boundaries as they are in the field.

As already explained, field conditions in the Yilgarn Goldfield have made the accurate mapping of boundaries impossible, and readers interpreting the geological maps are warned accordingly.

PREVIOUS GEOLOGICAL WORK.

The following list of publications embodies the main references to the Yilgarn Goldfield contained in Departmental reports:—

- 1891—*Woodward, H. P.*, Government Geologist: Report by Government Geologist upon the Yilgarn Goldfield. Perth: By Authority.
- 1894-95—*Woodward, H. P.*, Government Geologist: Mining Handbook to the Colony of Western Australia. Perth: By Authority. 1st Edition, 1894; 2nd Edition, 1895.
- 1904—*Gibson, C. G.*: Geology and Auriferous Deposits of Southern Cross, Yilgarn Goldfield. G.S.W.A. Bull. 17. Perth: By Authority.
- 1908—*Montgomery, A.*, State Mining Engineer: Report on the Mines of the Yilgarn Goldfield. Perth: By Authority.
- 1913—*Saint-Smith, E. C., Farquharson, R. A., and Simpson, E. S.*: Geology and Mineral Resources of the Yilgarn Goldfield. Part I., Southern Cross. G.S.W.A. Bull. 49. Perth: By Authority. (Geology by Saint-Smith, Petrology by Farquharson, and Chemical Notes by Simpson.)

1915—*Blatchford, T.*: The Geology and Mineral Resources of the Yilgarn Goldfield, Part II., The Gold Belt South of Southern Cross. G.S.W.A. Bull. No. 63. Perth: By Authority.

A more complete list of references is contained under the heading of Literature at the end of Chapter I. This list has been compiled by Miss B. M. Bowley, B.Sc., Technical Assistant to the Survey, and includes references to the geology and mines of all parts of the Yilgarn Goldfield. Those pertaining to that portion of the goldfield situated south of the Great Eastern Railway Line are suitably indicated.

G.S.W.A. Bulletins Nos. 49 and 63, published in 1913 and 1915 respectively, represent the results of the most recent extensive geological work done by the Geological Survey in this part of the goldfield.

HISTORY OF MINING IN THE AREA.

The early history of the discovery of gold in the Yilgarn goldfield is recorded in a publication entitled "Mining Handbook to the Colony of Western Australia" compiled by Mr. H. P. Woodward, then Government Geologist, and published in Perth in 1895.

An extract from this publication concerning this discovery is as follows:—

"In 1887, Mr. Glass, of Mugakine, while making a tank near his house, found a large speck of gold which caused him to start prospecting, but although he sank several holes, he never had the good fortune to find any more. However, this discovery drew attention to this district, and led to a party being organised and fitted out by the Settlers' Association, with assistance from the Government, to thoroughly prospect the district to the eastward of Newcastle and Northam. This party was placed under the leadership of Mr. Colreavy, who worked over all the country between Newcastle and the Yilgarn Hills, a distance of some 200 miles, and although his first journey was not crowned with success, yet he thought so highly of the country farther east that he immediately afterwards set out to prospect it on his own account.

"While this latter party was still in the field, a sensation was caused by the sudden return from the Yilgarn of Mr. Anstey with some surprisingly rich specimens of gold in quartz. This gentleman had gone in the same direction as Mr. Colreavy, with the intention of making an extensive prospecting and exploring tour. The excitement in consequence of his find was for some time very great, but it was found unfortunately, that the discovery was not as valuable as had at first been supposed, as further prospecting showed that although the surface indications were good, the reef at a very slight depth pinched out. Fortunately, just at this time Mr. Colreavy, who was prospecting Golden Valley, ten miles further south, struck a small reef which carried gold throughout the stone. This caused another rush, and several small gold-bearing reefs were found. Prospecting was continued still further by the Phoenix party, who discovered a rich series of reefs about 30 miles further south, which they named Southern Cross, from the fact of having made use of that constellation as a guide while travelling by night to the spot. Mr. Parker, following the same direction for 40 miles farther south, discovered in some low hills other reefs, which locality he named Parker's Range."

Some further information is contained in G.S.W.A. Bull. No. 49, p. 15, where Mr. Saint-Smith states:—

“I am informed by Mr. A. M. McIntyre, of the *Southern Cross Times*, that the prospectors comprising the Phoenix party consisted of Messrs. T. Risley, Michael Toomey, and Charles Crossland (a surveyor), and that the date of their original discovery was either January 21st or 22nd in the year 1888. They were accompanied by an aboriginal named Wheelbarrow. The site of the discovery was on Wimmera Hill, a low ridge of ‘jasper’ close to the present township. (Fig. 26.)

“It was the subsequent discovery in the same year of Fraser’s reef, however, which established the field, the earlier discoveries abovementioned being rather of a discouraging nature at the time, the actual quantity of gold present being somewhat misleading owing to the presence of much ‘paint gold’ through the stone.”

A detailed history of the gold discoveries at all the known auriferous localities of the Area is not intended in this section of the report, and the fortunes of the goldmining industry as a whole are more easily followed by a perusal of the yearly production figures shown in the Mineral Production Table on page 23 and the associated graphical representation of this information.

Of late years, particularly during the worst period of the world-wide financial depression from 1930 to 1933, the enhanced price of gold led to a very marked increase in prospecting activity, and many old known gold-bearing formations as well as new discoveries in known gold-mining centres helped to swell the production figures.

This latest gold-mining “boom” resulted in the discovery of two new gold localities in the southern part of the Yilgarn Goldfield, namely, at Edward’s Find situated about 28 miles south of Southern Cross in the year 1932, and at Palmer’s Find situated about 8 miles south-south-east of Yellowdine Railway Siding in 1934. Both of these new “finds” have yielded rich returns from narrowly restricted areas, but neither has so far developed into a group of small mines characteristic of the other mining centres of the Area.

The general mining revival throughout the Area has been particularly noticeable at Southern Cross and Marvel Loch, which were, prior to its advent, virtually struggling for existence. These two towns are now busy centres, and together with Nevoria are the localities where the development of old mines too low grade to work except at the enhanced price of gold (£8 17s. 1d. per fine oz. Australian currency as on March 24, 1937) is at present actively proceeding.

A new township has come into existence at Mt. Palmer, the scene of Palmer’s Find, and much spasmodic activity is to be observed all along the gold-belt from Southern Cross to Parker’s Range. The discovery of gold at Palmer’s Find was the cause of a mild gold rush, an occurrence not seen in Western Australia since the early days of gold discovery in this State. The country was pegged as mining tenements for many miles north and south along the possible and often

impossible auriferous country, but as already mentioned, the occurrence of payable gold was found to be restricted to one small locality, the site of the original discovery.

Of additional historical interest in connection with this "find" was the occurrence of a small patch of alluvial (strictly speaking geologically, *eluvial*) gold on and at the base of the slope of the hill on which the quartz reef outcropped. A small band of alluvial gold diggers worked here for a few months, and many and varied were the improvised mechanical devices used for treating the difficult pay dirt which carried the gold. The "dry-blower" was noticeably absent in this assemblage, and contrivances based on the use of the saline ground water obtainable in the lake near-by predominated.

Some litigation resulted between the mining company developing the quartz reef and the alluvial workers, the former seeking to exclude the alluvial miners from their leases on the grounds that the gold was not an alluvial deposit. The case was decided in favour of the alluvial miners on the grounds that the nature of the gold-bearing material came within the meaning of "alluvial" as defined in the Mining Act. The Warden, however, fixed an arbitrary line close to the reef beyond which the alluvial miners were not permitted to work in the direction of the reef.

Gold was found at Edward's Find on an area which had been cleared and cultivated for the growing of wheat. Edwards, the finder, was previously a prospector and miner for many years on the Eastern goldfields, but was at the time, engaged in agricultural pursuits on the land where the find was made. The sinking of a shaft through soil and clay for about 12 feet on the spot where a "floater" of quartz carrying gold had been found resulted in the uncovering of a gold-bearing quartz reef. Numerous other smaller reefs have since been similarly discovered here, and there is now a 5-head stamp battery treating the ore from several small privately owned mines in its immediate vicinity.

Further details of these two new gold localities are contained in G.S.W.A. Bulletins Nos. 98 and 99 respectively.

MINERAL PRODUCTION.

Gold is the only mineral which has been found in payable quantities, and there does not appear to be any record of the production of any of the other commercial minerals, copper, lead, zinc, etc. The Transvaal Mine, at present known as the "Jupiter" (April 1937) produced some arsenical concentrates as a by-product about the year 1919, but there is no official record of the amount produced. A very small quantity, probably a few tons only, of tin-oxide obtained from an albite-pegmatite dyke at Holleton in the south-western portion of the Area is more of mineralogical than commercial importance.

TABLE SHOWING ANNUAL PRODUCTION OF GOLD FROM THE YILGARN GOLDFIELD (SOUTH OF THE GREAT EASTERN RAILWAY) UP TO DECEMBER, 1936*

Year.	Ore Treated.	Gold Therefrom.	Dollied, Alluvial and Specimens.	Total Gold.	Grade per Ton.
	Long tons.	Fine ozs.	Fine ozs.	Fine ozs.	Fine ozs.
Prior to 1897	144,280·93	65,967·69	596·20	66,563·89	0·457
1897 ...	35,654·93	13,924·64	...	13,924·64	0·390
1898 ...	26,149·28	9,096·69	...	9,096·69	0·348
1899 ...	27,022·21	10,314·58	...	10,314·58	0·381
1900 ...	37,134·28	20,211·29	...	20,211·29	0·544
1901 ...	27,015·03	20,121·93	19·12	20,141·05	0·743
1902 ...	26,377·03	15,998·34	8·67	16,007·01	0·604
1903 ...	21,715·53	11,953·61	172·61	12,126·22	0·548
1904 ...	24,209·38	14,024·06	37·82	14,061·88	0·578
1905 ...	40,289·03	14,270·66	...	14,270·66	0·353
1906 ...	60,865·03	19,495·54	81·58	19,577·12	0·319
1907 ...	48,346·60	17,511·93	28·26	17,540·19	0·362
1908 ...	53,716·92	21,284·59	13·81	21,298·40	0·394
1909 ...	43,583·17	19,636·31	27·40	19,663·71	0·450
1910 ...	31,357·22	15,645·37	28·45	15,673·82	0·498
1911 ...	14,062·67	10,031·75	46·24	10,077·99	0·713
1912 ...	63,347·17	22,238·51	18·96	22,257·47	0·350
1913 ...	69,509·17	27,420·12	56·24	27,476·36	0·394
1914 ...	56,962·92	18,629·11	5·26	18,634·37	0·326
1915 ...	23,861·67	10,685·64	7·72	10,693·36	0·445
1916 ...	26,062·72	9,935·29	47·68	9,982·97	0·381
1917 ...	26,172·66	8,904·05	...	8,904·05	0·341
1918 ...	28,426·43	9,750·18	...	9,750·18	0·343
1919 ...	34,060·17	10,128·57	1·77	10,130·34	0·296
1920 ...	19,531·57	6,173·11	2·22	6,175·33	0·316
1921 ...	13,587·57	6,652·11	11·59	6,663·70	0·492
1922 ...	8,740·35	4,159·66	2·19	4,161·85	0·475
1923 ...	5,568·20	4,572·92	3·95	4,576·87	0·821
1924 ...	10,895·57	5,716·69	5·71	5,722·40	0·526
1925 ...	29,598·39	9,802·02	12·06	9,814·08	0·331
1926 ...	30,175·43	8,343·66	...	8,343·66	0·276
1927 ...	24,461·68	6,351·73	...	6,351·73	0·259
1928 ...	883·43	1,344·56	...	1,344·56	1·517
1929 ...	356·78	925·55	5·92	931·47	2·597
1930 ...	6,050·48	2,931·70	4·90	2,936·60	0·484
1931 ...	6,844·64	3,608·95	81·55	3,690·50	0·526
1932 ...	9,835·28	5,107·40	13·36	5,120·76	0·518
1933 ...	14,745·93	7,750·84	4·44	7,755·28	0·527
1934 ...	24,428·28	8,673·46	5·93	8,679·39	0·355
1935 ...	25,450·18	12,976·04	1,414·96	14,391·00	0·507
1936 ...	88,324·18	31,762·20	199·06	31,961·26	0·359
Total ...	1,309,636·34	544,033·26	2,965·63	546,998·89	0·415

* No battery returns or bank returns have been included here because the source of the ore could not be established. Parcels of ore from the northern portion of the Yilgarn goldfield or from other goldfields may have been treated in batteries situated in the southern part of the Yilgarn goldfield. The figures in the table are as nearly accurate as it is possible to get them.

There is a small proportion of silver in practically all of the gold, and this metal represents the chief accessory to the gold in the bullion produced from the various treatment plants.

The table on page 23 prepared from official Mines Department records by Mr. R. S. Matheson, gives the gold production data for that portion of the Yilgarn Goldfield situated south of the Great Eastern Railway from the time of discovery up to the end of 1936.

This information is represented graphically in Fig. 5.

A total of 1,309,636 tons of ore have yielded 544,033 fine ounces of gold, while 2,965 fine ounces of doliied, alluvial and specimen gold have been obtained from the Area.

The maximum annual gold yield was in 1936 when 31,762 fine ounces of gold were obtained from 88,324 tons of ore treated, the maximum tonnage treated in any one year.

The minimum annual production was in 1929 when 925 fine ounces were obtained from 357 tons of ore treated, the minimum tonnage treated in any one year.

The average grade of all ore treated up to the end of 1936 is 0.415 fine ounces per ton (about 8.3 dwt.).

In 1928 and 1929 unusually low tonnages were treated, but it will be noted that the grade was very much higher than usual, a feature which shows the mining to have been of a highly selective nature during these years.

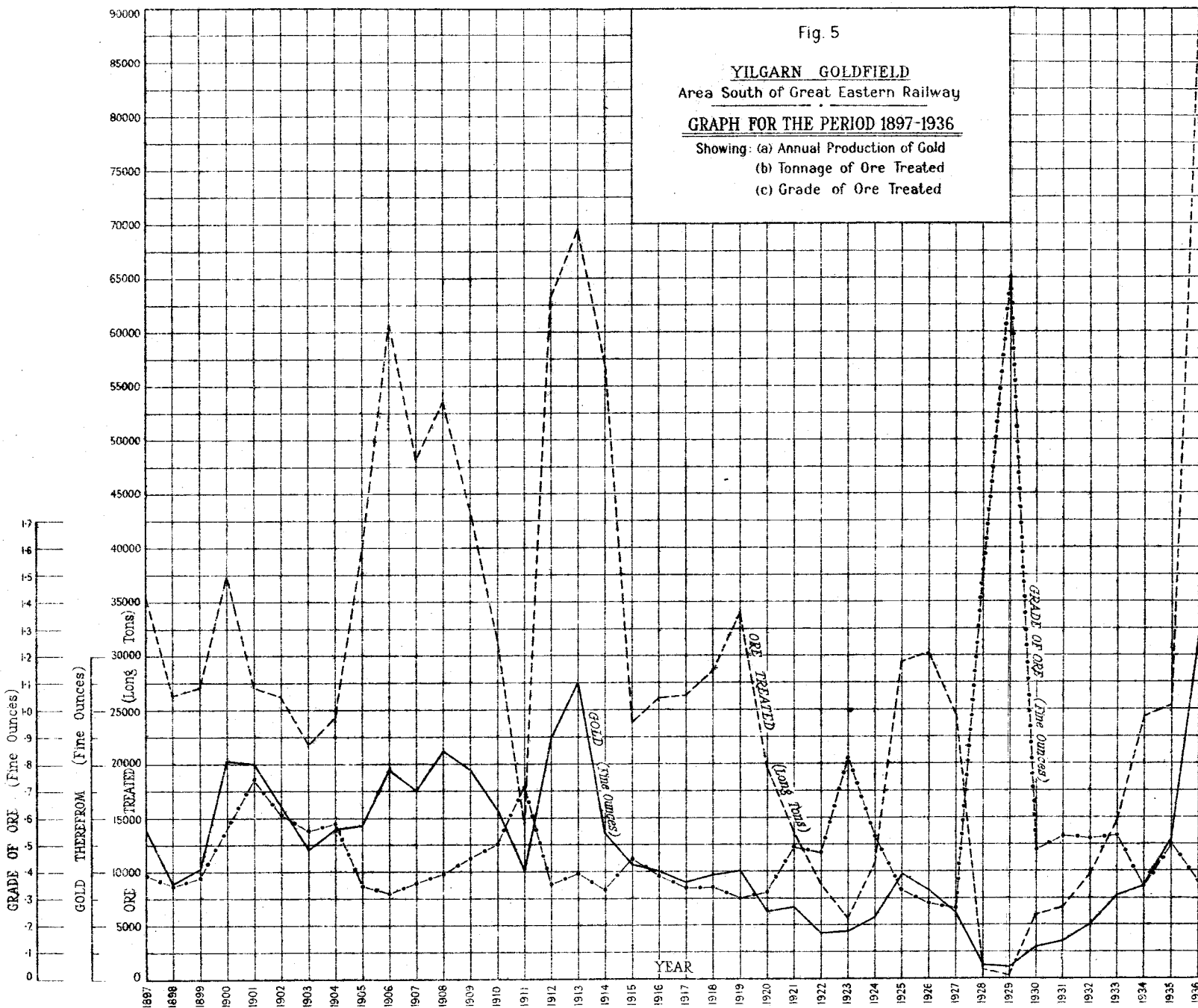
The grade of the ore treated has been, on the average, low, and the marked increase in production during 1936 is due largely to the reaching of the production stage by The Marvel Loch Gold Development N.L. Mining Company operating on low grade ore (4-5 dwt.) at Marvel Loch, and The Yellowdine Gold Development Ltd. Mining Company treating 15 dwt. ore at Mt. Palmer.

The high price of gold, averaging over £8 Australian currency per fine ounce during 1936, has also had a stimulating influence on gold production, and many small mine owners have been able to work ore of a grade which could not be mined and treated profitably at the old price of gold.

In 1937 several other mining companies, notably The Southern Cross United Mines Ltd. working the old Fraser's Reef at Southern Cross, and The Nevoria Gold Mining Company Ltd., developing the old "Never-Never" line at Nevoria will probably reach the production stage and a record annual production for that year is anticipated.

CLIMATE: TEMPERATURE AND RAINFALL.

The climate of the Area, the latitude and longitude of whose central point is approximately 31° 57' S. and 119° 37' E., is governed largely by its being situated some 140 and 230 miles from the nearest ocean to the south and west respectively, and by the existence of the main Australian continental land mass to the east and north.



These circumstances are sufficient to produce a continental type of climate with hot dry summers in which there is not a very marked disparity between day and night temperatures, and a winter season marked by relative extremes of heat and cold. A feature of the winter climate is the prevalence of very cold winds which blow from the south mainly, but which can produce equally bleak conditions when coming from any other quarter. Temperatures below freezing point are not infrequent during this season and there is often a considerable proportion of cloud in the sky. As will be seen from the rainfall table, p. 30, the winter months, May, June, July and August are those in which most rain usually falls, and this feature in conjunction with the prevalence of cold winds makes these months a period of very bleak conditions.

The shade temperatures of the summer months, December, January, February and March are often in excess of 100°F. for days at a time, but these periods are usually followed by intervals when moderate temperatures prevail. Not infrequently these hot spells are accompanied by humid conditions and high night temperatures which cause much personal discomfort. Winds approaching gale force and carrying very considerable quantities of dust are a feature of the Eastern Goldfields of Western Australia, and the Yilgarn Goldfield is no exception in the occurrence of these dust storms. Minor cyclonic disturbances known as "willy-willys" are also frequent during the summer months, and these seem to be restricted to periods of low or moderate wind velocities when sun and shade temperatures are unusually high.

The summer months, particularly January and February, are also characterised by the occurrence of thunderstorms in which large quantities of rain fall in a very short time. These storms fall over a relatively narrow strip of country which may however have a considerable longitudinal extent. The frequency of these thunderstorms does not seem to be controlled, and it is not uncommon for only one or perhaps none to occur during the course of a summer.

A table showing the mean daily maximum temperature, mean daily minimum temperature, with the highest and lowest temperature at Southern Cross taken over a period of 38 years is published on page 26.

The highest temperature recorded is 117°F. during February of 1933 and the lowest 24.3°F. in June of 1918.

The average annual rainfall for Southern Cross, situated approximately in the centre of the northern boundary of the Area taken over a period of 46 years, the period for which complete records are available, is 10.67 inches. The 10-inch isohyet follows a general north-westerly and south-easterly direction a little north of Southern Cross, and the 11-inch isohyet, though not delineated on the Commonwealth Rainfall Map of Western Australia, probably passes in a general east and west direction somewhere near the southern boundary of the Area.

TEMPERATURE DATA (DEGREES F.) AT SOUTHERN CROSS. (No. OF YEARS OF RECORD = 38.)

	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Year.
Mean Maximum	94.6	93.0	86.6	78.7	69.5	63.0	61.7	64.6	71.7	77.4	86.6	92.4	78.3
Mean Minimum	62.2	62.1	58.1	51.6	45.0	41.5	39.1	40.2	42.9	47.5	54.8	59.8	50.4
Extreme Maximum	115.0	117.0	112.0	101.1	92.0	79.0	80.0	85.9	94.3	102.0	110.2	114.6	....
Date	24/1910	11/1933	5/1934	6 and 7/ 1906	1/1914	1/1912, 16/1925	18/1919	29/1907	21/1931	4/1914	25/1913	26/1908	....
Extreme Minimum	42.0	42.0	38.2	30.0	26.0	24.3	25.0	25.0	26.0	30.6	35.6	41.0	....
Date	2/1921	8/1926	29/1910	20/1914	17/1914	28/1918	16/1914, 1/1929	8/1900	13/1932	12/1925	3/1907	22/1913	....

Data supplied by Divisional Meteorologist, Perth.

The average annual rainfall for the Area is therefore between 10 and 11 inches, with the greater amount falling towards the southern boundary as the coast is approached.

There is not a very marked difference between the wet and dry seasons, but in the northern part of the Area the wet season can be said to extend over the months April to August inclusive and in the southern part from May to October inclusive.

The distinctly unreliable nature of the rainfall can be gauged by inspecting the rainfall statistics on pages 30 and 31, where it will be seen that sometimes a certain month of one year had 4.69 inches of rain and the same month a few years earlier had no rain. An annual rainfall of 15.89 inches can be followed by one with only 7.5 inches and a maximum annual rainfall of 19.57 inches contrasts with a minimum annual fall of 4.87 inches.

These features are best illustrated in the form of graphs, and on pages 28 and 29 graphs showing the curves for the annual rainfall for Southern Cross from 1891 to 1936 inclusive, the rainfall for a typical summer month and a typical winter month over the same period are reproduced.

These vagaries in the rainfall of the Area have been responsible for the failure of the wheat growing industry where it has been attempted in the vicinity of Southern Cross. A reliable rainfall over the growing period of the wheat plant—April to October—is absolutely essential for its successful cultivation, and this portion of the Yilgarn Goldfield has been given a very thorough test and found wanting in its ability to grow wheat for grain.

The incidence of the rainfall being in the first place low, and spread as it is, fairly evenly over most months of the year, has a pronounced influence on the occurrence of potable ground water in the district. Much of the winter rain falls as a drizzle, often at intervals over several weeks at a time, and the lengthy periods between the falls gives the processes of transpiration and evaporation ample time to be fully operative. Hence it is that very little of the annual rainfall can find its way quickly to suitable natural underground reservoirs where these do exist.

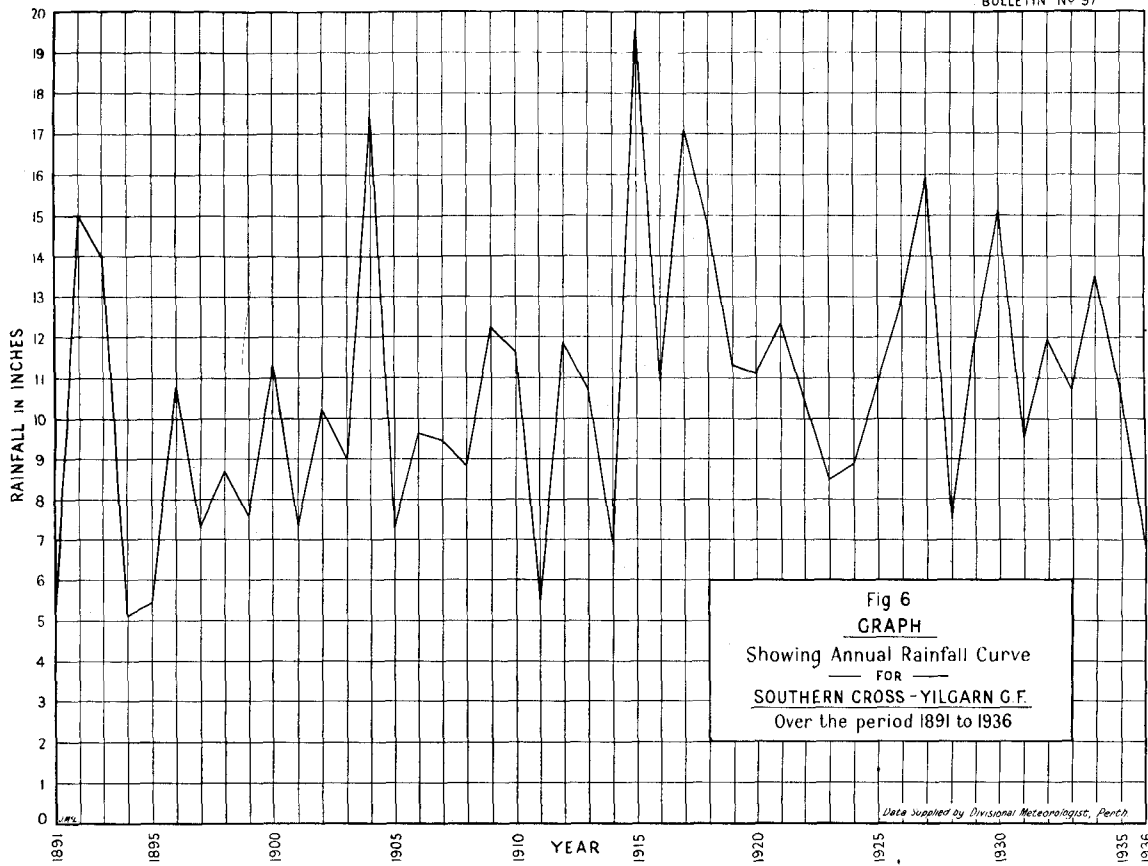
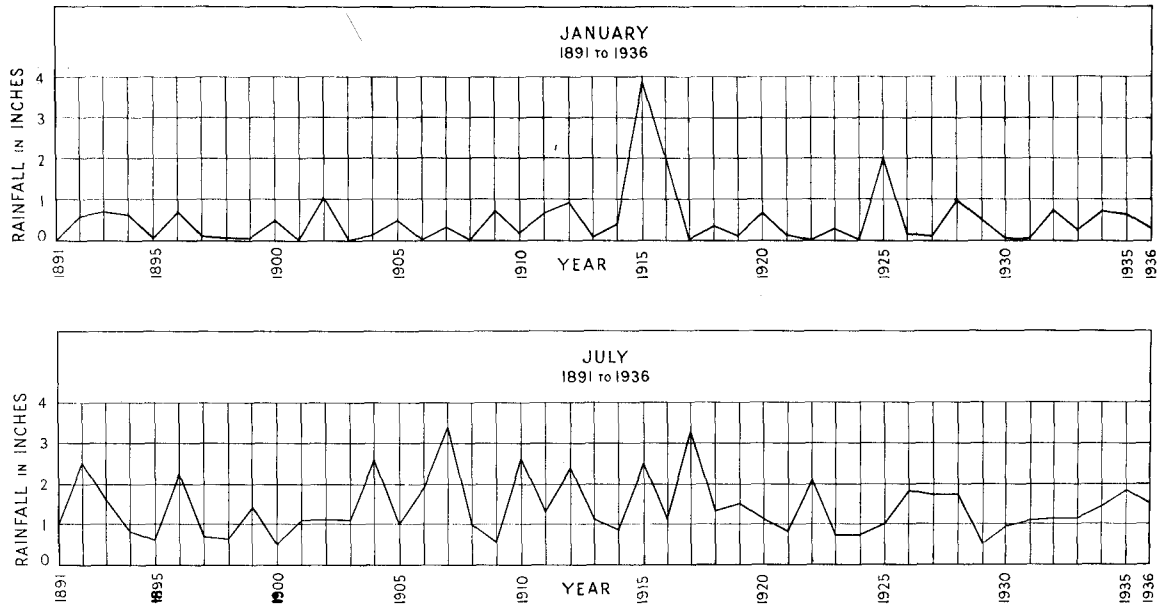


Fig 6
GRAPH
Showing Annual Rainfall Curve
FOR
SOUTHERN CROSS - YILGARN G.F.
Over the period 1891 to 1936

Data supplied by Divisional Meteorologist, Perth.

Fig. 7
GRAPHS

Showing the Total Monthly Rainfall for January (a typical summer month).
 and for July (a typical winter month), at Southern Cross—Yilgarn Goldfield
 Over the period 1891 to 1936



Data Supplied by Divisional Meteorologist Perth

COMMONWEALTH METEOROLOGY.

Element: Rain.

Station: Southern Cross, State of Western Australia.

100 points = 1 inch.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Total Annual.
1889	59	4	.....	46	224	227	170	88	101	59	39	.....	Points. 1,017
1890	N.R.	N.R.	N.R.	N.R.	N.R.	35	121	73	88	92	53	25	487
1891	.....	.....	21	3	145	135	100	22	50	24	.....	23	523
1892	62	4	417	86	206	41	252	179	79	119	25	40	1,510
1893	71	19	128	142	347	144	159	83	70	16	48	177	1,404
1894	63	18	108	4	37	46	80	69	42	5	19	21	512
1895	4	10	2	17	81	168	61	155	42	2	.....	.....	542
1896	73	19	316	.....	28	66	225	55	14	15	89	.....	1,078
1897	11	69	59	4	29	233	68	114	34	6	1	107	735
1898	1	145	.....	3	75	251	65	193	14	93	23	.....	863
1899	4	12	.....	4	12	158	142	55	89	55	226	.....	757
1900	55	12	25	260	224	129	54	73	59	171	40	27	1,129
1901	.....	39	45	10	133	143	108	189	49	7	12	3	738
1902	105	254	33	.....	94	128	115	83	93	54	45	17	1,021
1903	.....	70	.....	113	96	126	116	75	112	81	53	60	902
1904	14	.....	165	2	229	262	262	59	418	187	59	88	1,745
1905	43	54	.....	27	185	30	97	45	85	54	8	105	733
1906	3	98	.....	5	225	99	193	199	28	7	55	50	962
1907	35	12	190	16	62	86	339	79	84	3	12	17	944
1908	.....	25	35	212	176	107	110	59	32	28	88	11	883
1909	78	53	4	254	79	266	56	346	22	47	20	.....	1,225
1910	22	119	3	2	219	232	258	92	63	120	31	.....	1,161
1911	70	4	20	25	147	38	135	49	28	28	.....	10	554
1912	97	41	50	127	266	24	239	21	74	42	60	143	1,184
1913	7	.....	83	87	40	107	107	220	181	87	22	137	1,078
1914	38	7	.....	28	.....	54	85	83	.....	226	134	32	687
1915	389	306	58	123	350	174	246	162	77	30	.....	42	1,957
1916	203	.....	35	10	88	111	113	124	32	127	247	.....	1,090
1917	3	.....	461	131	138	191	333	162	93	80	57	65	1,714
1918	37	484	64	212	135	196	137	90	47	49	27	.....	1,478
1919	10	.....	39	310	76	153	147	158	59	130	43	53	1,128
1920	63	12	232	42	77	220	113	210	64	63	15	.....	1,111
1921	9	2	23	5	469	188	78	177	77	36	17	147	1,228
1922	.....	52	246	147	96	103	203	72	67	7	30	21	1,044
1923	14	3	71	86	66	283	68	34	135	11	.....	82	853

1924	....	....	1	31	83	28	206	85	72	132	127	104	14	3	886
1925	....	....	204	199	77	32	91	76	100	52	85	47	24	103	1,090
1926	....	....	16	29	348	204	51	164	179	57	55	68	98	25	1,294
1927	....	....	13	30	665	53	138	67	165	48	322	39	30	19	1,589
1928	....	....	95	....	56	33	130	71	156	100	45	17	....	47	750
1929	....	....	46	123	75	....	320	177	45	35	8	58	293	....	1,180
1930	....	....	....	200	89	275	106	267	92	121	50	8	16	282	1,506
1931	....	....	....	29	10	115	249	112	107	158	70	16	66	24	956
1932	....	....	74	31	74	76	173	75	110	261	53	226	6	33	1,192
1933	....	....	22	7	82	32	196	213	111	202	37	49	52	69	1,072
1934	....	....	66	....	113	504	1	142	139	219	90	40	25	13	1,352
1935	....	....	59	98	68	36	31	29	181	203	38	312	....	13	1,068
1936	....	....	33	8	23	8	46	150	154	92	20	16	....	126	676

TOTAL MONTHLY RAINFALL.

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Total.
1891-1936	2,213	2,728	4,705	3,893	6,318	6,320	6,475	5,466	3,413	3,010	2,130	2,413	49,084

AVERAGE MONTHLY RAINFALL.

Monthly. Average for 46 Years.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Average Annual.
	48	59	102	84	137	137	140	118	74	65	46	52	1,067

Note.—In calculating the averages, the first two years have been eliminated on account of the incompleteness of the record.

Rainfall data supplied by Divisional Meteorologist, Perth.

FLORA.

With the exception of a relatively small area cleared for agricultural purposes during the past 10 years or so, and the floors of salinas, the whole of the Area is covered with a moderately thick growth of eucalypt forest and woodlands and low shrubs and mallee.

In the Vegetation Map of Western Australia compiled by Mr. C. A. Gardner, Government Botanist, and issued by the Forests Department, the southern portion of the Yilgarn goldfield is situated approximately in the centre of the zone mapped as "Low rainfall temperate forests and woodlands with belts of sand heaths and mallee" in which eucalypts are the dominant species of the forests and woodlands. This vegetational type is known in the vernacular as "Salmon gum forest and sand-plains."

The difference between forest and woodland is one of degree only, the trees of the forest areas being more closely spaced than is the case in the woodlands where the trees are sometimes four or five chains apart and consequently attain a greater size.

The Government Botanist, Mr. C. A. Gardner, has kindly supplied the following list of Eucalypt species known to occur in the Area, and with the aid of that very useful publication, "Key to the Eucalypts of Western Australia,"¹ the writer was able to identify many of the types mentioned.

LIST OF SOME EUCALYPT SPECIES KNOWN TO OCCUR IN THE
YILGARN GOLDFIELD, SOUTH OF THE GREAT EASTERN
RAILWAY.

Vernacular Name.	Botanical Name.
Mallee	<i>Eucalyptus eremophila</i> , Maiden—This species sometimes has a tree form.
Ribbon Tree	<i>E. celastroides</i> , Turczaninow.
Goldfields Blackbutt	<i>E. Clelandi</i> , Maiden.
Mallee	<i>E. Forrestiana</i> , Diels.
Red Flowering Gum	<i>E. torquata</i> , Leuhm.
Winged Gimlet	<i>E. diptera</i> , C. Andrews.
Stunted Wandoo	<i>E. redunca</i> , Schau; <i>var elata</i> , Benth.
York Gum	<i>E. foecunda</i> , Schauer—As a mallee.
Black Morrel	<i>E. melanoxylon</i> , Maiden.
Morrel	<i>E. oleoso</i> , F. v. M.
Red Morrel	<i>E. longicornis</i> , F. v. M.
Gimlet	<i>E. salubris</i> , F. v. M.
Silver Topped Gimlet	<i>E. campaspe</i> , Spencer Moore.
Whip Stick Mallee	<i>E. leptopoda</i> , Benth.
Mallee	<i>E. Ewartiana</i> , Maiden } With a red
Mallee	<i>E. Websteriana</i> , Maiden } stringy bark.
Mirret	<i>E. celastroides</i> , Turcz.
Snap and Rattle	<i>E. gracilis</i> , F. v. M.
Yorrell	<i>E. gracilis</i> , F. v. M.
Salmon Gum	<i>E. salmonphloia</i> , F. v. M.
Merrit	<i>E. Flocktoniae</i> , Maiden.
Mallee	<i>E. leptophylla</i> , F. v. M.—A mallee form of a salmon gum, it sometimes has a tree form.

¹ 1924, Kessell, S. L., and Gardner, C. A., Key to the Eucalypts of Western Australia. Forests Department, Bulletin No. 34. Perth: By Authority.

The majority of the species listed occur as trees, though some are mallees. In the sand-plain areas there are some eucalypt species occurring as shrubs and marlocks, and in this case the tree and mallee forms are usually absent from such areas.

As there is often a direct relation between the type of vegetation and underlying rock, it may not be out of place to quote here a classification of the various types of eucalypt growth, from Forests Department Bulletin No. 34.²

“Eucalypts are divided, as regards habit, into Trees, Shrubs, Mallees and Marlocks. Trees are distinctive in habit in that they possess a well-defined trunk. Shrubs branch from the base, or close to the base. Mallees have a bulbous root-stock, either subterranean or half above the soil, from which arise stems (usually 4 to 8 in number), which are all of about the same height. Typical Mallees have a large woody stock. Marlocks, which may be called ‘sand-plain Mallees’ have a smaller reduced stock, or become true shrubs. It is often difficult to differentiate between a Marlock and a Shrub, as intermediate forms occur, which may be one or the other. Trees and Mallees, on the other hand, are quite distinctive forms of vegetation.”

In considering the distribution of the two types of vegetation, the forests and woodlands on the one hand, and the belts of sand heaths and mallee on the other, it can be generally stated for the Area that the former are to be found on the country underlain by rocks of the ancient metamorphic sedimentary and volcanic series, and the latter on the country underlain by the gneissic and granitic complex.

Serious errors in mapping would, however, be committed if the general distribution as outlined above were adhered to when defining the geological boundaries in the soil-covered areas. It frequently happens that the forest and woodland encroaches for long distances into the gneissic complex areas, and there are very extensive strips and patches of forest covered country, notably near the eastern boundary of the Area throughout its length, where it has not been found possible to determine the nature of the underlying rock, but where an extensive deposit of red to yellow coloured sandy-loam is indicated.

Again, in the southern portion of the goldfield, notably south of Mt. Holland and Holleton, extensive developments of the metamorphic sedimentary and volcanic series carry a heath and mallee vegetation, and even in the forests definitely known to be growing on rocks of the metamorphic volcanic series, patches and strips of heath and mallee occur.

Of the numerous eucalypt species growing in the Area, only those known as Morrel can be considered to have some value as an indicator to the underlying rock type. It is true that wherever rocks of the greenstone type outcrop as low bouldery hills or ridges there is frequently a strong growth of Morrels, hence when these trees are very numerous in any particular locality and the rock does not outcrop it is reasonable to map the area as greenstone.

² Op. cit. p. 8.

Only a broad classification of the vegetation according to the type of rock on which it grows can be given, and the following is the distribution as observed in the district examined:—

VEGETATION—DISTRIBUTION.

Rock Type.	Vegetation.	
	Normal.	Abnormal.
<i>Greenstone Series—</i>		
(a) Low hills and ridges with bouldery outcrops of greenstone	Morrel	Heath and Mallee.
(b) Soil-covered greenstone areas	Mostly Morrel, Gimlet, Snap and Rattle, Blackbutt, and Boree with Salt-bush	Salmon Gum.
<i>Whitestone Series—</i>		
Metamorphosed sediments with bands of greenstone	(a) In the north of the Area, Salmon Gum and Gimlet (b) In the south of the Area, Heath and Mallee	Heath and Mallee. Salmon Gum and Gimlet.
<i>The Gneissic Complex ...</i>	Heath and Mallee ...	Salmon Gum, Gimlet, Morrel, and Boree (on the margins and in soil-filled depressions).
<i>The Red to Yellow Sandy Loam-covered Areas</i>	Salmon Gum, Gimlet, Snap and Rattle, Boree, Blackbutt, Morrel	

In the southern part of the Area despite the slight increase in rainfall, the amount of forest and woodland decreases and the heath and mallee (scrub) growth increases. A strong development of vine growth also appears amongst the scrub here, and in the vicinity of the Middle and South Troncaps it is very difficult to force one's way through the thick vine-entangled undergrowth.

The marginal areas of the dry salt lakes carry a thick sapphire growth while two varieties of saltbush (*Atriplex sp.*) including "old man saltbush" are frequently seen in association with the forest and woodland on soils overlying rocks of the Greenstone Series.

On the sand plains a dwarfed pine which may be a *Callitris* species resembling the Cypress pine of far northern latitudes occurs, and in suitable localities groves of *Casuarina sp.* are of frequent occurrence.

Beautiful Kurrajong trees are to be seen growing on the small soil-filled depressions of the granite and gneiss "rocks," particularly in the eastern portion of the Area, and the quondong trees, small in

stature but shapely, are universally distributed through the forest and woodland.

Sandalwood (*Santalum lanceolatum*) is known to occur in the mallee and heath belt south of Karalee Railway Siding, but it must be very scarce in this southern part of the Yilgarn Goldfield now, all the marketable wood having been cut long ago.

A species of "spinifex" is common in the mallee and heath belts in the eastern part of the Area, but other natural grasses are extremely rare in the forest, woodland, and mallee and heath areas which have not been cleared and cultivated.

The mallee and heath vegetation so characteristic of the sand plains throughout the district investigated, provides a remarkable assemblage of wild flowers during the late spring months, September and October, and the stretch of high-level sand plain east of Ghooli Pumping Station and south of the railway line, is one of the most noteworthy localities for wild flowers in the State. A feature of this heath vegetation is the predominance of species of Leguminosae, Myrtaceae and Epacridaceae and the presence of dwarf varieties of species which elsewhere grow to larger dimensions. Near the 5-mile peg on the Yellowdine-Parker's Range Road there are some dwarfed species of "Black-boy" (*Xanthorrhoea*) trees in the sand plain country hereabouts.

During the late summer months, March and April, many of the eucalypts shed their bark, and the species known as "gimlets" present a very picturesque sight with their new glossy bark-covered trunks glistening in the sunlight amidst a waving mass of older stringy bark still attached to the upper parts of the trunks.

FAUNA.

Both birds and animals are very few in numbers and species. The arid nature of the climate with the accompanying total lack of permanent natural surface waters and remarkable paucity of natural herbage and grasses, causes almost a complete lack of the essential food supplies for animal and bird life. It is possible to work for weeks at a time in the forest and scrub covered country and not see or hear a bird or animal of any description.

During the survey of over 5,000 square miles of country, with the exception of a few crows, parrots, magpies, ground pigeons and small lizards, the writer saw one emu. Tracks of kangaroos were occasionally noted but not one was seen, and the occasional track of a dingo and the hearing of its nocturnal howl indicated the presence of that animal around several artificial water supplies.

Very few rabbits were seen and there is no evidence of their presence at all over the greater portion of the Area. This absence of rabbits can be regarded as a measure of the infertility of much of the district and also the lack of natural waters.

Flies, ants and termites ("white ants") are as plentiful here as in most other inland parts of the State. Snakes are seldom seen and disappear so quickly in the undergrowth that the species could not be recognised. A few long tailed goannas were seen, and the stump-tailed blue-tongued sleepy lizard is common.

The Area can be regarded as probably one of the most inhospitable stretches of country in Western Australia as far as bird and animal life is concerned. There are no aborigines living in it, and although a careful watch was kept for any sign of previous native occupation, none was found.

AGRICULTURAL PURSUITS.

The scarcity of water and the almost complete absence of edible herbage and natural grasses in the forest and sand-plain country in its natural condition, causes the pastoral possibilities of the Area to be very unattractive. The chief use to which some of the land is put is the growing of wheat under the dry farming system, and provided a good season is experienced in the way of rainfall, a considerable portion of the area cleared for cropping purposes returns satisfactory yields.

This portion of the Yilgarn Goldfield is situated on the eastern fringe of the wheat belt, and experience has shown that the rainfall is not sufficiently reliable to make it a safe wheat growing district. There are large tracts of cleared agricultural country on which wheat growing has been attempted but which are now abandoned.

Near the southern boundary of the Area much forest country was cleared some years ago with the object of growing wheat, but the soil proved to be too alkaline for the successful culture of the wheat plant and the cleared and partially cleared holdings were abandoned.

An attempt to grow wheat in the country in the vicinity of Bullfinch, immediately to the north of Southern Cross, has ended in failure; many thousands of acres of cleared agricultural country being recently abandoned with the loss to financial interests of a large sum of money.

SOILS.

A full discussion of the soils of the Area is not intended here since the intricate problem of soil classification is a matter for specialised research and does not come within the scope of the geological investigations carried out during this survey. The observations made on the relation of soil types to underlying rocks are recorded, since much of the geological mapping has been done on this basis.

The soils of the southern portion of the Yilgarn Goldfield have been classified by Prescott³ into two main groups, Mallee soils and Lateritic sand-plain soils, details of which are set out below:—

Soil Group.	Colour.	Horizon.	Character of Profile.	Character of Associated Vegetation.
Mallee Soils ...	Light red-brown	A B	Sand, Sandy Loam or Sandy Clay Solonised Clay, Calcium carbonate, Soluble Salts	Mallee and Sclerophyll Woodland.
Sand-Plain ...	Light grey to yellow with ironstone gravels	...	Presumed to be Tertiary pod-sols	Heath and Sclerophyll Scrub.

This broad classification is based on the international usage of the soil-profile (i.e., by the relative positions of the various soil constituents in the profile as controlled by the movements of the soil water), for the division of soil-types into groups.

Prescott⁴ describes this group of Mallee soils as follows:—

“Mallee Soils.”

“The mallee soils form a very important group in southern Australia within the zone of winter rainfall and within the influence of the Southern Ocean. Soils closely akin to the mallee appear to be unknown in other parts of the world, and the characteristics of the soil appear to be determined by the accession of cyclic salt, the low leaching effect of the rainfall and by the action of the wind in building up sandhill formations. Whether these sandhills were formed in a previous climatic cycle and have been subsequently vegetated, or whether they are still forming, is uncertain, but when cleared they begin to drift seriously in dry seasons. In Western Australia, however, these soils do not appear to suffer from sand drift.

“The mallee soils express themselves in a number of ways, but in general they have a uniformly pinkish light-brown colour, and are usually alkaline, with a normal range from pH 7.5 to pH 9.5, although more acid and more alkaline soils are known. The most alkaline soils in Australia occur in the mallee formations.

“The characteristic vegetation of these soils includes a number of associations, of which the salmon-gum-gimlet sclerophyll woodland of Western Australia and the true mallee of South Australia and Victoria appear to be most characteristic. On sandhills in the northern Murray Mallee, an association which includes *Callitris glauca* and *Casuarina lepidophloia* is very common.

³ 1931. Prescott, J. A. The Soils of Australia in relation to Vegetation and Climate. Australia. Council for Scientific and Industrial Research. Bull. No. 52. By Authority: Melbourne. p. 83.

⁴ Op. cit. p. 62.

“The mallee soils invariably contain calcium carbonate in the sub-soil, so much so that one is led to suspect in many instances some accession from outside sources. Where the parent material is essentially calcareous, sheet limestone surfaces and limestone rubble subsoils are very characteristic. In the eastern half, the mallee soils are derived principally from Tertiary to recent formations, but in Western Australia these soils are found directly on granite and the related intrusive basic rocks, where the parent rock is exposed in the lower levels of the dissected peneplain.

“In the Eastern States these soils are characterised by a low silt content, coarse sand and fine sand being present frequently in approximately equal proportions, while the clay content may arise in the better soils to satisfactory values. The presence of the illuvial clay horizon is presumably the result of a *solonisation process* and not of *podsolisation*. Chemically these soils are low in nitrogen, organic matter and phosphoric acid. Under natural conditions, the mallee soils have little or no pastoral value, and their development for wheat-growing has been one of the most interesting developments in Australian agriculture.”

The same author⁵ discusses the Western Australian Sand Plains and his remarks are relevant to the sand plain soils so extensively developed in the Area and are reproduced hereunder:—

“10. The Western Australian Sand Plains.”

“Of the soils derived from laterite, the Western Australian light lands or sand plains form a clearly defined group covering an estimated extent of 10,000,000 acres. That this formation is in all probability a fossil podsol is indicated from physiographic evidence, as well as from the character of the profile and from the data available regarding the soil reaction. The vegetation associations have already been noted as heath and sclerophyll scrub. Several types of sand plain are recognised by the Lands Department of Western Australia, the types ranging from deep yellow sands to heavy ferruginous gravels. The sand plains appear to show their most extensive development along an axis from Esperance towards Shark Bay; they cover both the granite and sedimentary formations, and on the latter west of Mullewa and near Yuna, show occasional evidence of wind influence in the form of vegetated sand hills.

“Related lateritic soils probably occur in tropical Australia, and in the light of present evidence one may tentatively map the sandstone tablelands of the Kimberleys and North Australia as lateritic formations. More authenticated is the Tanami region, where the association of mallee and sclerophyll scrub with ironstone gravel and sand plain affords a tropical parallel to the south-western formations.”

In the course of geological mapping in the absence of rock outcrops, the soils of the Area appeared to fall mainly into four groups sufficiently distinctive in colour and texture and associated vegetation to enable an approximate geological boundary to be drawn on the maps. The chief physical characteristics of the soils overlying the various rock types are as follows:—

Greenstone Soils.—Red to dark red or grey in colour, puffy and subject to crab-hole or “gilgai” structure. A fairly high percentage of clayey matter and much nodular calcareous material.

⁵ Op. cit. pp. 70-71.

Soils of the Metamorphosed Sedimentary Series.—A lighter coloured firmer soil than the greenstone type with a more sandy texture. Colours ranging from yellow to light red dominate, and there is little calcareous material in evidence.

Granitic and Gneissic-Complex Soils.—The white to yellow sandy soils with ironstone gravel and a great preponderance of quartz in their composition occurring mainly on the sand-plain country were found to overlie rocks with a granitic composition.

Indeterminate Soils.—Red to yellow sandy loam suggestive of derivation from granite, and covering extensive lower flat portions of the Area. The long narrow strip of this type of country mapped along the eastern border of the Area is an example. It is thought that much of this soil has been transported, probably by wind, to its present position. There are vegetated sand dunes in this belt and dry salt lakes with steep vertical banks, suggestive of loess deposits. These may be seen north-east of Harris' Find, east of Parker's Range.

This classification is admittedly broad, and is obviously based on the surface characteristics of the soil-types. Very many changes in texture and colour occur in any one group according to the particular nature of the underlying rock and the topographic situation of the soil. The occurrence of hybrid soils formed from the intermingling of soils from two different types of parent rock where these are in juxtaposition, as they frequently are in both the Whitestone and Greenstone Series, is not uncommon.

The occurrence of unweathered or only partially weathered rock fragments in a soil gives a valuable clue to the nature of the underlying rock, and the exposures in shallow shafts, costeans, etc., also enable one to verify the diagnosis of the parent rock made from the overlying soil.

The ability to recognise a soil type as being representative of a certain rock formation when no outcrops or fragments are to be found is only gained after a lengthy period of field work in which factors relating to associated vegetation, topographic expression, soil-colour and texture are mentally correlated with soils definitely known to overlie rocks of a particular type.

A large portion of the soils of the Area are residual soils formed *in situ* by decomposition of the rocks which they now cover. The soil mantle varies in thickness from zero in the case of bare granite surfaces and bouldery greenstone ridges to as much as 12 feet on undulating rises and flat areas of greenstone and metamorphosed sedimentary rocks. The zone of weathering also has wide limits, being as much as 200 feet in depth at Marvel Loch and only one or two feet in many of the bouldery greenstone ridges.

The soil mantle is very extensive and continuity of outcrop of any rock exposure is limited to a few chains only. There are many square miles of soil-covered and thickly forested country to the east of Parker's Range and Palmer's Find in which there are no outcrops and no fragmental rock material to give a clue to the possible nature of the underlying rock. The soils are mostly sandy loams of red or yellow colour and carry a mixed forest growth. They cannot be correlated with the soils recognised as overlying rocks of the Greenstone, Whitestone, or Gneissic Complex Series and have been called Indeterminate Soils in the broad soil classification outlined in an earlier part of this section of the report.

They are associated with dry salt lakes and vegetated dunes to the north-east of Harris' Find and south-east of Mt. Hampton and must be formed in part at least of wind-blown material. Much of the soil found on the margins of the dry salt lakes is of transported origin, and if the westerly migration of these lakes be accepted as a fact, as it suggested by Jutson,⁶ then this area of transported soil must be considerable.

Large quantities of the lighter portion of the soils are certainly transported by occasional sheet floodings brought about by abnormally heavy downpours of rain not uncommon in the summer time. Inspection of any de-watered mine into which surface run-off water has had access, particularly when a sands dump is situated in the vicinity, provides some idea of the quantity of material which can be transported by storm water.

The other important soil-carrier, the wind, must be conceded some effective part in the formation of at least portion of some of the soils of the Area. During the summer months, and to a lesser degree in the winter time, dust-laden winds are frequent. It may be urged that the source of much of this dust is the road surfaces and cleared agricultural land. While this is no doubt substantially true, fine soil can be frequently observed to be lifted and carried along by strong winds in the heart of the eucalypt forests and woodlands.

An inspection of the Lands Department Lithographs covering the Area reveals the distribution of the agricultural areas either as isolated blocks, small groups of blocks, or their arrangement in long and relatively narrow strips. The country south of Moorine Rock is a typical example. This country has been selected for agricultural purposes on account of the superior quality of the soil occurring there, and in every instance it was noted that these agricultural areas are situated in topographic depressions or basins.

The writer gained the impression that they were soil-filled depressions, noting the scarcity of outcrops in them. In some of them, dams have been excavated, and the presence of decomposed granitic material

⁶ 1934. Jutson, J. T. The Physiography of Western Australia. G.S.W.A. Bull. No. 95. Perth. By Authority, p. 224.

in the dam embankments suggests that possibly a granitic bed-rock underlies these depressions. It may be that the soils in such cases are composite, being partly represented by transported material and partly by a residual soil developed mainly on granitic parent rock.

Prescott⁷ states that these depressions in the sandplain country in the wheat belt of Western Australia represent areas of normal soil developed on granite which has been exposed as the result of denudation of the overlying laterite and sandy soil.

The vegetation in these hollows is almost invariably the salmon-gum—gimlet association merging laterally along the rising margins into mallee, and passing into the typical heath-mallee association of the higher sand-plains. This conception is difficult to fault, but further work is necessary to establish the relative proportions of transported and residual soils in these extensive basins, occurring in granitic rocks undergoing some step in the cycle of erosion under arid or semi-arid conditions.

During recent years Miss D. Carroll, B.A., B.Sc., D.I.C. of the University of Western Australia, has been carrying out investigations into the mineralogy and relationships of the soils of selected areas in Western Australia, mainly in the Kalgoorlie and Southern Cross districts. The results of some of her work are published in the *Journal of the Royal Society of Western Australia*⁸ and the *Geologica Magazine*.⁹

In an Abstract of a thesis on "The Mineralogy and Relationships of the Soils of Selected Areas in Western Australia (Kalgoorlie, Southern Cross and other Districts)" by Miss Dorothy Carroll, and kindly made available by the author, it is stated that:

"The purpose of this investigation was to collect soils from the areas where the geology is well known, to establish the heavy-mineral assemblages for the soils formed from the various rocks and to apply these criteria to soils in districts where the geology is obscure. Characteristic heavy residues were obtained from the Kalgoorlie and Southern Cross soils. These soils known as "Mallee" are peculiar to the southern part of Australia, and the mineralogical examination was able to throw some light on the processes of soil formation under the present arid conditions.

"The examination included mechanical analyses (to obtain the Fine Sand, 0.2—0.02mm. grade), separation into light and heavy fractions with bromoform, and a magnetic separation. The grains were identified by the usual optical methods, and counts were made of the species in the heavy residues to obtain the percentage compositions, which were tabulated and plotted in triangular diagrams to indicate the features of soils from different parent rocks. The varietal features of the species were particularly noted, and in several instances were found to establish the connection between the soil residue and that of the underlying rock.

⁷ Op. cit. p. 50.

⁸ 1937. Carroll, Dorothy: Some Aspects of Soil Mineralogy. *Journal of the Royal Society of Western Australia*, Vol. XXIII, pp. 7-12.

⁹ 1936. Carroll, Dorothy: Heavy Mineral Assemblages of Soils from the Gold-fields of Western Australia. *The Geological Magazine*, Vol. LXXIII, Nov., 1936, pp. 503-511.

“At Southern Cross a soil of Greenstone origin was indicated by abundant polyvarietal amphibole, and small amounts of opaque grains, epidote and zoisite; while a granitic or meta-sedimentary origin was shown by a small amount of amphibole, a considerable quantity of opaque grains, and a variety of polyvarietal species such as zircon, tourmaline, garnet, rutile and andalusite.

“The Kalgoorlie assemblage consisted of opaque grains, amphiboles, epidote, zoisite, tourmaline (pneumatolytically formed in the greenstones), rutile, andalusite, zircon, with pyrite, gold, and fuchsite occasionally present.”

In her Conclusions, the author states that:

“The Southern Cross soils yield different ‘heavy’ mineral assemblages for the various types of parent rock.

“It was found that a greenstone parentage for a soil was indicated by:—

- i. Large amount of ‘heavy fraction.’
- ii. Abundance of amphiboles; or, abundance of amphiboles and non-magnetic or slightly magnetic iron-ores.
- iii. Presence of zoisite and epidote, sometimes with a little rutile.
- iv. Chloritised and micacised amphibole grains in the light fraction, and less quartz than in soils of non-greenstone origin. Plagioclase often plentiful.

“A granitic, gneissic, or meta-sedimentary origin was indicated by:—

- i. Small amount of ‘heavy fraction.’
- ii. Fairly large amount of non-magnetic iron ore.
- iii. A considerable variety of ‘minor’ species such as polyvarietal zircon, tourmaline, and garnet, andalusite, brown mica, occasional monazite, and smaller amounts of amphibole than in soils derived from greenstones.
- iv. Kaolinised and chloritised grains are subordinate in the ‘light fraction’ to quartz.

“The results of this investigation, in which the varietal features of the species of the heavy residues, their significance with regard to the total assemblages, and their relationship to the parent rock has been considered, indicate that the parentage of these soils could be approximately inferred from their mineral composition.

“In following up this investigation, difficulty may arise in many districts in Western Australia owing to the presence of deep leads and old drainage channels which are often concealed by drifted soil material. The ‘heavy’ mineral residues of such soils will necessarily be of mixed origin, the assemblages yielding no definite information, except indirectly from such species as amphibole, rutile, tourmaline and zircon.

“The results also indicate that it is necessary to investigate the mineralogy of the country rocks of any area in order to realise the significance of the heavy residues, and this would be the only way in which a similar investigation could be applied to assist the mapping in areas where there are few rock exposures.”

In applying the principles of these researches by Miss Carroll to the extensive soil covered flats of the South Yilgarn Goldfield, considerable difficulty would be encountered on account of the following facts:—

- (a) The interbedded nature of both the greenstones and metamorphosed sedimentary rocks. There are many bands of

meta-sediments in the greenstones, and also many bands of greenstones in the metamorphosed sedimentary rocks.

- (b) The very extensive nature of these soil-covered areas and the total lack of any outcrops in them, from which to gain a knowledge of the country rock.
- (c) The extent of regional granitisation, which is, in places incomplete and which must give rise to abnormal rock types.
- (d) The fine silt portion of the soils on these areas cannot be regarded as being entirely formed *in situ* but must be conceded a partially transported origin, the transporting agencies being either wind or water or both.

The writer finds it difficult to visualise the absence of extensive areas of transported soil in a terrain which has internal drainage and is undergoing a phase in the cycle of erosion taking place under semi-arid conditions. The presence of vegetated sand hills must indicate that conditions unfavourable to the growth of vegetation obtained when these sand hills were being formed. The existence of vegetated sand ridges over a large part of Central and Western Australia seems to point to a more arid climate in those regions in the past than in the present. The extensive drift of soil is prevented by vegetation, and the sand ridges of the Area though not extensively developed now carry eucalypt forest and mallee growth.

MINING TIMBER, FUEL AND WATER SUPPLIES (MINING).

Mining Timber.

The goldfield possesses extensive forest reserves in which practically all of the eucalypt species occurring there are eminently suitable for the timbering of underground workings and for the construction of buildings and small treatment plants.

The species most extensively used are Black Morrel (*E. melanoxylon*), Red Morrel (*E. longicornis*), Gimlet (*E. salubris, campaspe*) and Salmon Gum (*E. salmonophloia*). The Gimlet species are particularly valuable to the prospector and small mine owner, being extensively used for the construction of ladders and as laths in prospecting shafts.

There are no timber mills in the Area and the sawn timber requirements of the mining industry (for shafts, mine-buildings, etc.) are supplied from Perth, the timber most commonly supplied being Jarrah (*E. marginata*).

Fuel.

Despite the increasing tendency to the use of internal combustion engines using crude oil fuel as a source of power in the mining industry, there is still a big demand for firewood for the various steam-operated

power plants, and the district is abundantly supplied with first-class firewood from the eucalypt forest reserves. The dead wood in the forests is not of sufficiently good quality for general use in the industry, being very much subjected to the attacks of termites. The eucalypt species has the ability of being very nearly burnable in boiler fires in the green condition, but the usual practice is to cut and stack green timber for a few months before use.

Practically all of the eucalypt species are good burning woods, and there is in consequence, no scarcity of fuel.

Water Supplies (Mining).

Southern Cross, Marvel Loch, Burbidge and Mt. Palmer, the four main mining centres, use water from the Goldfields Pipe Line, the water coming from Mundaring Dam near Perth. The Greenmount mining centre, now practically decadent, also has a branch pipe-line from the main supply. For many years the domestic water supplies of the mining and agricultural community have been provided by the Goldfields Pipe Line supply, in a system of reticulated pipe lines of various gauges extending as far as 30 miles away from the main pipe line at Southern Cross.

Mining centres such as Parker's Range, Edwards' Find, Holleton and Nevoria depend on sunken dams for part of their domestic needs, but very large quantities of water are carted to these places from the nearest "stand-pipe" on the pipe-lines. Details of water supplies at the various mining centres are given in Bulletins Nos. 98 and 99.

The underground water is everywhere very saline and the surface of the ground-water zone varies in depth from 50 to 260 feet or more. This saline ground-water has had to be used in both amalgamation and cyanidation treatment plants in many mines throughout the Area. The effect of this saline water on the process of amalgamation does not appear to have been serious, but its use in the cyanide process has undoubtedly led to the excessive consumption of cyanide, particularly when there is much magnesium chloride in the water as there not infrequently is.

Sunken dams in depressions in soil catchments and some blasted out of gneiss, as well as some soakage wells near the margins of granite "rocks" were provided by the Goldfields Water Supply Department in the earlier years of mining activity. These supplies were made to meet the domestic requirements of the mining community, but since the extension of the pipe-line systems into the auriferous belt they have not been kept in repair and are unreliable sources of supply. Their positions are indicated on Plate 1 and they are further discussed in the ensuing section.

As previously mentioned the depth to underground water level throughout the mining districts is variable. This feature is partially controlled by topography and partly by geological structure. The

quantity of water entering underground workings does not constitute a serious pumping difficulty in any of the mines at present operating, and often the paucity of the underground water supplies is keenly felt by owners of small treatment plants.

ROADS, TRACKS AND WATER SUPPLIES (DAMS, WELLS, ETC.).

(See Plate 1.)

Roads and Tracks.

In Plate 1 only the main roads and tracks are indicated. The main roads are indicated by solid lines and the tracks by broken lines. For details of roads in the agricultural areas reference may be made to Lands Department Lithographs Nos. 24/300, 19/300, 10/300 and 20/300 of the 300 chains to the inch series and to Nos. 6/80, 23/80, 24/80 and 36/80 of the 80 chains to the inch series. Many of the roads shown on these 300 and 80 chains plans have been surveyed but not cleared or formed. In the 40 chain geological plans accompanying this Bulletin only those roads actually existing are shown.

The Central and western portions of the northern part of the Area are fairly well supplied with roads, but the southern and eastern sections have very few roads or tracks. No useful purpose will be served by giving details of the conditions of the various roads and tracks, since their state depends on the amount of usage, seasonal conditions, maintenance, etc. Some general remarks on the nature of the roads and tracks will be found on Plate 1, printed alongside the less frequently used routes.

As a rule the road surfaces in the gold-bearing belt (the greenstones and metamorphosed sedimentary rocks) are very rough, and after heavy rain are not negotiable by motor vehicles. Deep boggy patches develop in them, and even after only light falls of 15 points or less, the surface is very slippery. It is a wise precaution to always carry tyre chains and equipment to extricate a motor vehicle from a bog when travelling in this country. A sudden thunderstorm can make a road difficult to negotiate without chains even in the summertime.

The gneissic and granitic country on the other hand usually provides good road surfaces negotiable after even heavy rain. The lower lying parts of this type of country need careful attention however in wet weather, as they frequently contain soft boggy patches.

The main Perth-Kalgoorlie road traverses the Area from east to west along its northern boundary, being more or less parallel to the Great Eastern Railway Line and on one side or the other of it throughout this distance. The western boundary can be traversed by using a very indifferent road alongside the No. 1 Rabbit Proof Fence from Burracoppin to the south-western corner of the goldfield. A general north-south traverse can be made from Southern Cross via Marvel Loch, Burbidge, Parker's Range, Mt. Holland and passing to

the east of the North, Central and South Ironcamps to the southern boundary of the goldfield on roads of many degrees of roughness. An east-west traverse of the Area can be accomplished by using a track going eastwards from the 91-mile peg on the Rabbit Proof Fence (91 miles south of Burracoppin along the fence) to the Ravensthorpe-Southern Cross road, then travelling north to Mt. Holland and turning south-east along the Mt. Holland-Kumarl track.

A main road and track frequently used runs from Yellowdine Railway Siding south through Mt. Palmer, Nevoria and Parker's Range, and joins the main Southern Cross-Ravensthorpe road there. A long straight road and track runs south-east from Moorine Rock to Parker's Range via Cockatoo Tank, and a road south from Moorine Rock passes through agricultural country to the gold mines at Holleton.

Most of the roads have sign-posts erected at important turn-offs.

Taken on the whole the roads of the district are rough and corrugated, and very little cross country driving can be indulged in on account of the thick scrub and dead timber in the forests.

Water Supplies (Dams, Wells, etc.)

It would be difficult to imagine a more waterless stretch of country than what the 5,500 square miles of the Yilgarn goldfield south of the Great Eastern Railway must have been before the provision of artificial water supplies in it.

As far as could be determined during the course of the survey, the only localities where surface water would be found, and then only immediately after rain, was in the shallow erosion basins on bare granite and gneiss "rocks."

These basins vary in size and hold from one gallon to several thousand gallons of water. They are always shallow and water is quickly lost from them by evaporation. Cronin's Lagoon, about 16 miles south of Mt. Holland and $\frac{3}{4}$ of a mile east of the Southern Cross-Ravensthorpe Road is a small, shallow fresh water lagoon and is not a permanent water. This occurrence is the only natural fresh water supply away from the "rocks" that is known to the writer.

There appears to be an entire absence of such natural permanent or good surface supplies of fresh water as occur in "rock-holes," "water-holes," "soaks," springs and "gnamma holes."

In Plate 1 all of the water supplies noted during the survey are indicated, and it cannot be too strongly urged that reliance cannot be placed on any supply except from the Goldfields Pipe-Line water stand-pipes.

Government maintenance of existing artificial supplies other than the pipe-line has ceased, and through the thoughtlessness and vandalism, as well as the stealing propensities of some of the travelling public,

it is unsafe to depend entirely on the water-supplies previously established in those parts of the Area remote from the Goldfields Pipe-Line.

There are a number of small rock-catchment and roof-catchment tanks at various points along the rabbit-proof fence, but these supplies are very limited and are intended for the use of the employees of the Vermin Branch of the Agricultural Department only.

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(W) refers to the Warden's reports.

(I) refers to the Inspector of Mines' reports.

CHAPTER II.

PHYSIOGRAPHY.

	Page.
The General Land Form	50
The Drainage System	53
The Ridges and Hills	54
The Sand Plains	58
The Depressions and Salinas	59

THE GENERAL LAND FORM.

The Area forms portion of the great inland plateau of Western Australia the origin of which is discussed in detail in G.S.W.A. Bulletin No. 95¹⁰. It also constitutes portion of the physiographic division of "Salinaland" the chief characteristics of which are the existence of internal drainage and dry salt lakes (salinas). No fresh evidence relative to the origin of this plateau was obtained during the survey, though it is admitted that only a limited amount of time was spent in work of such a nature as had a direct bearing on this section. The general sameness of the topography and the low relief tend to mask any slight changes in general elevation which may be present, and which may be important factors in arriving at the physiographical history.

The lack of definite geological information in some parts, notably in the great depressions, and the absence of complete topographic maps which would need to be closely contoured to be of use, makes it difficult to enter into a useful discussion to contribute to the literature dealing with the origin of the present land shapes.

The striking feature of the Area as a whole is its broadly undulating surface and the level horizon presented in almost any direction from almost any part of it. There are remarkably few outstanding land shapes, even the greenstone ridges being comparatively inconspicuous. There are no mesas or allied structures, nor are there any conspicuous lines of laterite cliffs commonly known as "breakaways."

In the central-western, and southern parts there are several prominent land shapes, notably Mt. Hampton, composed of granite, Mt. Holland and the North, Central and South Ironcaps. All these latter four owe their existence to the resistance to weathering of a band of jaspilite. None of these hills, designated as mountains on the Lands Department lithographs, rises to more than 250 feet above the general level of the surrounding country.

Scattered sporadically through the Area, though most frequent in the central-western and southern sections, are numerous bare granite

¹⁰ 1934. Jutson, J. T., The Physiography of Western Australia. G.S.W.A. Bull. No. 95, 2nd Edition, Revised, pp. 195-208.

hills known as "Granite Rocks," and these may occur either on the crests of the broad undulations or in the topographic basins. Some of them, notably Mt. Hampton and Strawberry Rocks when viewed from the east appear to occupy high points, but when approached from the west appear to lie in depressions. It can be said of Strawberry Rocks that it does occur on the western slope of a large depression and that there is rising ground for some distance to the west of it, but in many other instances the fixing of the relative positions of those "rocks" with respect to the surrounding country is a matter of judgment only, as no accurate measurements of height were available.

To show how deceptive is the undulating topography in attempting to estimate the relative differences in height of its component parts, it may be stated that the writer gained the impression that the general fall of the land surface was to the south as the result of numerous journeys across it in the course of the survey.

The results* of levelling data obtained from a railway line survey made from Southern Cross south-south-eastwards to Mt. Holland and then south-eastwards to the eastern boundary of the goldfield not far from the south-east corner, reveals the fact that there is a general rise in the country in this direction.

The levels* taken along another railway line survey south-south-west from Southern Cross showed that for a distance of about 34 miles in this direction from Southern Cross there was a gradual rise in the land surface. The levels were not taken beyond this point by the railway surveyors, but there was no obvious fall in the general level beyond this point to the western boundary of the goldfield in this direction.

Some of the highest country in the district appeared to be situated in the vicinity of Holleton, and a traverse along the Rabbit Proof Fence southwards from Burracoppin affords many opportunities of observing the broadly undulating nature of the country.

Further information concerning the general slope of the main land surface was obtained from personal conversation with Public Works Engineers who have been connected with water supply propositions south of Mt. Holland. They state that southwards from Mt. Holland there is a general fall, though only gradual.

The heights of the various railway stations and sidings on the Great Eastern Railway indicate a gentle rise to the east from Burracoppin on the western boundary to Koorarawalyee on the east, along the route followed by the railway.

Beyond the limits of the Area to the east there is a gradual fall in the land surface as indicated by railway survey data, and from the same source of information it is seen that the general level to the west also gradually falls.

* Information supplied by Chief Engineer's Branch, Railway Department, Perth.

It would seem then from the evidence quoted above, that the part of the Area as far south as a line passing through Holleton and say the Middle Ironcap, has a northerly and westerly slope in two directions roughly at right angles to each other (see Fig. 8). Southwards beyond this line there is probably a gentle southerly fall and eastwards there is certainly a gradual diminution in general surface elevations.

Although some of the more prominent land forms, notably the three Ironcaps in the south, appear to stand out prominently above the general level of the peneplain, particularly when viewed from the west, it would be unwise in the absence of accurate height determinations to conclude that they do rise to a greater elevation than the highest part of the undulating peneplained surface in more northerly situations.

It has been suggested that this part of the great inland plateau may represent a plane of marine abrasion¹¹ and that the Miocene sea penetrated far into the interior of Western Australia. No undoubted remnants of any Tertiary sedimentary formations were found, although a careful search was made for this evidence so necessary to firmly establish the marine invasion theory.

At the present time the entire surface, with the exception of a small portion cleared for agricultural purposes, and the comparatively small extent occupied by the floors of the salinas, is covered with low rainfall temperate forests and woodlands with belts of sand heaths and mallee in which eucalypts are the dominant species in the forests and woodlands. The average elevation above sea level is in the vicinity of 1,300 feet and the average annual rainfall about 10 inches. The entire drainage is internal and there are no large or even medium sized dry drainage channels. There is often a wide range in daily temperatures and extremes of heat and cold are common, temperatures below freezing point being frequent in the winter months. Winds of high velocity blow both in the summer and winter months and thunderstorms accompanied by sudden heavy falls of rain are a feature of the Area. The ground water, with the exception of a few isolated instances occurring under special conditions, is everywhere intensely saline, being quite unfit for use by man or beast.

It is obvious that the moulding of the land surface must be taking place to-day under conditions classified as belonging to the arid cycle of erosion. The presence of the thick growth of eucalypt species and heath is all that prevents the Area being classified as a desert—it possesses all of the other attributes of desert land in other parts of Australia; some to a marked degree.

This mantle of vegetation renders inoperative some of the main processes characteristic of the arid cycle of erosion, and it is very

¹¹ Jutson, *op. cit.* pp. 195-208.

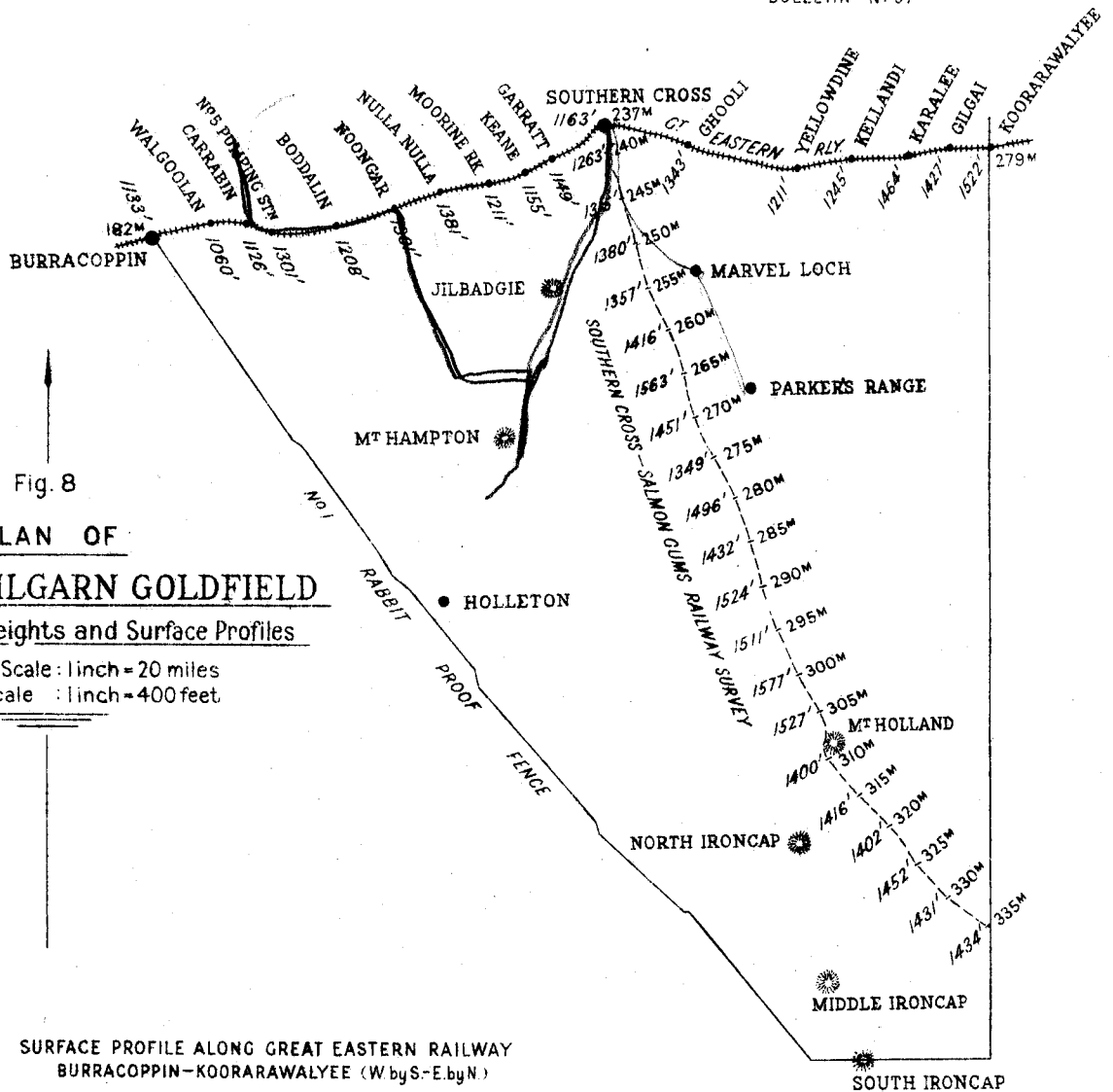


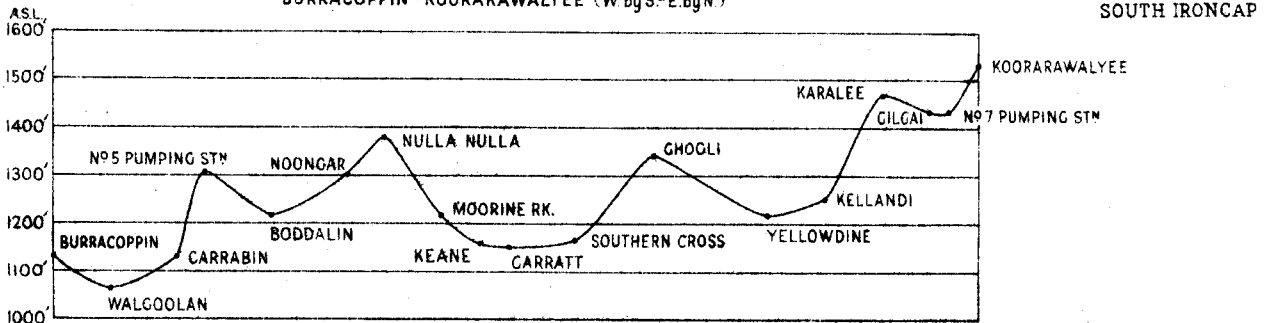
Fig. 8

**PLAN OF
PORTION OF YILGARN GOLDFIELD**

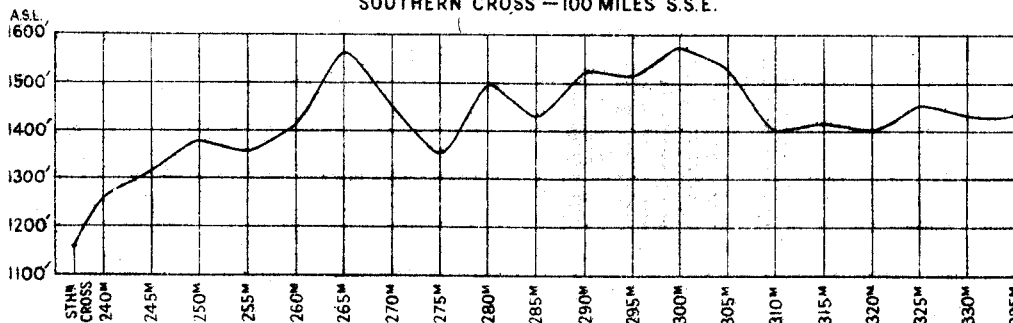
Showing some Heights and Surface Profiles

Horizontal Scale : 1 inch = 20 miles
Vertical Scale : 1 inch = 400 feet

**SURFACE PROFILE ALONG GREAT EASTERN RAILWAY
BURRACOPPIN-KOORARAWALYEE (W by S.-E. by N.)**



**SURFACE PROFILE ALONG PROPOSED ROUTE OF SOUTHERN CROSS-SALMON GUMS RLY.
SOUTHERN CROSS - 100 MILES S.S.E.**



difficult to explain satisfactorily some of the existing physiographical problems associated with the Area. From what has been stated above, the following agents of erosion must be operating to-day in the moulding of the existing land surface:—water, wind, insolation, frost and crystallisation of salts. Jutson¹² has ably described the action of the agents of erosion in “Salinaland” and has discussed their relative importance. He inclines to the view that of these agents rain is the predominating factor in the present stage of erosion but points out that if the general level of the peneplain is being lowered, then, since the drainage is entirely internal, the products of weathering must have been removed by wind action, that is, that the material has been “exported.” These views will be further discussed in subsequent sections of this chapter.

THE DRAINAGE SYSTEM.

A perusal of the rainfall data and the information contained in Chapter I., pages 24-31, relating to climate, temperature, etc., shows that only occasionally is there likely to be any water in excess of the demands of evaporation, transpiration and absorptive capacity of the soil. The rainfall is, in the first place, low and erratic. A large proportion of the rain falls either as a slight drizzle or as infrequent showers, and a very large part of the surface is covered with a sandy soil which quickly absorbs the light and intermittent rainfall.

Under these circumstances, which must be regarded as being normal, there is no run-off over very large tracts of country, and consequently there is not normally any surface drainage system being established. It is to the abnormal rainfall, then, the occasional storms capable of precipitating several inches of rain in a comparatively short interval of time and producing sheet flooding that we must look to for the production of a drainage system. On the steeper slopes of the low ridges and granite “rocks,” short narrow channels are cut but do not extend to more than a few chains out from the base of the elevations. In favourable localities several of these small gullies may unite and form a small narrow ephemeral stream having a maximum length of half a mile or so.

There are no dry creek beds extending along the flat country nor are there any obvious patches of water worn alluvium. There is, however, ample evidence of the movement of soil and dead vegetation down very gentle obvious slopes and along apparently flat country as the result of this action of sheet flooding.

In parts of the major depressions there are some salt lakes, dry for the most part of the year and covered with a varying thickness of silt with salt and gypsum crystals. These lakes retain the water which falls on their bare surfaces and a small amount of the concentrated run-off from low greenstone ridges which frequently occur on

¹² Op. cit. pp. 251-271.

their western margins. They do not receive the drainage from any substantial drainage channels since these latter do not exist.

The drainage system then, is poorly developed and is entirely internal, much of the rainfall being utilised by the forest and heath vegetation, some lost by evaporation, and a small proportion only, finding its way to the ground water zone.

THE RIDGES AND HILLS.

There is no evidence to suggest that these land forms owe their origin to anything but differential erosion, but if the broad crests of the major undulations are included here a controversial subject is at once introduced. It is proposed in this section to confine the discussion to the ridges and hills composed of greenstones, metamorphosed sedimentary rocks, granite and gneiss

The distribution of the land forms in which these rock types predominate have a direct relation to the geological structure as will be further emphasised in the chapter dealing with the structural geology.

It is necessary first of all to point out that the exact relation which the heights of the crests of these residual ridges and hills bears to the heights of the crests of the surrounding undulating country has not been ascertained with accuracy. Some of the ridges and hills occur in major topographical depressions, others appear to lie along minor crests in these depressions.

The Greenstone Ridges and Hills.

Practically all of the land forms included here represent the upturned edges of a highly folded series of metamorphosed basic igneous rocks and their associated pyroclastics and sediments and owe their origin to their relative resistance to weathering. They are frequently flanked by metamorphosed sedimentary rocks now represented by various types of schists and by gneisses of doubtful origin. They have been better able to withstand the disintegrating action of the agents of weathering, and now assume the form of low rounded hills and ridges, rough steep bouldery elevations or occasionally, hogbacks. Nowhere do they rise to a greater height than about 250 feet above the general level of the surrounding country, and their orientation varies from nearly north and south to east and west according to their position in the geological structure of the Area.

The main lines of greenstone ridges and hills are briefly described below:—

- (a) Running south-east from Keane Railway siding through Mt. Rankin for a distance of about 7 miles and then turning north to meet the railway line again at Southern Cross. In the Mt. Rankin sector a ferruginous quartzite or jaspilite band forms a marked hog-back with a length of about 5 miles.

- (b) From Southern Cross a belt of higher undulating and low hilly country extends south-south-eastwards to Marvel Loch, a distance of some 20 miles, and then runs to the south-east for another 8 or 9 miles to Nevoria, where its continuity is somewhat broken but can be traced to the N.N.E. in the direction of Mt. Palmer for another 11 miles, at which locality it gradually becomes indistinguishable to the north.
- (c) South of Nevoria a greenstone belt having a general north-south trend comprises Parker's Range, and this has an extent of about 17 miles.
- (d) An irregular shaped nest of hills and ridges at Holleton of comparatively small extent is composed mainly of greenstone.

None of these hilly tracts exceeds 6 miles in width, and for the most part they are considerably narrower.

There are small isolated hilly areas such as Toomey's Hills, Mt. Holland and to the east of the North Ironcap which are formed of greenstone, but the main lines of ridges and hills formed of this rock are as given above.

The characteristic feature of most of the hills of this class is their general smoothness of outline, freedom from short gullies, and the absence of a scalloped appearance.

The Ridges and Hills of the Metamorphosed Sedimentary Series.

Between Marvel Loch and Cheriton's Find and flanking Parker's Range on the west, is an area of undulating and somewhat dissected hilly country varying in width from one-half to three miles, and covered with thick Eucalypt forest and scrub. These hills are composed largely of schists of varying types and in places are higher than the adjoining greenstone hills to the east. Some 10 miles east of Parker's Range another narrow belt of low hills runs north-west and south-east for about 10 miles, and these are also composed predominantly of schists of sedimentary origin.

Some high points situated from 2 to 3 miles westwards of the main Southern Cross-Marvel Loch road between the 10 and 15 mile pegs are typical hills of this series, and to the south of Cheriton's Find in the southern portion of the goldfield there are extensive areas of broadly undulating and low hilly country which when closely examined are seen to be formed of metamorphosed sediments.

The North, Middle and South Ironcaps are conspicuous landmarks owing their prominence to the resistance to weathering of a jaspilite band which here seems to be associated with the metamorphosed sediments.

The land forms of this series represent the upturned edges of highly folded and metamorphosed sedimentary rocks and have a somewhat characteristic topographic expression. They are frequently rather sharply dissected and have a tendency to form angular contours and often present a short undulatory or scalloped appearance.

It may not be out of place to mention here a possible explanation of the occurrence of isolated greenstone, quartzite and jaspilite hills often noted in the otherwise undulating elevated tracts of metamorphosed sedimentary and greenstone country. It is sometimes difficult to account for the disappearance along the strike of a conspicuous rock type forming a prominent outcrop of a hilly nature. It has been stated already and will be shown in subsequent chapters, that we are dealing with a folded series of metamorphosed rocks, in which two series of folding approximately at right angles to each other have been recognised. The folding along the N.N.W.-S.S.E. axes has been intense almost everywhere, and that along axes at right angles to this direction has also been severe in places. Under these conditions it is possible for the beds forming the crest or trough of a tightly folded anticline or syncline to be cross-folded into an undulating structure when viewed in a vertical plane. Subsequent erosion may expose just the crest of one of these undulations when the outcrop would plunge along the strike in both directions, or it may leave only the synclinal trough portion in which case the outcrop would pitch into the hill at either end along the strike.

No clearly demonstrated instances of these structures can be quoted, but there is a strong suggestion of their existence in the hilly forested country north-west of Marvel Loch.

The jaspilite band associated with the Greenstone Series, being essentially a ferruginous quartzite and consequently very resistant to weathering processes, forms the backbone of several ridges, and nearly always appears as discontinuous parallel bands. The repetition of this bed and the influence it has on the topography is considered to be due to major dragfolding, and at Southern Cross there are many parallel or converging bands of jaspilite well exposed in the ridges to the south of the township.

The Granite "Rocks."

Scattered sporadically over the area, though of more frequent occurrence in the western portion, are numerous bare isolated hills of a granitic composition. These hills are of varying dimensions but do not exceed 250 feet in height above the general level of the surrounding country, nor more than about 40 acres in extent. Many of them are much below these measurements but all are characterised by being composed of either granite or migmatite. They are mostly bare of all vegetation, but some have numerous shallow weathered depressions in them usually filled with coarse to fine arkosic grit.

It is in these depressions that occasional Kurrajong trees grow and in which water accumulates after rain. The rate of removal of the products of weathering exceeds the supply on these hills, and occasionally rock floors occur near their margins. At the margins where run-off collects in ephemeral streams, there is a thin cover of detritus in transit tending to extend the rock slope. They are usually surrounded by sand-plain country, though in their immediate vicinity there is often a growth of eucalypt trees.

It is at the margins of these granite rocks that the only potable underground water in the Area can be found, and they also constitute valuable catchment areas on which contour drains can be constructed for the conservation in sunken tanks of the run-off during periods of moderate rainfall.

Their topographic situation is variable, some occupy apparent high points whilst others obviously lie in or on the slopes of depressions. They are conceived as representing the apices of granitic intrusions of a batholithic habit, laid bare by erosion.

Their composition is mainly a fine to medium grained grey biotite granite, only occasionally porphyritic, and showing few pegmatite or aplite dyke intrusions. This granite is predominantly massive and fresh in appearance, but sometimes shows a gneissic banding when it is considered to be an orthogneiss.

“Rocks” of this type are Strawberry Rocks, Mt. Hampton, Mt. Bailey, Dulyalbin Rock and Skeleton Rock, to mention only the better known and most prominent examples.

The other rock type of granitic composition forming bare hills known as “Rocks” is thought to be a migmatite, and is represented by Yellowdine Rock and Condarnin Rock, the latter being situated a little to the east of the Yellowdine-Mt. Palmer Road about 3 miles south-south-east of Yellowdine Railway Siding.

A noticeable feature of many of these “Rocks” is the absence of the “tor” type of weathering, the erosional process most prominent in reducing the elevation of the mass being ex-foliation in thin and thick foliae. Jointing is also not very prominent, and the massiveness of the granitic rock is displayed in practically every exposure. On many of them the small rock basins on their surfaces are connected by shallow water-cut drainage channels, and when several basins are so connected and the resulting overflow is conducted over a steeper face than usual, it is not uncommon to find a medium sized rock-basin at the base of the more acute slope. These rock-basins sometimes hold water for a considerable time after rains and are worth searching for on any granite “rock” when looking for water.

Dulyalbin “Rock” at its eastern margin towards the northern end, presents a peculiar type of weathering not noticed in other granite “Rocks” in the Area. The granite is of the normal biotite

variety and forms a very large irregular shaped mass with smooth weathered outlines. It rises gradually from level sand-plain and mallee country to a height of about 100 feet above the surrounding plain. On its eastern margin towards the northern end there is an arc of granite cliffs up to 20 feet high, concave to the east, very symmetrically undercut also in the shape of an arc. The symmetry of the weathering is remarkable and from a little distance east of the rock in the vicinity of a soakage well which has been sunk here, exceptionally clear echoes may be obtained from the granite cliff. The dominant weathering process in this cliff face seems to be exfoliation on a small scale.

THE SANDPLAINS.

Sandplains as here discussed comprise those portions of the Area represented by high and low-level flat to broadly undulating stretches of country, characterised by a white to yellow sandy soil with which is mixed a greater or less amount of ironstone gravel and which are covered with a growth of heath and sclerophyll scrub. They are frequently underlain at very shallow depths by laterite-like deposits of pebbles of ferruginous grit, and in places the sandy soil may be entirely absent, revealing bare patches of cemented pebbles of ferruginous grit.

They cover by far the greater portion of the area investigated, and occupy those portions of the district which infrequent outcrops indicate are composed of gneiss of doubtful origin. They do not occur on rocks of the Greenstone Series, but are seen to overlie the metamorphosed sedimentary rocks of the Whitestone Series, notably west of Parker's Range on the Moorine Rock-Parker's Range Road.

The high level sandplains are those which are found on the broad crests of the major undulations such as east of Ghooli Pumping Station, and the low-level sand-plains occur on the relatively lower country on the flanks of or in the troughs of the major depressions such as south of Jaccoletti Well on the Southern Cross-Parker's Range Road.

The origin of these stretches of sandy country, for the most part devoid of sand-ridges, is not at all clear. From their occurrence on those portions of the area known to consist of rocks composed essentially of quartz, felspar and a ferromagnesian mineral (mostly biotite) it would seem reasonable to assume that the bulk of the sandy soil, their characteristic feature, was derived from the underlying rock by weathering *in situ*. The ironstone pebbles frequently seen associated with the white or yellow sandy soil are small cemented masses of quartz grains bound together by a limonitic cement; and the laterite-like bed of pisolitic ferruginous grit pebbles frequently observed to underlie the sandy soil and to overlie the decomposed gneissic rock in occasional exposures, is an accumulation of these pebbles set in an aluminous and ferruginous (limonitic) cement.

On the crests of some of the major undulations, notably on the main road between Burracoppin and Koorarawalyee remnants of an arkosic grit sometimes possessing a rude banding may be seen overlying decomposed gneiss. This formation may have been very extensive at one time, and although a Recent age is ascribed to it in this report, there is no evidence to show that it may not be considerably older. The breaking up of this arkosic grit under the influence of weathering could provide all the ingredients found in the present day sand-plain.

J. A. Prescott, Chief of the Division of Soil Research in the Australian Council for Scientific and Industrial Research in discussing the West Australian Sand Plains states³³:—

“That this formation is in all probability a fossil podsol is indicated from physiographic evidence, as well as from the character of the profile and from the data available regarding the soil reaction. The vegetation associations have already been noted as heath and sclerophyll scrub. Several types of sand plain are recognised by the Lands Department of Western Australia, the types ranging from deep yellow sands to heavy ferruginous gravels. The sand plains appear to show their most extensive development along an axis from Esperance to Shark Bay; they cover both the granite and sedimentary formations, and on the latter, west of Mullewa and near Yuna, show occasional evidence of wind influence in the form of vegetated sand hills.”

It must be conceded that the conception of the sand plains and their associated laterite-like material as being the two horizons A and B respectively of a podsol soil is a well founded one. To regard them as fossil soil horizons necessarily implies their formation under very much wetter conditions than at present obtaining in the localities where they occur. This in turn has a direct bearing on the origin of the Great West Australian Plateau, since these sand plains or their associate, the laterite, are characteristic of the Plateau Surface as we see it to-day. The excessively humid conditions implied by attributing to them a fossil nature precludes the possibility of the formation of the plateau in late Tertiary times in a cycle of arid erosion.

THE DEPRESSIONS AND SALINAS.

The major topographical depressions form a characteristic feature of the land surface throughout the Area. They are long wide hollows, frequently closed at both ends by gently rising ground and carry a forest growth of mixed eucalypt species. In extent they may vary from 20 to 30 miles in length with a width of 5 or 6 miles and many of them are much smaller. Typical examples of these depressions occur to the east of the gravity tank at Ghooli Pumping Station, east of Yellow-dine Railway Siding, at Southern Cross and Moorine Rock. They mostly have a general north-south orientation. East of Holleton and

³³ 1931. Prescott, J. A. The Soils of Australia in relation to Vegetation and Climate. Council for Scientific and Industrial Research, Australia. Bull. 52. p. 71.

south of Mt. Holland there are extensive depressions in the sand plain country, and these depart somewhat from the general north-south trend.

The soil in these hollows is often a red sandy loam, but outcrops of rock are extremely scarce and there is some doubt as to the nature of the material now occupying these lower lying stretches. It has been suggested by Prescott¹⁴ that the sand plain and laterite has been removed by denudation from these depressions and that subsequent erosion has laid bare the underlying rock. The soil in them is regarded by him as representing mainly the weathering products of this parent rock.

While this may be partially true in some cases, there is abundant evidence available in many of those lower lying forested areas which points to a transported origin for much of this soil. One of two processes of the cycle of erosion must be operating in the depressions to-day; they must be either being filled with, or being emptied of the products of erosion. They have no natural outlets nor have they any running streams to carry away their detritus. In some of them the dry salt lakes occur, but it is obvious that these features are playing no part in the removal of waste. There is then only one agent whereby material can be exported, and that is the wind. The natural covering of forest and smaller vegetation appears to render inoperative any large scale removal of detritus by this means, and in no instance during the course of the survey were any dust storms noted originating in these depressions in their natural state.

It would seem then that the other process, the filling up of these hollows, was the one in operation at the present time. The scarcity of rock outcrops, the indefinite nature of the soil when compared with soils overlying definitely exposed rocks, and the occurrence of vegetated sand dunes makes it almost certain, when these occurrences are considered in conjunction with the facts of the previous paragraph, that many of these major depressions are filled with transported material.

The salinas, or dry salt lakes, are not extensively developed, being represented by comparatively small areas only in Lake Polaris at Southern Cross, in a narrow lake system extending as a broken chain from about 2 miles east of Yellowdine Siding southwards to the southern end of Parker's Range, and as isolated small lakes in a major depression extending southwards from Moorine Rock for about 18 miles.

These lakes are dry for the most part of the year and are covered with a varying thickness of blue to grey and black silt heavily charged with salt and gypsum crystals. Low cliffs of either greenstone or gneiss sometimes occur on their western margins, the other shores being fringed with either salt and gypsum impregnated sand dunes or puffy sandy loam. There is frequently a rock floor sometimes bare, but more often covered with a thin layer of silt on the western mar-

¹⁴ Op. cit. p. 49.

gins, and in those salinas east of Parker's Range there is a notable accumulation of angular quartz and greenstone fragments set in a hard ferruginous matrix forming very low banks on the western margins. These represent outwash talus material from the low greenstone hills flanking these salinas to the west here, and are brought to the lake edge by sheet-flooding.

The drainage of Lake Polaris is to the north into Lake Koor-koodine, but that of the Yellowdine—Parker's Range chain is not so definite, and a direction of drainage cannot be given, since at no time has the writer ever seen any flowing water in these lakes. Indications have been noted on this particular chain of lakes of both a northerly and southerly local drainage. The isolated lakes in the depression southwards from Moorine Rock are separated by undulating to flat country mostly under cultivation for wheat growing.

The relation of these depressions to each other could only be determined by a closely contoured survey of a large extent of country, and to gain any knowledge of the exact nature of the material forming the floors of them would necessitate boring. This information is necessary if any concise conception of the mode of origin of these major depressions is to be gained.

CHAPTER III.

GENERAL GEOLOGY.

	Page-
Resumé of Regional Geology	62
Classification and Correlation	64
The Yilgarn System	66
(a) The Whitestone Series	68
(b) The Greenstone Series	74
The Basic Intrusive Rocks	83
The Granite, Gneiss, Acid Dykes and Quartz Reefs	85
Petrological Report on a Suite of Granitic, Gneissic and Pegmatitic Rocks from the Area	93
The Recent Deposits	113
Soil	113
Alluvium	113
Sand Dunes	113
" Cement "	114
The Grits	114
The Ferruginous Laterite	114

RESUMÉ OF REGIONAL GEOLOGY.

As far as can be ascertained, all the rocks of the Area can be grouped into two divisions representing some of the oldest known rocks of the earth and also the youngest. The youngest formations of geologically Recent age, consist of alluvium, soil, lake deposits, sand dunes, "cement" and possibly arkosic grits and laterite. These form a covering of varying thickness on a highly folded metamorphic series of sedimentary and intrusive and extrusive basic igneous rocks, which has been intruded by granite and epidiorite dykes and subjected to peneplanation in comparatively recent geological times. On account of the structural and lithological similarity of the rocks of this metamorphic series to those occurring in South Africa, Madagascar, India and North America, where they are of known Pre-Cambrian age, a similar age has been presumed for the Western Australian rocks.

The remnants of the metamorphic series form comparatively narrow but long belts of low relief distributed throughout the Area in accordance with the major geological structure. The tectonic axes have a general north-westerly trend and the nature of the folding has resulted in steep regional dips to the east or west and sometimes in the overturning of the strata. A series of cross-folds, the axes of which are approximately at right angles to the main north-west axes, causes the regional strike to vary between north-west and north-north-east on the limbs of the various folds, and to approach an east-west direction near the axes of the cross-folds. A series of major anticlines and synclines pitching either northwards or southwards has thus been formed, but these structures are very difficult to recognise on account of the poor outcrop conditions.

Granite appears occasionally from beneath sand-plain country and usually at some distance away from the margins of the recognisable metamorphic rocks. It forms low rounded hills and is mainly a mas-

sive, fine to medium grained biotite granite. Sometimes it can be seen invading the greenstones of the metamorphic series, and occasionally it is intrusive into gneiss. The country marginal to the recognisable metamorphic rocks and the granite is almost everywhere obscured by recent deposits, but migmatites and granitised zones have been recognised as marginal facies in several localities.

Gold-bearing quartz reefs have been formed in shear planes mostly along or near the axial planes of minor folds in the greenstone rocks and also in the metamorphosed sedimentary beds. These auriferous quartz reefs are confined mainly to the Greenstone Series of the metamorphic rocks close to their contact with either granite or rocks of a granitic composition. These marginal granitic rocks frequently have a gneissic structure which is parallel to the schistosity of the adjoining metamorphic rocks. It cannot be ascertained for certain what is the exact nature of the granitic rocks found under these circumstances. They may be gneissic granite (orthogneiss), granitised zones (replaced gneiss), migmatite (injection gneisses), or they may be recrystallised felspathic grits (paragneisses).

The folded rocks are divisible into two series, namely, The Whitestone Series and The Greenstone Series, the latter being the lower in the stratigraphical succession, hence the older. The Whitestone Series consists of a series of schists and quartzites with interbedded amphibolite schists; these latter representing metamorphosed igneous rocks, either intrusive, fragmental or flow. They pass downwards into the Greenstone Series without any recognisable stratigraphical break and in this latter series amphibolite schists predominate, while pillow lavas and amygdaloidal lavas are also represented. There are numerous bands of quartzite and metamorphosed erosion sediments interbedded with the metamorphosed igneous rocks in the Greenstone Series, which also contains one or more horizons of jaspilite of sedimentary origin.

It has been difficult to determine to what extent the Whitestone Series and Greenstone Series have been intruded by basic or ultra basic dykes or sills, but there certainly has been some igneous intrusion other than the granite. Some of these basic intrusive rocks may have been pre-folding, others are post-folding. The intrusive granite has also provided a host of pegmatite dykes, which cut through the metamorphic rocks in all manner of transgressive and concordant intrusions.

In the southern portion of the area, fine grained epidiorite dykes occur in the granitic and gneissic areas and cut gold-bearing quartz reefs at the Forresteria mining centre. These appear to represent the latest period of igneous activity recorded in the area. Boulders of igneous rock thought to be phonolite were found in several places in the greenstone belts in such a manner of occurrence as to suggest their transgressive intrusive nature.

The Whitestone and Greenstone Series form the Yilgarn System of presumed Pre-Cambrian age, but the age of the granite and basic dykes which are intrusive into the rocks of this system cannot be deter-

mined on account of the absence of rocks of post-granite or post-basic intrusive age. They are tentatively regarded as of Pre-Cambrian age.

The Greenstone Series, the lowest in the recognisable stratigraphical succession, contains erosion sediments such as andalusite and graphitic schists, quartzites, etc., and the base of the Series has not been definitely recognised. This series must therefore have been deposited on an existing surface on which erosion was taking place. These basement rocks on which the Greenstone Series was laid down have not been recognised, and they may be represented by migmatites, regionally granitised areas, or paragneisses underlying the sandy scrub covered country in the central portion of some of the major anticlinal structures, as for example that between Southern Cross and Mt. Palmer.

CLASSIFICATION AND CORRELATION.

The various rock types found in the Area are classified below, and a suggested correlation with strata of a presumed Pre-Cambrian age found in other parts of Western Australia is also given in the table on page 65. This correlation table¹⁷ has been compiled by Mr. F. G. Forman, Government Geologist, and is a suggested correlation based on the Geological Survey's present knowledge of the Pre-Cambrian succession in various parts of the State.

TABLE SHOWING CLASSIFICATION AND RELATIVE AGES OF THE ROCKS OF THE AREA.

Classification.	Series.	System.	Geological Age.
Soil, Alluvium, Sand dunes and Lake deposits. Arkosic Grits and Ferruginous Laterite (the two latter may possibly be of Miocene Age)	...	...	Recent.
Epidiorite, Dolerite and Phonolite Dykes	...	...	Post Granite.
Granite, Gneiss, Acid Dykes and Quartz Reefs			
Coarse grained Amphibolites and Epidiorites (Younger Greenstones)	...	...	Post Folding but Pre Granite.
Metamorphosed erosion sediments with bands of Amphibolite schist	Whitestone	} Yilgarn	Pre-Cambrian.
Metamorphosed lavas, pyroclastic rocks and basic intrusives with numerous bands of metamorphosed erosion sediments	Greenstone		

¹⁷ 1937. Forman, F. G., A Contribution to Our Knowledge of the Pre-Cambrian Succession in some parts of Western Australia. Journal of the Royal Society of Western Australia, Vol. XXIII, 1936-37, p. XXV.

A SUGGESTED CORRELATION OF THE PRE-CAMBRIAN ROCKS IN SOME PARTS OF WESTERN AUSTRALIA.

Kimberley District.	Pilbara District.	Central Goldfields.			South-West Division.	Eastern Division.
		Leonora.	Kalgoorlie.	Southern Cross.	Darling Range-Avon Valley.	Warburton Range.
Gabbro <i>igneous contact</i>	Porphyrite and Dolerite dykes <i>igneous contact</i>	Dolerite dykes <i>igneous contact</i>	Dolerite and Gabbro <i>igneous contact</i>	EPIDIORITE DYKES <i>IGNEOUS CONTACT</i>	Epidiorite dykes <i>igneous contact</i>	Norite, etc. <i>igneous contact</i>
Nullagine Series	Nullagine Series		Kurrawang Series			Nullagine Series
Granite and felsite <i>igneous contact</i>	Gneisses, granite and porphyry <i>igneous contact</i>	Gneisses, granite and porphyry <i>igneous contact</i>	Granite and porphyry <i>igneous contact</i>	GNEISSES, GRANITE AND PORPHYRY <i>IGNEOUS CONTACT</i>	Granite and Gneisses <i>igneous contact</i>	Granite and porphyry <i>igneous contact</i>
			Younger Greenstones <i>igneous contact</i>	YOUNGER GREENSTONES <i>IGNEOUS CONTACT</i>		
			Kundana Series <i>Unconformity</i>			
Mosquito Creek Series	Mosquito Creek Series <i>Unconformity</i>	Meta-Sediments	White Flag-Yindarlogooda Series <i>Unconformity</i>	WHITESTONE SERIES	Jimperding-Cardup Series	
Greenstone Series	Warrawoona Series	Greenstone Series	Black Flag-Tuffaceous Series Kalgoorlie Series (Older Greenstones)	GREENSTONE SERIES		Meta-Sediments and Greenstones

The folded series of stratified metamorphic rocks bear a remarkable structural and lithological resemblance to rocks of Pre-Cambrian age occurring in South Africa, India and North America and on account of this resemblance, they are presumed to be of a like Pre-Cambrian age.

There are no fossiliferous stratified rocks of post-granite or post-basic intrusive age in the district, hence the age of the intrusive rocks cannot be determined. Relative ages can however be given to the various igneous intrusions. Epidiorite and phonolite dykes are intrusive into granitic rocks and the Greenstone Series, and cut through auriferous quartz reefs at Forresteria. Some coarse-grained amphibolites and epidiorites are intrusive into the Greenstone Series but are not sheared and are post-folding. They contain reef quartz and pegmatite dykes hence they must be pre-granite in age.

Bands of anthophyllite schist, in which chromite occurs as an accessory mineral, are present in the Greenstone Series and have taken part in the folding. The basic nature of this rock and the presence of chromite is presumptive evidence for the occurrence of basic or ultra-basic intrusive rocks of pre-folding age in the Greenstone Series. In a bore core from a borehole on the old Transvaal Mine a little to the south of Southern Cross a basic igneous rock is seen to be intrusive into beds belonging to the Whitestone Series. No other definite intrusive basic igneous rocks have been recognised in the beds of the Whitestone Series though they might well exist.

In grouping the Whitestone and Greenstone Series together, and calling it the Yilgarn System a nomenclature intended to apply only to the Yilgarn Goldfield has been established. If this restriction is maintained until the formations can be traced away from the Yilgarn Goldfield, a useful purpose will have been served.

THE YILGARN SYSTEM.

The folded metamorphic rocks whose chief characteristics have been recognisable and whose distribution has been able to be mapped are grouped together in the Yilgarn System of assumed Pre-Cambrian age.

This System is divisible into two Series, namely, the Whitestone Series and the Greenstone Series, so named because the beds of the former comprise mainly metamorphosed erosion sediments which weather to a white, yellow or grey colour, while the beds of the latter are composed mainly of igneous rocks of volcanic flow or fragmental origin, and have a characteristic green or black colour. The Whitestone Series contains a number of bands of greenstone, and the Greenstone Series has numerous bands of metamorphosed erosion sediments interbedded with the greenstone bands. The term "greenstone" as applied here, embraces the rocks of a basic or intermediate composition

derived from a volcanic or intrusive igneous origin. The term includes the dark-coloured sediments, tuffs, and all fragmental volcanic material (metamorphosed) associated with the flow and intrusive rocks.

The Whitestone Series overlies the Greenstone Series, and the latter in turn must have been deposited on a basement rock, because it contains erosion sediments. Neither the top nor the bottom of either Series can be definitely recognised, and it is possible that the passage upwards from the predominantly volcanic igneous phase of the Greenstone Series to the predominantly sedimentary phase of the Whitestone Series is a gradual one in a conformable series. No stratigraphical break could be recognised in the field, but this might well exist since outcrop conditions are notoriously poor in the goldfields.

The rocks of the Yilgarn System have been involved in mountain making folding processes and outcrop to-day as a highly folded complex on a peneplained surface, largely covered with deposits of recent age. They form long and comparatively narrow belts of low relief flanked by rocks of granitic or gneissic origin, some of which may represent the basal complex on which they were laid down. Almost everywhere dips are steep, and the regional strike varies from N.W. to N.N.E. and is determined by the major geological structure (see chapter IV.). The distribution of the two series of the Yilgarn System is also entirely controlled by the processes of folding, and it is only from their relation to each other in the major folds that their relative ages can be determined.

The rocks have suffered regional metamorphism of a moderately high grade as a result of the intense folding to which they have been subjected, and also from their intrusion by granite either subsequent to or during the folding. There is some evidence to support the statement that the rocks of the Greenstone Series at least, contained pre-folding basic intrusives, and also post-folding but pre-granite basic intrusive rocks. A post-granite intrusive dyke occurs in the Greenstone Series in one locality, at the Olga Group, Parker's Range, and the presence of similar dykes has been suspected elsewhere. Numerous pegmatite dykes derived from an intrusive granite are frequent in both Series of the Yilgarn System.

The main economic importance of the rocks of this system lies in the fact that they are the host rocks of the gold-bearing quartz reefs which are being mined at numerous centres distributed throughout the Area from Southern Cross in the North to Forresteria in the South. These reefs are confined mainly to the rocks of the Greenstone Series close to their contact with either granite or rocks of a granitic composition, and their occurrence is controlled by both the minor and major geological structures. (See chapter IV.) The Whitestone Series also carries auriferous quartz reefs but less frequently than the Greenstone Series.

In Plate II. the rocks of this System are shown occupying an area of approximately 1,050 square miles, of which 750 square miles is represented by the Whitestone Series and 300 square miles by the Greenstone Series.

(a) *The Whitestone Series.*

Blatchford¹⁶ recognised the existence of a series of highly folded metamorphosed sedimentary rocks in the southern portion of the Yilgarn Goldfield in 1913, and referred to them as the Yilgarn Series. Unfortunately, the bedded nature of the greenstone rocks was not recognised by him at the time, and he regarded the Yilgarn Series as being extensively intruded by greenstones of various types, both coarse and fine grained. Some of the greenstone rocks are intrusive, but a large portion of them consist of lava flows and fragmental volcanic material forming a series of metamorphosed bedded deposits, on which the metamorphosed sediments are resting. In seeking a name for the lower bedded rock series, the term "Greenstone Series" was decided upon, and since the prevailing colour of the weathered metamorphosed sedimentary rocks of the original Yilgarn Series is white or of a light colour, it was thought appropriate that the name "Whitestone Series" could, with advantage, be given to them. Since both the Whitestone and the Greenstone Series are well represented in the Yilgarn Goldfield, the two series have been grouped together and called the Yilgarn System.

The beds of the Whitestone Series are everywhere highly folded and contain metamorphic minerals, such as sillimanite, garnet, andalusite, chiastolite and staurolite. Their outcrops are exceedingly weathered, and it is frequently only from the presence of casts of garnet crystals or tabular metamorphic minerals that the decomposed rock can be recognised as belonging to this series. The distribution of the series is shown on Plate II where it is shown flanking the Greenstone Series in a strong northerly pitching anticlinal structure south of Nevoria, and also occupying a southerly pitching syncline to the south of Southern Cross. From Cheriton's Find south to the southern limit of the goldfield, a comparatively extensive area of these rocks has been mapped largely on topography and soil type, outcrops being extremely scarce.

It is impossible to form any conception of the original thickness of the series since neither the top nor bottom has been recognised and there has been undoubted thickening of the outcrop width by intense folding. The beds of the Whitestone Series are shown on Plate II occupying approximately 750 square miles, and it is probable that they occupy a greater extent but could not be definitely recognised on account of the cover of detrital deposits.

Although the dominant rock types of this series indicate that they have been formed from normal erosion sediments, there are

¹⁶ 1915. Blatchford, T., The Geology and Mineral Resources of the Yilgarn Goldfield. Part II., G.S.W.A. Bull. No. 63, p. 29 et seq

numerous bands of dark coloured rocks composed mainly of ferromagnesian minerals and now represented by amphibolite schists in the sequence. These may have been originally basic sediments, sedimentary tuffs, or some of them may even have been lavas, as is suggested by the occurrence of some fine grained greenstone at Harris' Find. Some of these basic bands have garnets developed in them and may be schistose basic intrusive rocks.

The following rock types have been recognised in the field and specimens of most of them have been collected and added to the Departmental Rock Collection:—*Quartzite, Quartz Mica Schist, Phyllite, Greywacke, Andalusite Schist, Chlorite Schist, Garnet Schist, Biotite Mica Schist, Biotite Gneiss, Chistolite Schist, Sillimanite Schist, Staurolite Schist, Augen Gneiss, Amphibolite Schist, Graphitic Schist, Schistose Conglomerate and Knotenschiefer.*

It was not found possible to trace any of these beds for more than a few chains along the strike, nor could they be correlated across the strike in any of the severe folding to which they have been subjected.

The best outcrops of the rocks of this series can be seen in the following places:—

- (1) Near the butts of the Southern Cross Rifle Range east of the railway line, about one and a half miles west of the Southern Cross Post Office. (Plate III.)
- (2) About four miles south of Southern Cross on a low ridge and in some old workings about one mile south of the old Transvaal Mine. An old road runs a little south of east between Greenmount and Kennyville here, and the first outcrops of quartzite, and garnet and chistolite schist, etc., appear immediately south of the road. (Plate III.) Outcrops of quartzite, etc., along the strike of these rocks, form a low ridge east of the 7-mile peg on the Southern Cross-Strawberry Rocks Road. (See N.W. corner of Pl. IV.)
- (3) The hills three miles west of the 10-mile peg on the Southern Cross-Parker's Range Road. Andalusite Schist, Quartzite and Amphibolite Schists are prominent here. (Plate IV.)
- (4) The hills four miles west of the Marvel Loch turn-off on the Southern Cross-Parker's Range Road. (Plate IV.)
- (5) In the vicinity of the old Mountain Queen Mine and the Jaccoletti Group, Marvel Loch. This is a particularly good locality in which very many types of schists and some greenstone bands in the Whitestone Series may be observed. This locality has been considered to be near the top of the Greenstone Series, or near the base of the Whitestone Series. (Plate IV, also Plate XV, Bulletin 98.)

- (6) The underground workings of the Great Victoria Mine at Burbidge and the hills to the west of the townsite. (Pl. V).
- (7) The western shore of the lake system about one mile east of the 13-mile peg on the Yellowdine-Parker's Range Road. This is a very good locality. (Pl. VI.)
- (8) West of the road near the 5-mile peg on the Nevoria-Parker's Range Road. (Pl. V.)
- (9) The country immediately east and south-west of Harris' Find. (Pl. V.)

With the exception of one instance, intrusive basic igneous rocks were not recognised in this series. Some of the greenstone bands interbedded with the metamorphosed sedimentary rocks may be intrusive, but no intrusive contact was seen. Such contacts as were observed, appeared to be normal sedimentary ones. There are some rocks in the series which may be classified as intermediate in composition between the acid schists and the basic amphibolite schists, and appear to be of sedimentary origin.

In some diamond drill bore-holes put down to cut the reef in the "Jupiter" (Old Transvaal) mine south of Southern Cross, a number of thin greenstone bands were found interbedded with garnet, sillimanite, andalusite and graphitic schist bands, and in Bore No. 4, site F, the core at a depth of 387 feet (2/1830) shows an intrusive contact between a coarse-grained greenstone and the schists. The "Jupiter" mine is situated in the Whitestone Series (Pl. III.) and it is therefore certain that there are some basic intrusive rocks in the Series. Whether they are of pre-folding or post-folding age cannot be definitely stated, but the absence of schistosity in the coarse-grained greenstone seen in the bore core is suggestive of the latter age.

No rocks of a recognisable volcanic fragmentary nature were seen in the series. The weathered outcrops of some beds contain cubical casts suggestive of having been occupied originally by pyrites, and in general appearance have a very strong resemblance to the weathered outcrops of the Black Flag Series of tuffaceous origin, as exposed on the western shore of Black Flag Lake north-west of Kalgoorlie.

No good exposures of conglomerate bands were found, but their presence was noted in three localities. The first is situated in a cleared field immediately west of the Southern Cross-Parker's Range Road about eight and a half miles south of Southern Cross. A road goes to the west here, and there is a tank and pipe-stand on the northern side of this road. In this field immediately south of this tank, boulders showing fragmental igneous rocks and rounded quartzite and metamorphosed grit pebbles up to five inches in diameter were found. The matrix is mostly a massive, crystalline amphibolite rock suggestive of metamorphosed lava. (2/1412, 2/1413, 2/1414, 2/1416, 2/1503.) The rock is not exposed in situ, and the country to the west and east of this locality has been mapped as belonging to the Whitestone and Green-

stone Series respectively. The impression conveyed by the nature of the matrix of this fragmental bed is that these boulders represent waterworn and angular material caught up in a lava flow. Its stratigraphical position is suggestive of the possible existence of a break in the Yilgarn System at the top of the Greenstone Series. When considering this possibility, it must also be remembered that there are beds of fragmental and sedimentary material in the Greenstone Series.

The second locality where the possible existence of conglomerate beds in the Whitestone Series may be suspected is at G.M.L. 3632 ("Prince") situated about 30 chains south-east of the old Mountain Queen mine at Marvel Loch. Here some highly sheared basic sedimentary material in the dump of one of the shafts is suggestive of a sheared conglomerate (2/1296, 2/1340). This locality is also situated near the junction of the two series.

The third locality where the undoubted sedimentary nature of the conglomerate can be seen is at Burbidge, near the south-western corner of the townsite. Numerous small waterworn pebbles of quartz and quartzite are scattered through the soil and on the flat and undulating ground here and one small exposure in the form of a northerly pitching syncline showed the pebbles set in a decomposed quartzose and felspathic matrix. The pebbles do not exceed 3 inches x 2 inches x 1 inch in maximum dimensions. This band appears to be situated higher up in the Whitestone Series than the other two occurrences mentioned above.

The presence of conglomerate bands in the Whitestone Series is to be expected, and unless they can be associated with an abnormal distribution of the two series as revealed by mapping, they have little significance.

Numerous pegmatite dykes and barren quartz reefs, both large and small, are frequent, and in those beds of the series which happen to be situated within the influence of certain major geological structural features associated with gold deposition, gold-bearing quartz reefs occur. The mines at Edward's Find, Burbidge, Harris' Find, as well as the old Transvaal mine near Southern Cross and the old Mountain Queen mine at Marvel Loch, are all in rocks of the Whitestone Series.

Some of the quartzite bands in this series are highly drag-folded, notably in the hills situated four miles west of Cheriton's Find at the southern end of Parker's Range. Quartzites are usually fairly competent beds, but only when they are massive or thick-bedded. The introduction of any impurity in the form of thin layers causing the beds to be thin-bedded renders them relatively incompetent. From the manner in which some of the quartzites disappear along the strike, it is probable that they are of a lenticular nature.

The almost universally deeply weathered nature of the outcrops of the beds of the Whitestone Series makes it difficult to conceive what

they would look like in an unweathered condition. The only unweathered samples of these rocks seen during the survey came from the diamond drill bore-cores from bores put down to cut the reefs at the old Transvaal Mine south of Southern Cross. As seen in the bore-core specimens, they are mainly grey to black, garnet—andalusite—and graphitic schists, showing numerous rapid alternations in composition as indicated by closely spaced bedding planes. (Specimens of bore-cores from these bore-holes are in the collection of the G.S.W.A.) Schistosity and bedding planes appear to be coincident in the hand specimens.

The rocks of this series would provide an interesting field for metamorphic petrological research, although unweathered specimens would be exceedingly difficult to collect. The most prominent metamorphic minerals seen in the weathered rocks are andalusite, chiastolite, and garnet. Specimens of the weathered metamorphosed sedimentary rocks showing any prominent crystals were collected and submitted to the Government Chemical Laboratory for examination. The only mineral noted in these specimens not previously recorded from the Yilgarn Goldfield, was *staurolite*. Dr. Simpson, Government Mineralogist and Analyst, reports as follows on the occurrence of this mineral:—

“Lab. No. 2107, G.S.W.A., No. 2/1439, from G.M.L. 3542, Jaceoletti South, Marvel Loch. A grey graphitic slate, weathered and apparently affected by the decomposition of pyrite. The porphyroblasts are of two kinds:—

- A. *Staurolite* in black rectangular prisms, G.3.62. Pleochroism, light or strong greenish yellow to colourless. Extinction parallel. N slightly > 1.74 . Opt. ax. angle approaching 90° .
Staurolite has not previously been recorded from this region.
- B. *Andalusite*. Pale to deep grey prisms up to $10 \times 5 \times 5$ mm. One shows chiastolite structure. Gr. 3.13, N 1.634-1.623. Pleochroism pink to colourless. Elongation negative. Opt. ax. angle large. Carbonaceous and rod-like inclusions.

Numerous garnetiferous rocks were also examined by Dr. Simpson, and the following description of some almandine garnets from the Marvel Loch district is reproduced from a paper contributed by him to the Royal Society of Western Australia.¹⁷

Almandine, Marvel Loch.

“The recent detailed geological survey of the South Yilgarn area, and the keenness displayed in mineralogical problems by the field staff, has enabled the writer to examine in detail four specimens of almandine from different matrices in the one small area. For the specimens described he is indebted to the Government Geologist, Mr. F. G. Forman, and Mr. H. A. Ellis.

¹⁷ 1937. Simpson, E. S., Contributions to the Mineralogy of Western Australia: Proceedings of the Royal Society, W.A., Series X., Vol. 23, pp. 17-18.

“The rock mass in the vicinity of the gold mining centre of Marvel Loch is a Precambrian complex of highly tilted and foliated sediments with metamorphic greenstones, both interbedded and intrusive, and occasional pegmatite veins. There are granite outcrops a few miles distant both to north-east and south-west.^{18 19} Almandine occurs freely in bands of metasediments, greenstones and pegmatites.

“The workings of the Mountain Queen G.M. are in more or less graphitic mica schist, including some bands in which andalusite is plentiful, and others thickly seeded with garnets. The latter are invariably well crystallised in rhombic dodecahedra, usually quite symmetrically developed, but not uncommonly distorted by elongation along a crystallographic axis, or in other cases along the axis of the zone (022). The diameter is commonly 3 to 4 mm. The crystals are usually black and almost opaque, probably from minute inclusions of graphite, but in some cases have a translucency of 1 to 2 mm. with a brownish red colour. Several carefully selected uncontaminated crystals from the 280ft. level were analysed with the results given in Col. 1. They prove the mineral to be a manganiferous almandine.

“On the east side of Agricultural Loc. 405 there is another bed of dark grey graphitic mica-schist carrying about 5 per cent. of reddish brown almandine in 1 to 3 mm., rhombic dodecahedra. The composition of this is given in Col. 2, showing it to be a magnesian almandine, differing considerably in composition from that first described, though taken from a similar matrix.

“Close to No. 2 is an almost black garnetiferous hornblende schist, probably a metasomatic eclogite, which carries many precisely similar looking garnets, forming in the specimens examined about 30 per cent. of the whole rock. The cleanest concentrate that could be obtained for analysis was still contaminated with about 4 per cent. of felspar and hornblende. The composition of this concentrate is given in Col. 3. The principal subsidiary molecule present is spessartite, as in No. 1, but the pyrope, grossularite and andradite molecules are also prominent.

Finally in the Comet G.M. there is a fine grained quartz-albite-microcline pegmatite, carrying a little muscovite, and thickly studded with small red grains of garnet, mostly 1mm. or less in diameter. These were concentrated by panning and then with heavy solutions, and finally analysed with the results given in Col. 4.

A comparison of the proportions of the different isomorphous molecules in the four garnets, reveals by far the greatest proportion of spessartite in that occurring in the pegmatite vein. This is in keeping with experience elsewhere, most pegmatite garnets being either manganiferous almandines or spessartites. Of the two garnets found in metasediments, the chief associate of the almandine molecule is spessartite in one case, pyrope in the other, a difference which must be due to differences in composition of the original sediments. The garnet from the schistose amphibolite contains almost equal proportions of spessartite, pyrope, grossularite and andradite co-crystallised with the preponderating almandine, corresponding to the wider range of metallic oxides available for garnet building in the original basic igneous rock. In only one case, viz., that from the pegmatite, was any of the skiaquite molecule present.”

¹⁸ 1915. T. Blatchford, Geol. Survey Bull. 63, pp. 3-64.

¹⁹ 1937. H. A. Ellis, W.A. Mining and Commercial Review, Apr., pp. 52-4.

ANALYSES OF ALMANDINE, MARVEL LOCH.

No.	...	...	1	2	3	4
Matrix	...	...	Mica schist	Mica schist	Amphibolite	Pegmatite
SiO ₂	...	...	36.22	36.44	39.44	36.20
TiO ₂	...	...	.08	.72	1.04	n.d.
Al ₂ O ₃	...	...	20.38	21.70	19.08	20.76
Fe ₂ O ₃	...	...	3.26	.61	2.05	1.08
FeO	...	...	27.57	32.89	27.90	27.19
MnO	...	...	6.40	.49	3.91	13.34
MgO	...	...	1.93	4.03	1.72	1.22
CaO	...	...	4.40	2.08	4.34	.56
H ₂ O+	...	...	Nil	.87	n.d.	Nil
			100.24	99.83	99.48	100.30
G.	...	...	4.17	4.16	4.15	4.20
Analyst	...	...	E. S. Simpson	H. P. Rowledge	H. P. Rowledge	H. P. Rowledge

Molecules per cent.

Alm.	...	.....	64	77	67	61.5
Sps.	...	...	15	1	10	30.5
Pyr.	...	...	8	16	8	5
Grs.	...	...	4	4.5	8	Nil
And.	...	...	9	1.5	7	1.5
Ski.	...	...	Nil	Nil	Nil	1.5

(b) *The Greenstone Series.*

The several belts consisting mainly of hard, dark coloured crystalline rocks of either massive or schistose structure and coarse or fine grained texture distributed throughout the Area have been classified as belonging to the Greenstone Series, the distribution of which is shown on Plate II. The members of this series consist predominantly of rocks of igneous origin whose unweathered outcrops possess a more or less greenish colour and whose chief mineral constituent is one or more of the varieties of amphibole. Actinolite is extensively developed and in some of the coarser grained varieties, there is some pyroxene (augite). Numerous bands of metamorphosed erosion sediments, such as quartzite, mica-schist, andalusite schist, etc., alternate with the dark coloured amphibolite schists and massive amphibolite rocks.

The term "greenstone" as used in this report includes the metamorphosed rocks of a basic or intermediate composition derived from a volcanic or intrusive igneous origin as well as the dark coloured basic sediments (greywackes) tuffs and all fragmental volcanic material associated with the flow and intrusive igneous rocks.

The rocks outcrop as a series of low ridges of varying length and breadth in such a manner that in some cases, their regional strikes and dips and their distribution with relation to the beds of the Whitestone Series enables the broad geological structure to be interpreted. The interpretation of the major geological structure as revealed by regional mapping, shows that the Greenstone Series underlies the Whitestone Series and is therefore the older of the two.

The rocks are everywhere highly folded and steep opposed dips are of frequent occurrence. Some of the beds are highly schistose, others more or less massive, and the occurrence of schistosity is in no way restricted to the supposed granite contact areas. The exact interrelation of the numerous types of igneous rocks found in this series is difficult to determine from field evidence, as outcrop conditions are very poor, but the following characteristics can be fairly definitely claimed to be the outstanding geological features of the series.

- (1) It contains metamorphosed doleritic lavas, in which structures characteristic of volcanic lava flows e.g., amygdaloidal and pillow structure can be seen.
- (2) It contains numerous bands of metamorphosed erosion sediments such as quartzite, mica schist, grey graphitic schist etc., as well as one or more bands of jaspilite (ferruginous quartzite, banded ironstone formation, or more commonly, "jasper bars").
- (3) It contains bands of anthophyllite schist which are in all probability metamorphosed, ultra-basic, pre-folding intrusive rocks.
- (4) It contains metamorphosed rocks of a fragmental volcanic origin (greywackes, fine volcanic breccias and tuffs).
- (5) It has been intruded in a concordant and transgressive manner by post-folding but pre-granite amphibolite and epidiorite dykes which have a massive structure.
- (6) Some of the recognisable lavas are sheared, others are massive.
- (7) There is a considerable development of medium grained massive rocks of the amphibolite and epidiorite type, whose field relation to the schistose and finer grained rocks cannot be determined.

These features are all confirmable by field evidence and are not based on deductions made from petrological evidence only. Amygdaloidal and pillow lavas occur on the western shore of the lake at Mt. Palmer where they are highly schistose, but still retain these characteristic features of lava flows. Typical small detached pillows of a basic lava (2/1415) were found amongst massive fine grained greenstones on the Southern Cross-Parker's Range Road, on a ridge crossed by this road, about nine and a half miles south of Southern Cross. Other localities where amygdaloidal lavas may be seen are at Cheriton's Find and in the hills which have a general northerly trend, and are situated about two and a half miles east of Strawberry Rocks. (See Plate IV.) In this last locality, the lavas are both massive and schistose. There are numerous other localities where the fine grained greenstones are suspected of having been lavas, but in which neither the amygdaloidal nor the pillow structures can be seen.

Bands of metamorphosed erosion sediments occur in the Greenstone Series at Donovan's Find on the Bohemia lease, at Toomey's Hills south-west of the main workings, west of the Banker Group at Kelly's Bluff, about one mile east-north-east of the main Leviathan workings at Kennyville, in the west crosscuts of the upper levels of the Marvel Loch Gold Development Coy's mine at Marvel Loch, on the L.S.D. lease at Parker's Range, and half a mile along the road which goes to the east at the school situated eleven and a half miles south-east of Southern Cross, on the Southern Cross-Parker's Range Road. These are the best localities but there are many others where these bands can be inferred to exist from the nature of the soil and from the presence of rock fragments. The jaspilite bands whose outcrops consist mainly of rapidly alternating bands of quartz and iron oxides, are of sedimentary origin, and are well developed at Southern Cross, Mt. Rankin, Nevoria, Mt. Palmer and Parker's Range.

The anthophyllite schist bands whose distribution has been discussed in Chapter IV. (pp. 118-119) have definitely taken part in the folding responsible for the major geological structure, and chemical and mineralogical investigation by Dr. E. S. Simpson, Government Mineralogist and Analyst, shows that this rock type has been derived from an ultrabasic rock. From the manner in which it is now distributed, and the type of igneous rock from which it has been formed, it is a reasonable assumption to consider it as originally a sill of ultrabasic rock in the Greenstone Series.

On a dump at some old workings at the south-eastern end of the Mountain Queen sand dump at Marvel Loch, some good specimens of tuff and fine volcanic breccia were found (2/1430). The structure is plainly visible in these specimens, and demonstrates the presence of these types of rocks in the series. The dumps of the old Marvel Loch Mine at Marvel Loch show good examples of banded basic sediments (greywackes) in which bands of varying coarseness of grain are visible.

About fifteen chains north of the old New Zealand Gully dam, just south of Southern Cross, a massive amphibolite rock can be seen to be transgressively intrusive into a band of anthophyllite schist. Other places in this locality show the amphibolite rock to have a general distribution parallel to the anthophyllite schist. (See Plate III.) At Holleton, a massive very coarse grained epidiorite dyke is transgressively intrusive into the schistose greenstones of the Greenstone Series. The massive dyke is itself intruded by a tin-bearing pegmatite dyke, and the amphibolite rock at New Zealand Gully contains small quartz lenses. The massiveness of these dykes and their intrusion by quartz reefs and pegmatite dykes, suggests that they are post-folding but pre-granite in age.

Almost everywhere that the rocks of the Greenstone Series occur, there is a considerable development of coarse to medium grained

amphibolite and epidiorite types of rock which have a massive structure, and whose relation to the finer grained schistose types cannot be seen on account of the lack of suitable exposures. Typical localities where some of these rocks may be seen are just west of the road between the 14 and 15-mile pegs on the old back road between Marvel Loch and Southern Cross, and about one mile north-east of the May Queen Gold Mine on the track to Lenneberg's Find. (Plate IV.) Some of these rocks have pyroxene as well as amphibole developed in them, but their massiveness and relative coarseness of grain-size is not sufficient to attribute to them an intrusive habit. Some of these coarser grained greenstones which appear to be massive and outcrop as bouldery ridges have a distinctly clastic microscopic structure, and are almost certainly recrystallised tuffs (2/1814).

When the possibilities of the formation of many of the greenstones from material which was originally lavas, crystal tuffs, ordinary tuffs and sedimentary tuffs are considered, it is a very difficult matter to decide what is a recrystallised fragmental rock. A sedimentary tuff (one deposited in water from the air) is essentially one made up of a mass of equal falling particles, and so long as the supply of material is continuous, a bed of more or less massive structure and heterogeneous composition will be formed. A feature of sub-aerial and sedimentary tuffs is their massiveness, and it is only when the tuffaceous material has been resorted by running water and deposited in water, that a definite fine banding appears in the tuffaceous beds. These then become the basic sediments (greywackes) numerous instances of which occur in hand specimens of the greenstones seen in the field.

Some of the coarse and medium grained greenstones may be of an intrusive nature, but in the absence of field evidence demonstrating this feature, the writer prefers to include them in the bedded deposits of the Greenstone Series until evidence of their intrusive nature is found. Most of the greenstone types could have been formed from the metamorphism of a series of basic lava flows of fine grained doleritic or medium grained gabbroid composition with associated beds of pyroclastic material.

Neither the top nor the bottom of the Greenstone Series has been recognised, but in several instances (east of the Glendower Group and Lenneberg's Find) there is a strong suspicion that metamorphosed erosion sediments occur below the predominant greenstone horizon. This conception cannot be given much weight because the series is highly folded and these beds may be present in this position as a result of this folding.

No acid lavas have been recognised in this portion of the goldfield though they are present in the northern part of the Yilgarn Goldfield east of Marda. It is difficult to place the amygdaloidal and pillow lavas in the succession of the Greenstone Series on account of the presence of sharp folding, but they have been recognised as

occurring at intervals throughout the width of the greenstone belt south-east of Southern Cross. It is likewise also difficult to fix the stratigraphic horizon of the jaspilite band for the same reason. At the Olga Group the greenstone and associated jaspilite bands have a moderately steep regional westerly dip and there is about an even width of greenstone on both sides of the jaspilite. This would suggest a somewhat central position in the succession for the jaspilite horizon, but there is always the possibility of thickening of the rocks by folding to be considered as well as the fact that in no instance has either the top or bottom of the series been recognised.

At Palmer's Find there are pillow lavas and amygdaloidal lavas in close proximity to the jaspilite, and it can be said that here at least is proof of an association which can only be suspected of existing as other localities where the jaspilite outcrops. In every instance where outcrops of jaspilite occur, as far south as Mt. Holland, the enclosing rocks are greenstones.

The rocks which could be considered on structural grounds to underlie the lowest exposed members of the Greenstone Series are very poorly exposed, and the occasional outcrops of these rocks which were seen, suggest that the Greenstone Series passes into migmatites, granitised rocks (replacement gneisses) and granite.

The rocks of the Greenstone Series are of great economic importance, since it is in them that most of the auriferous quartz reefs occur. The distribution of the gold-mining centres and the occurrence of gold reefs within the Greenstone Series is discussed in Chapter IV. There are three rock types occurring within this Series which merit some discussion, and these are the anthophyllite schist, the jaspilite, and the granitised rocks.

The Anthophyllite Schist.—Rocks composed almost entirely of anthophyllite, either massive or schistose, have a wide distribution in the northern part of the Area. They occur mostly as bands up to as much as fifteen chains in width, and their distribution is controlled by the folding which the Greenstone Series has undergone. There are two almost parallel bands of this rock with which are associated its decomposition products, consisting of ironstone carrying small black specks of chromite and much secondary, often banded siliceous material, extending from near Nevorina, to the west of Kennyville. (See Plate IV.) Other prominent bands run southwards from near the New Zealand Gully at Southern Cross (see Plate III.) on the western side of the Southern Cross-Strawberry Rocks Road. An outcrop of this rock also occurs on the western shore of the lake about three and a half miles south of Palmer's Find. Specimens of this rock have been examined by Dr. Simpson, Government Mineralogist and Analyst, who reports on them as follows:—²⁰

²⁰ 1937. Simpson, E. S. Contributions to the Mineralogy of Western Australia: Series X. Proceedings of the Royal Society of Western Australia, Vol. XXIII., pp. 19-20.

ANTHOPHYLLITE, MT. PALMER AND MARVEL LOCH, Cen.

Anthophyllite and kupfferite are two rare members of the amphibole group differing from one another only in crystalline form, the former being orthorhombic, and the latter monoclinic. Both are characterised by an absence of calcium and sodium, and a preponderance of magnesium over iron, the common formula being $H_2(Mg, Fe)_7Si_8O_{24}$. The practical distinction between them is not easy as the following table shows:—

	Anthophyllite.	Kupfferite.
Composition	$H_2(Mg, Fe)_7Si_8O_{24}$	$H_2(Mg, Fe)_7Si_8O_{24}$
Crystal Group	Orthorhombic	Monoclinic
Sp. Gr.*	3.0	3.05
Hardness	5½	5½
Ref. Indices*	1.610, .601, .590	1.615, .603, .590
Elongation (optical)	+	+
Extinction, $c \wedge Z$ ... ..	... 0° on every prism face	0°(100) to 20° ±(010)

* Increase with iron content.

The only important distinction of assistance in practical determination is the oblique extinction of kupfferite on all faces in the prism zone except a (100).

The occurrence of several dykes of an almost pure anthophyllite rock in the South Yilgarn Goldfield is of unusual interest, because of its rarity. My attention was first drawn to these unusual looking rocks by Mr. Ellis, of the Geological Survey, who kindly supplied me with typical specimens for determination and with the permission of the Government Geologist placed his field observations at my disposal.

The Archaean complex from Southern Cross southwards beyond Marvel Loch is made up of alternating belts of rock predominantly sedimentary and predominantly igneous (granite and greenstone). The anthophyllite rock appears in several long narrow parallel dykes in three greenstone belts. Further to the east, between Mt. Palmer and Meiers' Find, is another small outcrop of similar rock.

Two specimens of this rock type have been analysed. No. (1) is from N.E. of the May Queen G.M.L. 3459, four miles N.N.W. of Marvel Loch, and is slightly weathered. No. (2) is from 3½ miles S. of Mt. Palmer, and is practically fresh. The analytical results obtained are shown in the accompanying table with those of several other rocks of similar composition.

As rocks there are several unusual features to note in them, viz.:—

- (a) The unusually low proportions of alumina, lime and alkalis amongst the major constituents; and of phosphorus, sulphur and titanium amongst the minor.
- (b) The preponderance of magnesia over all other common bases, and of chromium over other minor elements.

These features are characteristic of the hypersthénites, peridotites, serpentines and talc schists, to one or more of which the rock must therefore be related. In looking for other Western Australian rocks of similar composition it was found that the serpentines invariably had a much lower silica percentage, viz., 37 to 42. Even when allowance is made for the extra water in the serpentines, and a comparison is made on the basis of equal water content, the silica in the serpentine is only raised to 40 to 45 per cent., as against 52 to 58 in the anthophyllite rocks. On the other hand, there is a close resemblance as shown in the table to a hypersthénite, and to certain talc rocks which have been thought to be derived from hypersthénites. It would appear, therefore, that the South Yilgarn antho-

phyllite rocks are derived from hypersthenites, either by direct hydration, or in two stages, viz., by hydration to a talc rock, followed by recrystallisation under heat and pressure to an amphibole rock.

In hand specimens the rocks are of an almost uniform neutral grey colour, and appear to be made up almost entirely of equidimensional crystals, 3 to 5 mm. across, of anthophyllite of that colour. Scattered at rare intervals over the fractured surface, are green crystals of tremolite of similar size, whilst a lens reveals a rather uniform distribution of small black specks of chromite and magnetite.

Microscope mounts of rock slices and powder show that the apparent coarse grains of anthophyllite are really each composed of an aggregate of almost parallel but slightly undulating and intertwining colourless fibres of extreme fineness, viz., 1 to 4 microns. There are also many small felted bunches of unoriented fibres. In both forms it is impossible to measure a true extinction angle owing to the overlapping and twisting of the fibres. When, however, the rock is reduced to a fine powder, about 95 per cent. of the single fibres give a straight extinction characteristic of anthophyllite. The remaining fibres, as well as some coarse splinters, give extinctions ϵ up to 13° and are almost certainly tremolite. In the rock slides this tremolite is visible as rare, and usually non-fibrous, colourless crystals. The black iron ores chromite and magnetite are scattered irregularly over the slide.

ANTHOPHYLLITE ROCK AND RELATED ROCKS, WESTERN AUSTRALIA.

No. ...	1		2		3	4	5	6
	%	Mols.	%	Mols.	%	%	%	%
SiO ₂ ...	57.60	47.63	52.31	43.98	55.27	61.00	57.37	47.44
Al ₂ O ₃ ...	1.90	.94	3.95	1.96	3.67	.68	1.14	6.23
Fe ₂ O ₃ ...	1.56	.50	3.26	1.03	.45	n.d.	.51	.76
FeO ...	5.45	3.86	5.37	3.77	7.17	6.14	6.52	6.78
MnO ...	.31	.22	.16	.11	.03	.20	n.d.	n.d.
MgO ...	26.35	33.21	26.39	33.05	28.36	27.88	26.98	26.68
CaO ...	1.60	1.42	3.17	2.85	2.93	<i>Nil</i>	.53	3.39
Na ₂ O ...	.01	.03	.12	.10	.86	Tr.	.25	.33
K ₂ O ...	.04		.06	.03	.18	Tr.	<i>Nil</i>	Tr.
H ₂ O+ ...	4.22	11.91	4.57	12.81	.30	4.72	6.17	5.68
H ₂ O- ...	.66	...	.70	...	.04	.12	.87	.78
TiO ₂ ...	.09	.06	.23	.15	.16	.01	n.d.	.20
Cr ₂ O ₃ ...	.57	.19	.31	.10	.46	.01	n.d.	.22
P ₂ O ₅ ...	<i>Nil</i>	...	<i>Nil</i>	...	Tr.	.10	n.d.	Tr.
CO ₂ ...	<i>Nil</i>	...	.05	.06	<i>Nil</i>	<i>Nil</i>	Tr.	2.06
FeS ...	.07	.03	<i>Nil</i>	...	.17	n.d.	n.d.	n.d.
G ...	100.43	100.00	100.65	100.00	100.05	100.86	100.34	100.55
	2.81	...	2.94	...	3.25	2.83	2.82	2.82

(approx.)

Analyst:—1, H. P. Rowledge; 2, C. R. Le Mesurier; 3, C. C. Williams; 4, E. S. Simpson; 5, A. J. Robertson; 6, E. S. Simpson.

- (1) Anthophyllite rock, near May Queen, G.M., Marvel Loch.
- (2) Anthophyllite rock, 3½ miles south of Mt. Palmer.
- (3) Hypersthenite, Norseman, G.S.M. 5646.
- (4) Talc Schist, Mt. Taylor.
- (5) Talc rock, Meekatharra, G.S.M. 11579.
- (6) Talc-chlorite rock, Kalgoorlie, G.S.M. 3391.

The Jaspilite.—The banded ironstone formation or ferruginous quartzite commonly called “jasper bars” by prospectors has a wide distribution in the Area, and can be found in practically all of the greenstone belts which have been mapped. Its outcrop lines are shown on the various geological maps accompanying this report, and its distribution has been discussed in Chapter IV. In hand specimens this rock type is usually a finely banded brown to black coloured rock consisting of alternating bands of quartz grains and iron oxides (magnetite and haematite). Sometimes the proportion of iron oxides is far in excess of the siliceous material, when the bed becomes a fairly pure iron ore. Occasionally, fine needle-like crystals of actinolite may be seen in the outcrops, and in the only specimen obtained from the unoxidised zone, one from the dump of a shaft on G.M.L. 3515, Nevoria (2/1660), the jaspilite consisted of bands of tightly compacted quartz grains alternating with bands composed of short prisms and irregular shreds of augite, some portions of which showed uralitisation. There were occasional grains of magnetite in the rock section.

Holmes²¹ describes a jaspilite in the following manner:—

“A term applied to rocks composed of interbanded layers respectively rich in silica (quartz or chalcidony) and iron oxides (magnetite, haematite, etc.) The chert-like bands have a red colour owing to the inclusion of flakes of haematite. Variable amounts of ferruginous amphiboles are generally present, and the rocks are not only conspicuously banded but are often contorted and brecciated.”

This term seems to be eminently suitable to the banded ironstone formations now being discussed.

The red banding in the jaspilites so conspicuously present in the northern portion of the Yilgarn Goldfield is absent from those in the area south of the Great Eastern Railway. At Glendower and Nevoria the jaspilite has bands of decomposed grey schist interbedded with it, and in very many of its outcrops elsewhere it is highly contorted. In all instances it is flanked by greenstone of either sedimentary or lava flow origin, and is so obviously of a sedimentary nature that no other possible origin need be considered. It is part of an incompetent zone in the Greenstone Series, and shows relative degrees of competency within itself. Long stretches of outcrop do not contain drag folds, while other portions of it are intensely folded. The jaspilite could represent a metamorphosed bed originally consisting of thin bedded shales and sandstone, in which a considerable quantity of ferromagnesian mineral such as augite or hornblende was common, and this could account for the difference in appearance of the various outcrops and their varying composition with relation to the iron and silica content. It would also account for the relative degrees of competency within the jaspilite.

²¹ 1928. Holmes, Arthur, *The Nomenclature of Petrology*, p. 127.

Whether or not there is more than one horizon of jaspilite cannot be definitely stated. Sometimes, as at Southern Cross, there are a number of parallel or sub-parallel bands of jaspilite in the greenstone beds. Some of these bands are actually tightly compressed anticlines or synclines, although on first appearances they look like single bands of jaspilite. Repetition of these beds by drag folding has obviously occurred at this locality. There are two parallel bands at Mt. Rankin sometimes less than a chain apart, and the shape of drag folds in these bands shows that here again there has been repetition by folding. At Nevoria and Parker's Range there are several closely spaced jaspilite beds but proof of repetition by folding is lacking here.

The width of the outcrops of the jaspilite seldom reaches forty feet, and most of them are less than twenty feet. The original thickness of the band or bands cannot be accurately estimated anywhere on account of the great difficulty introduced into any such estimate by the possibility of thickening brought about by tight folding.

South of Mt. Holland the jaspilite beds have been mapped as occurring in the Whitestone Series at the three Ironcamps. The associated beds may or may not belong to the series, and it is not unlikely that an increase in the sedimentary phase of the Greenstone Series has taken place in this direction. The almost complete lack of outcrops in this locality has prevented the elucidation of the major structure and it was not found possible to definitely trace the Greenstone Series south of Cheriton's Find. At Mount Holland the jaspilite is interbedded with greenstones, and in this area there seems to be an increasing development of metamorphic and sedimentary rocks in its immediate vicinity.

The Granitised Rocks.—The process of granitisation which some of the rocks of the Greenstone Series appear to have undergone, seems to be of a similar nature to that described by Horwood in the Cross Lake Region, Manitoba.²² This writer states that:—

“In the Cross Lake Map area in Northern Manitoba, gneissic or schistose andesites, arkoses and tonalites show all variations from the normal character to gneisses of granodioritic or granitic nature. Field examination of specimens in localities where the change is well exposed, and laboratory examination of specimens secured from these localities indicate that the change was brought about by a replacement process. The products of the reaction have been called replacement gneisses.”

He also points out that the process takes place along the strike and that in the case of the granitisation of the andesites, the two striking changes are the decrease in hornblende and the increase in quartz. The essential characteristics of the process are that sheared andesite can change gradually along the strike to a rock having all the appearances of granite and that the alteration is due to a replacement process brought about by dilute aqueous alkaline solutions that contained amounts of SiO_2 , K_2O , Al_2O_3 .

²² 1936. Horwood, H. C., Granitisation in the Cross Lake Region, Manitoba, Royal Society of Canada, Section IV., third series, Vol. XXX., May 1936, pp. 99-117.

In several localities where the rocks of the Greenstone Series outcrop, notably at Southern Cross, in the railway cutting one and a half miles east of Yellowdine Railway Siding, at Palmer's Find and on the western shore of the salt lake south-east of the Olga Group at Parker's Range, there is distinct evidence of the effects of this process on the schistose basic lavas and tuffs of the Greenstone Series.

A continuous suite of specimens showing the change from sheared greenstone to granite or gneiss along the strike could not be obtained, but on the Three Queens G.M.L. 3770, situated immediately south-east of the Palace Hotel at Southern Cross, excellent examples of the decrease in hornblende and the increase in silica in bands of granitised greenstone can be seen, (2/1819).

As represented in the cutting east of Yellowdine Railway Siding, the process appears to be taking place across the strike of the folded greenstones, being well displayed on the western end of the cutting. There is some actual introduction of granite magma here also, but the folded nature of the replaced rocks is very evident and the passage is a gradual one eastwards to unaltered greenstones.

In the other localities mentioned the granitisation process can mostly be traced back to unaltered sheared greenstone along the strike, but not in the other direction on account of soil and sandy cover. A feature of the granitisation process as observed at Southern Cross is the sharpness with which the replacement process terminates in the bands in a direction at right angles to the strike. The granitised bands have sharp lateral boundaries, but alteration along the strike is gradual. Many of these granitised bands have been mapped in the past as sheared granite, or sheared quartz porphyry and it may be suggested that what are now being taken for granitised zones are metamorphosed sedimentary bands in the greenstone.

It is difficult to confuse these two types in the field once the process of granitisation is visualised, and the various bands of metamorphosed erosion sediments noted in the Greenstone Series can be unmistakably recognised where they do occur.

An extensive collection of the rocks of the Greenstone Series has been made and numerous rock sections of them have been cut. This material has been added to the Departmental collections.

THE BASIC INTRUSIVE ROCKS.

Field evidence points to the occurrence of three periods of intrusion of rocks of an ultra-basic, basic or intermediate composition into the bedded greenstones of the Greenstone Series. The existence of basic intrusive rocks in the Whitestone Series was not definitely established by field evidence except in one instance. They may be present in the series elsewhere, but were not unquestionably recognised in any of the exposures of the metamorphosed sedimentary rocks.

It has already been stated in the preceding section of this chapter that the comparative coarseness of crystallinity and massiveness of structure of any of the dark coloured crystalline rocks is insufficient to justify conceding to them an intrusive habit. Consequently, the intrusive nature of any of the greenstones has had to be established, from the writer's point of view, by the actual finding of transgressive intrusive contacts in the field, or by the distribution of a particular rock type in such a manner that its transgressive nature can be reasonably inferred.

The Ultra-Basic Intrusive Rocks:—The anthophyllite schist previously mentioned under the Greenstone Series seems to be almost certainly of igneous origin and was probably injected into the bedded lavas, pyroclastic rocks and sediments of the Greenstone Series as sills during the very early stages of the folding processes which these rocks have undergone. The original composition of these rocks now converted mostly to anthophyllite, is thought by Dr. Simpson, Government Mineralogist and Analyst (see pp. 79-80) to have a close resemblance to the hypersthénites. Thin quartz reefs carrying gold have been found in the anthophyllite schist in several localities, notably on the Alexander Lease, G.M.L. 3642 at Marvel Loch, and also south-west of Southern Cross. There may be other occurrences of these rocks which are pre-folding and pre-granite in age but they have not been recognised.

The Basic Intrusive Rocks:—Massive rocks transgressively intrusive into the Greenstone Series and composed almost entirely of amphibole, or amphibole and a plagioclase feldspar, were found in two localities, at Southern Cross and at Holleton. These seem to be the equivalent of the Younger Greenstones of the Kalgoorlie District in which the main mines are situated. At Southern Cross the intrusive nature of an amphibolite showing a coarse grained pegmatoid phase in places can be seen in the hills immediately north and north-west of the old New Zealand Gully Dam about one mile south-west of Southern Cross. This rock (2/1800, 2/1801) in thin section is composed mainly of green hornblende, diopside and zoisitised plagioclase feldspar, and in hand specimens is greenish coloured, and varies in texture from medium to coarse grained. The basic pegmatitic phase consists chiefly of large crystals of diopside partly altered to actinolite with large plagioclase feldspars mostly zoisitised. Numerous outcrops of this rock occur along the eastern side of the anthophyllite schist band which runs north and south immediately west of Greenmount (Plate III), and boulders showing a basic pegmatite structure were also found in the country north-west of the May Queen Mine (south-east of Kenmyville) indicating the probable existence of intrusive rocks in this locality also. The outcrops of this amphibolite near New Zealand Gully are massive, but occasionally shallow workings were seen in them and quartz was noticed in the dumps.

This particular intrusion would therefore appear to be of post-folding but pre-granite age.

Almost one mile south-south-west of Holleton on M.L. 30 a very coarse grained epidiorite dyke (2/1796) composed of hornblende and labradorite is seen to be intrusive into the schistose greenstones of the Greenstone Series. It is a massive rock but is intruded by a tin-bearing pegmatite dyke. This epidiorite dyke appears to be also similar in age to the amphibolite dyke at New Zealand Gully.

Dolerite dykes cut the auriferous quartz reefs at Forresteria, and are intrusive into the granite and gneiss one mile south of the North Ironcap.

The distribution of some boulders of a dark coloured rock which appears to have the microscopic characteristics of a phonolite at the Olga Group at Parker's Range, is suggestive of a transgressive intrusive habit. The line of boulders is across the direction of the regional strike of the greenstones at this locality, although a definite intrusive contact cannot be seen. This rock (2/1743) is almost black in colour and shows feldspar phenocrysts in hand specimens. In thin slice it shows the following characteristics:—

Feldspars—in large euhedral crystals—acid type, probably orthoclase, sericitised.

Pyroxene—Bright green hence aegiritic and indicating a sodic environment. Alteration to hornblende has taken place in the larger crystals but the original euhedral form is often preserved.

Nepheline—as small laths and prisms in the ground-mass.

The Ground-mass—consists of nepheline, the remains of small crystals of augite or amphibole and the remains of glass.

Accessories—Magnetite, Perovskite.

Texture—Porphyritic, andesitic.

The only definite occurrence of an intrusive rock in the White-stone Series was found in a bore core from a diamond drill hole put down on the old Transvaal Lease south of Southern Cross. The core at a depth of 387 feet in bore No. 4 showed an intrusive contact between a garnetiferous pyroxenite and a garnetiferous biotite schist (2/1830). The pyroxene in this rock is mostly diopside undergoing change to an amphibole. The contact as seen in the bore core is unquestionably of an intrusive nature, and the absence of schistosity in the thin dyke cut by the drill suggests that the intrusion was post-folding in age.

THE GRANITE, GNEISS, ACID DYKES AND QUARTZ REEFS.

In the geological maps accompanying this Bulletin, granite and gneiss are represented only in those localities where they were found actually outcropping and could be differentiated. Over a very large

part of the area, the presence of granite and/or gneiss has been suspected under extensive sand-plain and generally sandy soil-covered country, but owing to the absence of outcrops, the extent and relation of these two types to each other could not be determined.

The whole question of the interrelationship of the rocks represented by granite, gneiss, pegmatite, aplite, quartz porphyry and quartz reefs as they exist in the southern portion of the Yilgarn Goldfield is one of complexity, rendered well nigh impossible of solution by the field geologist on account of the lack of necessary exposures and contacts. The problem of the relation of these various rock types to each other is of importance when the origin of the gold bearing quartz reefs is being investigated.

In the goldfields of Western Australia, the host rocks of the auriferous ore bodies differ very little in nature over very widely separated districts, being confined mainly to the greenstone beds of a metamorphic series of sediments, pyroclastic rocks, lava flows and acid and basic intrusive rocks. Quartz is the characteristic gangue mineral and the ore bodies occur almost universally within the greenstone beds close to the contact with either granite or rocks of granitic composition. There is frequently an abundance of acid dyke rocks intruding the greenstone, and it has been reasonably concluded that intrusive granite has constituted the ore magma which has provided the gold bearing quartz reefs and also the magma which has provided the acid dykes and barren quartz reefs.

It is also worth noting that in very many parts of the goldfields basic intrusive rocks are found in the areas associated with gold reefs, but there does not appear to be any evidence connecting them with the formation of auriferous quartz reefs, or rather, the evidence for assuming that the auriferous quartz reefs owe their origin to granitic magmas is stronger than for that associating them with the basic intrusive rocks.

In no instance either on the surface or in the numerous small mines examined in the Area was a gold-bearing or barren quartz reef seen to pass along the strike or down the dip through phases represented by pegmatite, porphyry, or greisen into granite. The relation of the numerous quartz reefs and pegmatite and aplite dykes to each other which occur in the migmatites exposed in Yellowdine "Rock" near the Yellowdine Railway Siding was not closely investigated. In making a close investigation of the granitic rocks some useful information would probably be found here.

The mode of occurrence of the granite, gneiss, acid dykes and quartz reefs as recorded by Messrs. Hobson, Matheson and the writer during the course of the survey will be set out below, and an attempt will be made to interpret the significance of the various facts.

The Gold Bearing Quartz Reefs.

In every mine being worked for gold the ore contains quartz in large or small quantities. Even in those formations which can be called lodes, i.e. gold impregnated country rock, the presence of quartz in minute stringers can be detected, and the statement "No quartz, no gold," seems to be universally true as far as the mines of the Area are concerned. The gold reefs occur almost everywhere in planes which are parallel to the schistosity of the enclosing country rock, in only very few instances being found in massive or poorly schistose rocks in planes which intersect the planes of regional schistosity. To the north-east of the Fraser's line of reef at Southern Cross, in the workings of the Three Queens Lease, G.M.L. 3770, a narrow belt of granitised greenstone (see page 83) contains thin gold bearing quartz reefs parallel and transverse to the schistosity. In the Comet gold mine at Marvel Loch, a thin auriferous quartz vein occurs in a fault plane which has displaced a pegmatite dyke. The faulted pegmatite dyke itself occurs in a fault plane which has displaced an auriferous quartz reef. In the main shaft at the southern end of G.M.L. 11 P.P., Edward's Find, a nearly vertical quartz reef is cut by a flatly dipping pegmatite dyke. The reef was not displaced and the owners reported an abrupt termination of the reef on top of the dyke and a sharp resumption immediately below. A few feet to the west of the main reef a thin stringer of quartz said to carry gold was reported to have been followed downwards through the pegmatite dyke to ultimately junction with the main reef.

Barren Quartz Reefs.

This type of quartz reef is very widespread and occurs much more frequently than the auriferous type. They occur both parallel with and transverse to the schistosity of the enclosing rock, and in the Pro Patria Mine at Donovan's Find and in the main mine at Marvel Loch cut through auriferous quartz reefs. The fault planes of the north-easterly trending fault system are frequently occupied by barren quartz reefs and much of the granite, gneiss and migmatite is liberally veined with quartz. At Southern Cross in particular there is a strong development of this type in the greenstone rocks close to or at the junction with the gneiss, and in other parts of the area many barren quartz reefs occur in the folded rocks close to the country which has had to be mapped as granite and/or gneiss. The very large development of quartz about three miles south-south-west of Edward's Find is another example of this manner of occurrence. About three and a half miles north-north-east of the main mine at Mt. Palmer, there is a small hill of quartz surrounded by greenstone. There is a considerable quantity of felspar mixed with quartz fragments on the slopes of this hill, and it appears that this particular quartz occurrence represents a very acid phase of a pegmatite.

The Pegmatite Dykes.

A feature of the geology of the Yilgarn Goldfield South of the Great Eastern Railway is the wide distribution and frequent occurrence of pegmatites. In nearly every mine no matter how small, pegmatites of some description are found cutting the auriferous quartz veins but never observed to be grading off into gold bearing quartz reefs. To instance only one mine, the "Comet" at Marvel Loch shows an auriferous quartz reef faulted and displaced laterally, with a pegmatite dyke occupying the fault plane. In some mines, for example, G.M.L. 11 P.P. at Edward's Find, the pegmatite cuts through the reef without the reef being displaced. This is the case in many other small mines also. Sometimes the pegmatites are faulted, as in the main mine at Mt. Palmer, the "Bohemia" at Donovan's Find, Fraser's Gold Mine at Southern Cross and in the "Comet" at Marvel Loch, where a thin auriferous quartz vein occurs cutting a faulted pegmatite (see *The Gold Bearing Quartz Reefs* p. 87). The pegmatites form characteristically irregular shaped masses cutting through the country rock in all directions, as can be seen in the workings of the main mine at Marvel Loch and Nevoria. Besides cutting completely through the auriferous quartz reef they replace the quartz reef by assimilation, as in the main workings on G.M.L. 12 P.P. at Edward's Find, where in a drive on a quartz reef a pegmatite dyke comes in from one wall, follows along the reef channel for a few feet and then leaves the reef for the wall rock again.

In the main mine at Mt. Palmer the relation of the pegmatite to the quartz mass in the eastern side of the fifty foot level of the workings on Egan's Reef, and in the northern end of the eastern leg of Whinfield's Reef at the 50 and 100 foot levels suggests that the auriferous quartz has been invaded and assimilated by the pegmatite.

In the main workings of the Cricket G.M.L. 13 P.P. Edward's Find, a rich quartz reef was cut off by a pegmatite dyke which had not been pierced in 23 feet of sinking in the main shaft at the time of inspection (August, 1935). The reef was not actually seen at its junction with the pegmatite, but numerous stringers of pegmatite occurred throughout the 15 inches or so of reef in the level situated about 15 feet above the surface of the pegmatite. This is suggestive of invasion by the pegmatite rather than of formation of the quartz reef from the solidifying pegmatite.

The granite, gneiss and migmatites all carry pegmatitic intrusions, and the rocks of the Whitestone and Greenstone Series are also freely invaded by pegmatite dykes. Some of the pegmatites are garnetiferous, others carry tourmaline; some have a graphic intergrowth of quartz and felspar with or without muscovite mica. Coarse grained graphic pegmatites with big muscovite and biotite mica flakes are common, and coarse grained pegmatites with biotite mica only are also found.

At Holleton a pegmatite dyke carrying cassiterite is intrusive into a basic igneous rock which is itself intrusive into the rocks of the Greenstone Series.

A noteworthy feature about practically all of the pegmatites examined microscopically is the presence of a plagioclase felspar approaching albite or oligoclase in composition.

The Aplite Dykes.

Aplite dykes were noticed in some of the granite "rocks," and one specimen was collected from the mine workings on G.M.L. 3377 at Holleton where a thin aplite dyke cuts across a quartz reef. Other thin aplite dykes occur in these workings in which the country rock is more or less massive greenstone. No aplite dykes were seen cutting pegmatite dykes in any of the mine workings examined, and their relation to pegmatites in the granite "rocks" were not carefully observed.

Quartz Porphyry Dykes.

Rocks of this type were found in one locality only, namely, southeast of Mt. Holland, where a small outcrop of quartz porphyry occurs apparently intrusive into rocks of the Whitestone Series. Outcrop conditions are so poor in this locality that a more definite statement than this cannot be made. The "sheared quartz porphyry dykes" of previous writers on the geology of the Yilgarn Goldfield south of the Great Eastern Railway, are considered by the writer to be either bands of metamorphosed felspathic grit, granitised greenstone, or mica schist of sedimentary origin.

The Granite.

Material which can be definitely recognised as granite forms most of the "rocks" of the Area. The granite in these usually low, bare, rounded hills is nearly always massive, has few joints, and is mostly a medium grained biotite granite. It has quartz veins, pegmatite dykes which are sometimes magnetite-bearing, aplite dykes, and pegmatite segregations in it, but these intrusive types are not frequent in most of the exposures seen during the survey. The relation of the pegmatite, aplite, and quartz reefs to each other in the granite "rocks" was, unfortunately, not carefully studied.

At Holleton and Mt. Palmer, fine to medium grained biotite granite is intrusive into the Greenstone Series. In both localities it can be seen cutting across the direction of regional schistosity of the greenstones. The typical coarse to medium grained granite was not seen cutting gold bearing quartz reefs or pegmatite dykes in any of the mine workings examined. It is intrusive into the Southern Cross gneiss on the western shore of Lake Polaris east of Southern Cross

townsite, and it also intrudes a decomposed biotite gneiss on the main Kalgoorlie Road 4 miles east of Southern Cross.

The petrological examination of numerous specimens of granite collected from very widespread localities has shown that there is no fundamental mineralogical difference in any of the granite outcrops investigated. (See Petrological Report by Mr. R. A. Hobson below.)

The Gneisses.

Some injection gneisses or migmatites have been recognised in Yellowdine "Rock" and Coondarmin "Rock" near Yellowdine Railway Siding, and the granitisation of folded greenstones resulting in a replacement gneiss is well exhibited in the railway cutting situated about one and a half miles east of Yellowdine Railway Siding. The granitisation of schistose greenstone resulting in the formation of acid replacement schists and gneisses is also prominently displayed in the "Three Queens" G.M.L. 3770, Southern Cross; on the western side of the lake north of Mt. Palmer (see Pl. VI) and on the western shore of the lake immediately south-east of the Olga Group, Parker's Range. Gneiss of doubtful origin also occurs, such as that on the western shore of Lake Polaris at Southern Cross, the biotite gneiss in many of the pipe line cuttings on the Goldfields Pipe Line, as well as the decomposed quartz felspar gneiss carrying veinlets of injected quartz seen in the sand plain country about six miles east of the Glendower Group. Orthogneiss (gneissic granite) is to be seen in portions of the granite "rocks" and at the Marvel Loch tank situated about one and a half miles north-east of the townsite.

On the assumption that a granitic magma or magmas provided the material for the formation of the auriferous quartz reefs, it now remains to endeavour to find out from the facts as set out above how many periods of granitic intrusion there are and which was the granite that provided the gold-bearing quartz reefs. There are some areas of greenstone in the goldfields of Western Australia associated with granite or rock of a granitic composition in which no auriferous quartz reefs have been found, and there are also extensive gaps in other greenstone belts between known gold-bearing localities. If suitable structures exist in these greenstone belts then the absence of auriferous quartz reefs could be accounted for by the lack of a suitable type of granite in their vicinity. If there is any particular type of granite which can be definitely stated to be the one responsible for the mineralisation in any district, and a similar type could be recognised as the source of similar mineralisation in a distant locality in another goldfield, then a very useful correlation of granite magmas would be established. It might then be possible to estimate the probable mineral bearing capabilities of the greenstone belts when granite could be found in their vicinity.

In the Yilgarn Goldfield south of the Great Eastern Railway, there is some evidence for thinking that there are two periods of

auriferous quartz deposition, from the manner of occurrence of the gold reefs in the Comet Mine at Marvel Loch and in the main shaft on G.M.L. 11PP. at Edward's Find. (See *The Gold Bearing Quartz Reefs*, p. 87). The only type of granite recognised is a medium to fine grained biotite granite, and it has to be assumed that this is the type associated with gold deposition. It also has to be assumed that the biotite granite was responsible for the formation of migmatites, granitised greenstone, pegmatites, aplites, quartz-porphry and barren quartz reefs. The orthogneiss is gneissic biotite granite. It has been shown that there is a structural control of auriferous quartz deposition, and therefore the structure caused by the folding of the rocks must have existed before the auriferous siliceous solution had access to the rocks. The distribution of the barren quartz reefs is also largely controlled by geological structure.

Pegmatite dykes cut across faulted quartz reefs (in some instances the drag of the fault can be seen) and occupy the fault plane. Aplite dykes cut across reefs and fine to medium grained biotite granite intrudes greenstones and gneisses. It is probable that there were two periods of granitic intrusion from the one magma and that the first one was responsible for the formation of migmatites, granitised belts, gold-bearing quartz reefs, barren quartz reefs and some pegmatites. A second period represented by the granite intrusion into the greenstones and gneisses and by the pegmatites and aplites cutting the faulted quartz reefs may not have been so extensive as the first one, but could have provided another gold-bearing quartz and could have formed migmatites and granitised zones and barren quartz reefs.

There is no method of measuring the time interval between these two supposed periods of granitic intrusion since there are no post granite rocks in this part of Western Australia. The facts relating to the occurrence of the granite, quartz reefs, etc., are no doubt open to a different interpretation to that put upon them here, and there may not be a necessity to postulate more than one period of granitic intrusion. The writer realises the shortcomings of his observations and remarks in this section of the report, and considers that the question of the granite and allied derivatives is of such a complicated and important nature that it deserves to be the subject of special investigation.

General Remarks.

The Greenstone Series contains erosion sediments interbedded with the lavas and pyroclastic rocks and this is sufficient evidence for the assumption that they were laid down on a pre-existing surface. The Greenstone Series of the Yilgarn System, and its equivalents in the Pre-Cambrian succession in other goldfields, are the oldest recognisable rocks of Pre-Cambrian age yet found in Western Australia. On structural evidence the country between Southern Cross

and the greenstone belt one and a half miles east of Yellowdine Railway Siding should contain basement rocks, representing as it does the central portion of a southerly pitching anticline. Whenever the greenstone can be seen in contact with rocks of granitic composition, and this is a very rare occurrence, the junction is either an unmistakable intrusive one transgressive to the strike, or the granitic rock is gneissic, with the planes of gneissosity parallel to the regional strike of the greenstones. The exact nature of the gneiss in contact with the greenstone has not been determined, and the mantle of soil and almost complete lack of outcrops make it impossible to examine any of the gneiss for any distance across the direction of gneissosity.

Where the basement rocks might be expected to outcrop the country is covered with sand plain, and the few exposures seen in the pipe line and railway cuttings between Southern Cross and Yellowdine are either migmatites, very decomposed biotite gneiss with injected quartz veins, a decomposed quartz feldspar gneiss with no recognisable mica or ferromagnesian minerals but carrying thin injected quartz veins, or a massive biotite granite. No regional strike or dip can be ascertained, and altogether, very little definite information can be obtained about these possible basement rocks.

The mineral assemblages and textures of the various pegmatites and granites as revealed by microscopic examination are not sufficiently distinctive to warrant the supposition that they have been derived from magmas of different initial composition. If different varieties of an early crystallising accessory mineral, such as zircon, were found in the granites, it might be reasonable to suspect that the original magmas differed materially in composition. The only occurrence of a tin-bearing pegmatite known in the area is at Holleton. This is an albite pegmatite, much the same in nature as many of the other albite pegmatites found cutting quartz reefs and invading the country rock in the Greenstone and Whitestone Series in other widely separated parts of the goldfield. Up to the present (June 1937), no tin-oxide has been found in the Yilgarn Goldfield away from Holleton, and this may have some significance, pointing to the existence of a separate granitic magma capable of providing tin-bearing pegmatites. The formations which have provided the detrital and lode tin and tantalite in other parts of Western Australia are mainly albite pegmatites occurring in Pre-Cambrian rocks marginal to granite intrusions.

The microscopic examinations carried out by Mr. R. A. Hobson were made mainly on one thin slice cut from one rock specimen. In collecting the material in the field, usually only one sample considered to be representative of the rock mass was obtained. Local variations in the rock masses were disregarded, and in a more thorough investigation into the granite and allied rocks it would be necessary to collect a number of samples from any exposure and to crush specimens and concentrate the heavy minerals.

Minerals in the Pegmatites.

The mineral composition of the pegmatites examined microscopically is given on pages 110 and 111, and the information contained in this section is to be regarded as supplementary to that contained in Mr. Hobson's petrographical report (pages 108-111).

The tin-bearing albite pegmatite (2/1707) intrusive into a coarse-grained amphibolite on M.L. 30, situated about 1 mile south-south-west of the Holleton Store and Post Office was examined by Dr. Simpson, Government Mineralogist and Analyst in 1929²³ and the following accessory minerals were found to be present:—

Cassiterite, tantalite, garnet, ilmenite, tourmaline, bismuth, and apatite.

Dr. Simpson also examined an albite pegmatite carrying veins and impregnations of biotite (2/1789, 2/1790, 2/1791) from "Radium" Hill or "Look Out" Hill, situated about three miles south-east of Holleton. He states that—

"A small proportion (up to one per cent.) of a uranium-bearing xenotime (phosphate of yttrium) can be concentrated from the biotitic portions."²⁴

A sample of gneiss (2/1690), from one mile south of the North Iron Cap (see page 105) was treated at the Government Chemical Laboratory, and Dr. Simpson reports as follows:—

"751/37, 2/1690.—The concentrate recovered on panning and treatment with bromoform weighed 0.016 per cent. It contained:—Magnetite (.036%), Ilmenite, Zircon, Biotite, Muscovite, Hornblende, Apatite, Epidote, Tourmaline, Pyrite and Limonite, with a minute amount of a colourless mineral of high refractive index and extreme birefringence. One grain of a green isotropic mineral (spinel?) was also present. No garnet was detected."

PETROLOGICAL REPORT ON A SUITE OF GRANITIC, GNEISSIC AND PEGMATITIC ROCKS FROM THE AREA.

R. A. HOBSON, B.Sc. (Hons.).

	Page
Locality and field determination of specimens examined	98
The Granites	99
Group 1.—Medium grained biotite granite	99
G.S.W.A. No. 2/1574	99
G.S.W.A. No. 2/1691	101
Group 2.—Porphyritic biotite granite	101
G.S.W.A. No. 2/1352	101
Group 3.—Fine grained biotite granite	102
G.S.W.A. No. 2/1807	102
Group 4.—Fine grained muscovite granite	102
G.S.W.A. No. 2/1600	102
Group 5.—Spene hornblende granite	102
G.S.W.A. No. 2/1804	102

²³ Chemical Branch Annual Report, 1929, p. 4.

²⁴ Op. cit. p. 4.

PETROLOGICAL REPORT, ETC.—continued.

	Page
The Gneisses	103
Group 1.—Primary ortho gneiss	103
G.S.W.A. No. 2/1688	103
G.S.W.A. No. 2/1594	106
G.S.W.A. No. 2/1820	106
Group 2.—Para gneiss	106
G.S.W.A. No. 2/1822	106
Group 3.—Gneisses of doubtful origin	106
G.S.W.A. No. 2/1821	107
G.S.W.A. No. 2/1817	108
The Pegmatites and Aplites	108
The Acid Hypabyssal Rocks	112
G.S.W.A. No. 2/1679	112
Rocks not included in previous groups	112
G.S.W.A. No. 2/1770	112
Conclusions	112

Note.—The thin slices used for microscopic examination were cut from one specimen considered to be representative of the rock mass from which it was collected. Rocks of granitic origin vary considerably in texture over comparatively short distances in any exposure, and in a more detailed investigation of these rocks a number of specimens from each outcrop would need to be examined. H.A.E.

TABLE GIVING LOCALITY AND FIELD DETERMINATION OF GRANITIC, GNEISSIC AND PEGMATITIC ROCKS, EXAMINED PETROLOGICALLY.

G.S.W.A. Registered Number.	Section Number	Map Reference Fig. 9.	Locality.	Field Determination.
2/1271	5847	F. 3	Near B. 8 shaft, 100ft. level, crosscut connecting B. 8 and B. 9 shafts, Main workings, Marvel Loch Gold Development, N.L., Marvel Loch	Granitic dyke.
2/1277	5850	F. 3	From 187ft. in No. 2 Main Shaft, Marvel Loch Gold Development, N.L., Main workings, Marvel Loch	Pegmatite dyke.
2/1287	5854	F. 3	From rise from stope, 224ft. level, 40ft. north of Main Shaft, Comet Mine, G.M.L. 3455, Marvel Loch	Pegmatitic granite with garnets.
2/1288	5855	F. 3	From roof of stope, 224ft. level, 40ft. north of Main Shaft, Comet Mine, G.M.L. 3455, Marvel Loch	Pegmatite dyke.
2/1311	5875	F. 4	155ft. V.D. in Shaft B, G.M.L. 13PP, Edward's Find	Granite dyke.
2/1317	5878	E. 3	Strawberry "Rocks," 15 miles south, 10° west of Southern Cross	Granite.
2/1355	5893	F. 3	Dump of Main Shaft, old Magpie lease (now "Alexander" G.M.L. 3642), Marvel Loch	Pegmatite.
2/1352	5905	D. 5	Granite "Rock," 4 miles north, 10° east from Mt. Hampton (L.D. 19/300)	Porphyritic granite.
2/1360	5912	D. 5	Granite "Rock," 4 miles north, 10° east from Mt. Hampton (L.D. 19/300)	Aplite dyke in granite of 2/1352.
2/1378	5924	F. 4	Main Shaft, G.M.L. 12PP, Edward's Find	Dyke (pegmatite), tourmaline-bearing.
2/1400	5935	F. 3	East Crosscut, 100ft. level, "Alexander," G.M.L. 3642, Marvel Loch Group	Pegmatite.
2/1508	5970	F. 3	Dump of late "Comet" workings, "Comet," G.M.L. 3455, Jacoletti Group	Pegmatite.
2/1574	5974	G. 2	$\frac{1}{2}$ mile west of Yellowdine Siding	Granite intruding Gneissic rock.
2/1580	5975	G. 2	$\frac{1}{2}$ mile west of Yellowdine Siding	Gneiss.
2/1582	5976	G. 2	$\frac{1}{2}$ mile west of Yellowdine Siding	Magnetite in Pegmatite in gneissic rock.

TABLE GIVING LOCALITY AND FIELD DETERMINATION OF GRANITIC, GNEISSIC AND PEGMATITIC ROCKS, EXAMINED PETROLOGICALLY.—*continued.*

G.S.W.A. Registered Number.	Section Number.	Map Reference Fig. 9.	Locality.	Field Determination.
2/1594	5977	F. 3	Marvel Loch Tank, 1½ miles north-east of Townsite, Marvel Loch	Gneiss.
2/1600	5978	H. 3	Meier's Find, south of Palmer's Find	Granite.
2/1644	5981	G. 5	Olga Rocks, Parker's Range ...	Gneiss.
2/1648	5982	G. 3	Dump of Shaft K, G.M.L. 3515, Nevoria	Pegmatite.
2/1652	5983	G. 5	Olga Rocks, Parker's Range ...	Gneiss.
2/1659	5984	G. 3	Dump of Shaft K, G.M.L. 3515, Nevoria	Pegmatite with garnets.
2/1676	5986	H. 3	9 miles south of Kellandi Siding	Granite.
2/1677	5987	F. 6	Skeleton Rocks, west of Parker's Range	Granite.
2/1679	5988	H. 8	About 3 miles south-east from Mt. Holland	Quartz porphyry (?)
2/1684	5990	G. 11	105-mile gate, Rabbit Proof Fence. Water Tank 1 mile west of fence	Granite.
2/1687	5991	G. 6	Split Rocks, south of Cheriton's Find Group, Parker's Range	Gneiss.
2/1688	5992	G. 9	"Rock," 1 mile south of North Ironcap	Gneiss.
2/1690	5994	G. 9	1 mile south of North Ironcap ...	Garnetiferous (?) Gneiss.
2/1691	5995	H. 12	Digger Rocks, south of South Ironcap	Biotite Granite.
2/1692	5996	G. 6	Split Rocks, Parker's Range-Ravensthorpe Road	Gneiss.
2/1707	5997	D. 7	M.L. 30, Holleton	Tin-bearing pegmatite.
2/1708	5998	D. 7	M.L. 30, Holleton	Fine-grained portion of stanniferous pegmatite.
2/1710	5999	D. 7	M.L. 30, Holleton	Garnetiferous Quartz? (may be fine-grained aplite).
2/1715	6000	E. 5	½ mile north of north-west corner Location 541 (19/300).	Gneiss.
2/1717	6001	D. 3	About 13 miles south of Moorine Rock	Granite.
2/1718	6002	D. 5	Mt. Hampton	Granite (and felspar from dyke in it).
2/1719	6003	E. 9	"Rock" 80-mile peg Rabbit Proof Fence	Granite.

TABLE GIVING LOCALITY AND FIELD DETERMINATION OF
GRANITIC, GNEISSIC AND PEGMATITIC ROCKS, EXAMINED
PETROLOGICALLY.—*continued.*

G.S.W.A. Registered Number.	Section Number.	Map Refer- ence Fig 9.	Locality.	Field Determination.
2/1726	6004	D. 7	35ft. level, P.A. 4579, Crosscut going west (Holleton)	Apatite bearing pegmatite.
2/1729	6005	D. 6	G.M.L. 3377, Holleton	Dyke, aplite.
2/1732	6007	G. 5	White Horseshoe Lease, G.M.L. 3540, Parker's Range	Pegmatite with garnets.
2/1736	6008	H. 3	15 chains south of south corner G.M.L. 3647, Meier's Find. (South of Mt. Palmer.)	Granite.
2/1745	6012	H. 3	From south-east corner of Location 677, north of road, Palmer's Find (19/300)	Granite.
2/1748	6013	H. 3	27 chains south and 132 chains east of 9-mile peg, Yellowdine-Parker's Range Road	Gneiss.
2/1749	6014	H. 3	25 chains south, and 146 chains east of 9-mile peg, Yellowdine-Parker's Range Road	Granite from dump.
2/1760	6015	H. 2	204 chains east, and 40 chains north of 5-mile peg, Yellowdine-Parker's Range Road	Granite.
2/1770	6018	H. 3	Mt. Palmer, 26 chains south of south-west corner of G.M.L. 3666	Granitised greenstone.
2/1771	6019	F. 2	Leviathan Gold Mine, G.M.L.'s 3432 and 3664, Kennyville, Main Workings, No. 3 level, 20 feet south of Main Shaft	Pegmatite.
2/1789	6025	D. 7	Dump of old shaft, west slope of Mt. Lookout, Holleton	Pegmatite.
2/1790	6026	D. 7	Dump of old shaft, west slope of Mt. Lookout, Holleton	Pegmatite.
2/1791	6027	D. 7	Dump of old shaft, west slope of Mt. Lookout, Holleton	Pegmatite.
2/1798	6031	D. 3	North end of Location 337 (23/80), large granite rock	Granite.
2/1799	6032	D. 4	Dulyalbin "Rock," Water Reserve 20212 (23/80)	Granite.
2/1803	6036	H. 3	3 miles south of Mt. Palmer, west shore of lake	Granite.
2/1804	6037	E. 3	From "Rock" on Reserve 19320/251, south of Location 353 (23/80)	Granite.
2/1807	6038	D. 2	Main outcrop, crest of Moorine Rock	Granite.
2/1808	6039	E. 2	Outcrop on Location 202 (36/80) Dyke cutting Jaspilite (Mt. Rankin Line)	Large garnetiferous pegmatite intrusion covers several acres.

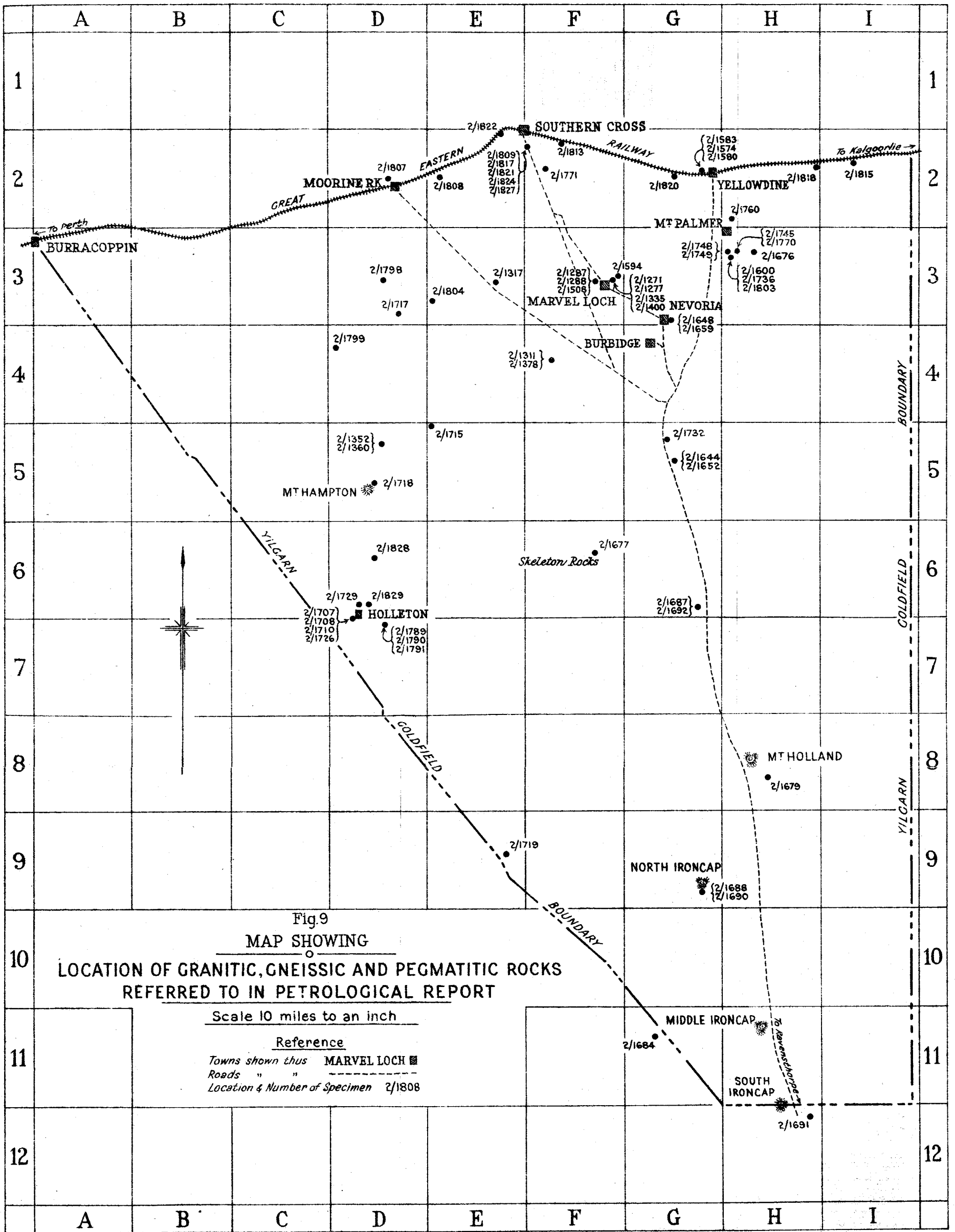
TABLE GIVING LOCALITY AND FIELD DETERMINATION OF GRANITIC, GNEISSIC AND PEGMATITIC ROCKS, EXAMINED PETROLOGICALLY.—*continued.*

G.S.W.A. Registered Number.	Section Number.	Map Reference Fig 9.	Locality.	Field Determination.
2/1809	6040	F. 2	Causeway across Lake Polaris, Southern Cross-Marvel Loch Road	Coarse-grained gneiss.
2/1813	6042	F. 2	4 miles east of Southern Cross on main Kalgoorlie Road	Gneiss with aplitic phase in it.
2/1815	6044	I. 2	34·4 miles east of Southern Cross on Kalgoorlie Road, pipe track	Pegmatite.
2/1817	6046	F. 2	West shore Lake Polaris, 7 chains north-west of Causeway, Marvel Loch Road	Gneiss.
2/1818	6047	H. 2	30·4 miles east of Southern Cross on Kalgoorlie Road, "Rock" on south side of road. Also outcrops as "Tors" on north side of road	Granite.
2/1820	6049	G. 2	Pipe line, 16 miles east of Southern Cross on Kalgoorlie Road	Gneiss.
2/1821	6050	E. 2	South shore Lake Polaris, 10 chains west of Kalgoorlie Road Crossing	Gneiss.
2/1822	6051	E. 2	Target Pit, Rifle Range, Southern Cross	Augen gneiss.
2/1824	6053	E. 2	South shore Lake Polaris, 10 chains north-west of Kalgoorlie Road Causeway	Gneiss.
2/1827	6054	E. 2	South shore Lake Polaris, bearing 220° to Railway Hotel, Southern Cross	Granite.
2/1828	6055	D. 6	Between Holleton and Mt. Hampton, 8 miles south of Mt. Hampton.	Porphyritic Granite
2/1829	6056	D. 6	One mile east of main mines at Holleton	Granite.
2/1853	6062	G. 2	½ mile west of Yellowdine Siding	Gneiss.

Locality and Field Determination of Specimens Examined.

The table on pages 95-98 gives the locality and field determination of each specimen.

The map references, given in this table, have reference to Fig. 9, which shows the localities of specimens. The map is regarded as being divided into two series of columns, at right angles. One set is lettered from A to I, and the other numbered from 1 to 12. The map reference gives the square in which the specimen occurs.



The rocks have been divided, mainly on the field evidence, into five main types:—

Granites.

Gneisses.

Pegmatites and Aplites.

Acid Hypabyssal Rocks.

Rocks not included in the above groups.

Those rocks, which have a gneissosity visible in the field, but not visible in hand specimen, are included in the gneisses.

The Granites.

From a megascopic and microscopic examination five petrographic types are recognised, as shown in the table on page 100.

The specimens examined vary from fine to medium grained. Portion of one specimen, 2/1818, is, however, somewhat coarser grained. The essential minerals are quartz, orthoclase, microcline, oligoclase (perhaps intermediate between oligoclase and albite), and biotite, with the addition of muscovite in group 4, and hornblende and sphene in group 5. The biotite flakes, and occasionally the orthoclase grains are hypidiomorphic, but the remainder of the minerals, except the accessory minerals, are quite allotriomorphic. The orthoclase sometimes shows zonary banding. The feldspars are the most abundant minerals, and are generally quite fresh. The biotite is sometimes slightly altered to chlorite. The accessory minerals are scarce, with apatite as the most frequent. The order of crystallization, appears, with some exceptions, to be normal for granites.

The rocks have undergone very little metamorphism—the only metamorphic effect consistently noted is the presence of wavy extinction in the quartz. The degree of wavy extinction in the quartz grains varies from being just noticeable to being quite noticeable. In most rocks this wavy extinction is confined to the quartz, but is occasionally observed in orthoclase. Very occasionally a slight bending of the albite twinning lamellae is observed.

The following are descriptions of typical specimens from each of the groups.

Group 1.—Medium grained biotite granite.

G.S.W.A. No. 2/1574.—

This is a medium grained rock, with feldspar, quartz and biotite visible in hand specimen. It is even grained, with very occasional larger feldspar grains.

Biotite occurs in more or less elongated ragged grains, with defined pleochroism from very dark brown to light yellow brown. The grains are generally hypidiomorphic, with crystal faces developed parallel to the cleavage, and with ragged ends. There is a slight alteration to

TABLE SHOWING TYPES OF GRANITE, AND THE MINERAL COMPOSITION OF EACH SPECIMEN.

Group Number.	Petrographic Type.	G.S.W.A. Registered Number.	Section Number.	Quartz.	Orthoclase.	Microcline.	Oligoclase. ||	Micropegmatite.	Biotite.	Muscovite.	Chlorite.	Hornblende.	Sphene.	Zircon.	Apatite.	Magnetite.	Epidote.	
Group 1	Medium-grained biotite granite	2/1574	5974	+++*	†	†+++	+++	%	†	...	...	...	...	...	++	...	...
		2/1677	5987	†	†	†+++	+++	...	†
		2/1684	5990	†	†	†+++	+++	...	†
		2/1691	5995	†	†	†+++	+++	...	†
		2/1717	6001	†	†	†+++	+++	...	†
		2/1718	6002	†	†	†+++	+++	...	†
		2/1719	6003	†	†	†+++	+++	...	†
		2/1745	6012	†	†	†+++	+++	...	†
		2/1749	6014	†	†	†+++	+++	...	†
		2/1760	6015	†	†	†+++	+++	...	†
2/1818	6047	†	†	†	%	...	†	...	...	...	...	...	...	...	...	...
Group 2	Porphyritic biotite granite	2/1352	5905	+++	†	†	†	†	†	...	...	...	...	...	...	...	...
		2/1317	5878	†	†	†	†	†	†	...	...	...	...	...	...	...	...
		2/1799	6032	+++	†	†	†	†	†	...	...	...	...	...	...	...	...
		2/1828	6055	†	†	†	†	†	†	...	...	...	...	...	...	...	...
Group 3	Fine-grained biotite granite	2/1807	6038	†	†	†	†	...	†	...	...	...	...	...	...	...	...
		2/1676	5986	†	†	†	†	...	†	...	...	...	...	...	...	...	...
		2/1736	6008	†	†	†	†	...	†	...	...	...	...	...	...	...	...
		2/1803	6036	†	†	†	†	...	†	...	...	...	...	...	...	...	...
		2/1829	6056	†	†	†	†	...	†	...	...	...	...	...	...	...	...
Group 4	Fine-grained muscovite granite	2/1600	5978	†	†	+++	+++	...	†	†	...	...	...	...	...	...	...
		2/1827	6054	†	†	+++	+++	...	†	†	...	...	...	...	...	...	...
Group 5	Sphene-hornblende granite	2/1804	6037	†	†	+++	†	...	†	...	...	+++	†	...	+++	†	...
		2/1798	6031	†	†	+++	†	...	†	...	...	+++	†	...	+++	†	...

* The quantity of any mineral present is approximately indicated as below. † Present in normal quantity. ‡ Not very abundant (for mineral concerned). § Present in very small quantity (for mineral concerned). The method is only approximate, but is used to give a rough idea of the amount of any mineral present relative to the normal amount of that mineral which is itself an indefinite amount. No measurements have been made, and the amount indicated is based upon the impression gained during examination of the rock slide.

|| Plagioclase feldspar intermediate between oligoclase and albite, but much closer to oligoclase.

chlorite along the cleavage, and inclusions are generally absent. An acid plagioclase is present, with a composition intermediate between oligoclase and albite, but closer to oligoclase. The width of albite twinning lamellae varies, and in one grain these were very slightly bent. Microcline is not abundant and occurs as small irregular shaped grains. Orthoclase is the most abundant feldspar. It is generally allotriomorphic, but may be hypidiomorphic. Only slight alteration has occurred, and cleavage is frequently visible. Twinning is not observed. Quartz is not abundant and the grains are allotriomorphic. It is free from all except minute inclusions. Micro pegmatite is present only in small quantities. Very minor quantities of apatite are observed.

The order of crystallization is probably normal, but there may be two exceptions. Irregular inclusions of microcline are observed in oligoclase and of orthoclase in biotite, but both the microcline and the orthoclase are allotriomorphic.

Wavy extinction is observed in the quartz grains.

G.S.W.A. No. 2/1691.—

This is a medium grained rock consisting mainly of quartz, feldspar and biotite. It differs somewhat in appearance from 2/1574.

Biotite occurs in ragged grains generally with no crystal face developed. The pleochroism is strong, from dark brown to light yellow brown. Small inclusions are sometimes very abundant, and one biotite grain has quartz inclusions. One hypidiomorphic grain of hornblende with pleochroism from blue green to green, is observed. Acid plagioclase grains are infrequent, and sometimes show carlsbad as well as albite twinning. Microcline is fairly conspicuous, and forms large allotriomorphic grains. Orthoclase is fairly abundant, and frequently shows zonal banding. One hypidiomorphic grain is included in a microcline grain. Quartz grains are allotriomorphic, and show only slight wavy extinction. Minor quantities of micropegmatite, magnetite, and apatite are observed.

There are fairly abundant aggregates and veinlets of small quartz and microcline grains, with some biotite and perhaps some orthoclase. In this respect 2/1691 differs from 2/1574 and other members of group 1.

Some of the quartz grains show strain shadows, while these are completely absent from others. Examination of the gneissic rocks shows that aggregates of small quartz and feldspar grains increase in amount as the degree of gneissosity increases, and they are thought to be due to pressure towards the end of the period of consolidation.

Group 2.—Porphyritic biotite granite.

G.S.W.A. No. 2/1352.—

This rock contains feldspar phenocrysts, with a maximum length of 3.5 cms., in a ground mass of quartz, feldspar and biotite, which makes up the bulk of the rock.

Biotite forms scattered ragged flakes, sometimes with crystal faces developed parallel to the cleavage. Pleochroism is from dark brown to light yellow brown. Oligoclase forms allotriomorphic grains, with narrow twinning lamellae, and shows only slight alteration. Orthoclase occurs as allotriomorphic grains, with no twinning. It also forms the large phenocrysts noted above. Orthoclase and microcline, in large allotriomorphic grains, are the most abundant minerals. The quartz shows only slight wavy extinction.

Group 3.—Fine grained biotite granite.

G.S.W.A. No. 2/1807.—

The specimen is light brown in colour, equigranular, fine grained, and contains quartz, felspar and biotite.

Except for grain size this rock resembles those of group 1, and the ground mass of those of group 2. Biotite is hypidiomorphic, and has partly developed crystal faces parallel to the cleavage.

Group 4.—Fine grained muscovite granite.

G.S.W.A. No. 2/1600.—

In hand specimen this resembles 2/1807.

Under the microscope it is seen that biotite occurs much as in previous rocks. Muscovite is not very abundant, and in mode of occurrence is very similar to that of the biotite. Neither plagioclase nor microcline is abundant. The most conspicuous felspar is orthoclase, which occurs in allotriomorphic grains. Twinning is generally absent, but one grain having carlsbad twinning is seen. Zonary banding can sometimes be observed. Quartz occurs in allotriomorphic grains, showing wavy extinction.

Group 5.—Sphene hornblende granite.

G.S.W.A. No. 2/1804.—

The rock is equigranular and medium grained. It is slightly coarser grained than 2/1574 and contains occasional large felspar grains.

Biotite occurs as fairly large ragged grains, with pleochroism from dark brown to light yellow brown. There are occasional inclusions of zircon. Sphene forms irregularly shaped grains, or somewhat tabular grains usually with abundant irregular cracks. It is frequently associated with the biotite. The pleochroism is usually not distinct, but one grain shows defined pleochroism from brown to a lighter brown. The usual colour of the grains is light brown. The hornblende is not abundant, and is not distributed evenly throughout the rock. The best development is a large ragged grain, very dark in colour, and with pleochroism from dark green to green. Elsewhere only smaller grains of hornblende are observed. Oligoclase is not abundant, and occurs as scattered fairly large grains, with narrow twin lamellae. Orthoclase occurs in allotriomorphic grains and is fairly abundant. Twinning is

absent. There are fairly large scattered grains of microcline. Quartz grains show only a slight wavy extinction. Minor quantities of magnetite and apatite are observed.

In group 5 biotite is still the most abundant dark mineral, and sphene is of more frequent occurrence than hornblende.

The Gneisses.

The gneisses have been divided into three main groups, according to their mode of origin, as indicated in the table on page 104.

Group 1.—Primary ortho gneiss.

This group includes the majority of the specimens, and there is considerable variation in appearance. They have been subdivided into two main groups—those rocks which show gneissic structure in hand specimen, and those which are massive in hand specimen. In mineral composition and other properties they resemble the granites. A curious feature, however, of those with a gneissic structure visible in hand specimen is the almost complete absence of a plagioclase feldspar. There is considerable variation in grain size, and individual rocks may also show considerable variation. The more gneissic have an abundance of small feldspar and quartz grains, due to crushing towards the end of consolidation. The quartz grains show only slight strain shadows.

The mineralogical and textural resemblance of these rocks to the granites indicates that they are primary gneisses. The degree of metamorphism has been different in different parts of the area, but nowhere has the degree of metamorphism been great.

The following are described as typical specimens:—

G.S.W.A. No. 2/1688.—

Medium grained gneissic rock consisting of quartz, feldspar and biotite.

Biotite occurs as scattered hypidiomorphic grains, with no defined parallel arrangement. Pleochroism is from dark brown to light brown. Some grains are partly altered to green chlorite. Occasional light yellow green grains or granular aggregates of epidote, with very faint pleochroism, are seen. Hornblende is found as elongated or tabular grains, with defined pleochroism from dark blue green to green. One large allotriomorphic, somewhat tabular, grain of oligoclase, with narrow albite and pericline twinning lamellae, is present. It is partly turbid due to alteration. Microcline and orthoclase occur as allotriomorphic grains of varying sizes, with only very slight alteration. Quartz forms large allotriomorphic grains, generally free from all except minute, dust-like, inclusions. Slight strain shadows are shown by some quartz grains, but are quite absent from others. Quartz also occurs as an intergrowth (micropegmatite) with orthoclase. Magnetite is fairly frequent, and apatite is occasionally found.

There is considerable variation in grain size, and the spaces between the larger grains are filled with smaller grains mainly of quartz,

TABLE SHOWING TYPES OF GNEISS, AND THE MINERAL COMPOSITION OF EACH SPECIMEN.

Type and Group Number.	Petrographic Type.	G.S.W.A. Registered Number.	Section Number.	Quartz.	Orthoclase.	Microcline.	Oligoclase.	Micropegmatite.	Biotite.	Muscovite.	Chlorite.	Hornblende.	Sphene.	Zircon.	Apatite.	Magnetite.	Garnet.	Epidote.	Tourmaline.		
Group 1— ORTHO GNEISS	A. Gneissosity visible in hand specimen—			*																	
	Biotite granite gneiss	{ 2/1688	5992	†	†	††	††	††	†	...	††	...	...	...	...	...	†	...	††	...
		{ 2/1652	5983	†	†	†	...	††	†	...	...	...	...	...	...	...	...	...	...	...
		{ 2/1808	6039	†	†	†	...	††	†	...	...	...	...	...	...	...	...	††	...	...
	Muscovite biotite granite gneiss	{ 2/1594	5977	†	†	†	...	...	††	†	†	...	...	...	...	...	...	...	...	...
		{ 2/1644	5981	†	†	†	...	...	††	†	†	...	...	...	...	...	...	...	...	...
		{ 2/1687	5991	†	†	†	...	...	†	†	††	...	...	...	...	...	...	...	...	...
	B. Gneissosity not visible in hand specimen—	Medium-grained biotite granite gneiss	{ 2/1580	5975	†	†	...	†	...	†	...	...	...	...	...	†	...	...	...	...
			{ 2/1853	6062	†	†	†	†	††	†
			{ 2/1820	6049	†	†	††	†	†	†	††
{ 2/1813			6042	†	†	††	†	†	†	...	...	...	...	...	...	...	...	...	...	...
Medium-grained muscovite biotite granite gneiss		{ 2/1692	5996	†	†	†	†	...	†	†	...	...	...	...	...	...	...	...	...
Fine-grained biotite granite gneiss		{ 2/1748	6013	†	†	...	†	...	†	...	...	...	...	...	...	†	...	...	...	...
		{ 2/1715	6000	†	†	†	†	...	†	...	...	...	...	...	...	...	...	...	...	...
Group 2— PARAGNEISS	Quartz muscovite gneiss	2/1822	6051	†	...	...	...	...	†	†	...	...	...	...	...	...	...	...	†

Group 3—

OF DOUBTFUL
ORIGIN

A. Gneissosity visible in hand specimen— Muscovite gneiss	{ 2/1821 2/1824	6050	†	†	†	†	....	....	§	†	§	....	....	....	....	....	....	....
		6053	†	†	†	....	....	§	†	....	....	....	....	....	....	....	....	....
B. Gneissosity not visible in hand specimen— Quartz felspar gneiss	{ 2/1817 2/1690	6046	†	†	....	†	....	....	....	....	....	....	....	....	....	....	....	....
		5994	†	†	†	....	....	....	....	....	....	....	....	....	....	....	....	....

* The quantity of any mineral present is approximately indicated as below. † Present in normal quantity. ‡ Not very abundant (for mineral concerned). § Present in very small quantity (for mineral concerned). The method is only approximate, but is used to give a rough idea of the amount of any mineral present relative to the normal amount of that mineral which is itself an indefinite amount. No measurements have been made, and the amount indicated is based upon the impression gained during examination of the rock slide.

micropegmatite, and orthoclase, with some microcline and biotite. This is probably due to partial granulation before consolidation was complete. There is nothing to suggest intense metamorphism, and the almost complete absence of cataclastic effects indicates high temperature during metamorphism. Mineral composition and texture resemble those of the granites, and the rock is regarded as a primary granite gneiss.

G.S.W.A. No. 2/1594.—

A medium grained gneissic rock, with quartz, felspar and biotite showing in hand specimen.

Biotite occurs as elongated, hypidiomorphic flakes, with intense pleochroism from dark brown to light yellow brown. A minor amount of chlorite has formed from the alteration of the biotite. Muscovite is seen as large irregularly shaped flakes. One such flake is hypidiomorphic against biotite. Orthoclase and microcline are usually found as allotriomorphic grains, but one hypidiomorphic grain of orthoclase is included in a large microcline grain. The quartz shows only slight strain shadows. No gneissic structure is visible under the microscope, and in mineral composition and texture the rock resembles the granites. It is to be regarded as a primary granite gneiss.

G.S.W.A. No. 2/1820.—

In hand specimen the rock varies from fine to medium grained, and no gneissic structure is visible.

The chief minerals found are biotite, oligoclase, orthoclase, microcline (not abundant), and quartz, with magnetite and epidote (one grain only) as accessory minerals. These minerals occur in a similar manner as in previous specimens. No gneissic structure is visible under the microscope.

Group 2.—Paragneiss.

This group is represented by only one specimen.

G.S.W.A. No. 2/1822.—

This is a fine grained micaceous augen gneiss. Under the microscope it is seen to consist of more or less rounded eyes of quartz in a fine grained matrix, mainly of quartz and muscovite, but with some biotite, and occasional grains of tourmaline. The muscovite grains have a general parallel orientation, but are also seen to run across the schistosity. The rock differs from all other gneisses examined in that it has undergone intense metamorphism, and appears to have taken part in the main folding of the area. It is described as a quartz muscovite gneiss, and is probably a metamorphosed grit.

Group 3.—Doubtful origin.

This group has been subdivided into two sub groups—one in which gneissic structure is visible in the hand specimen, and the other in which the hand specimen appears massive. This second sub group is further characterised by the almost complete absence of biotite. Muscovite is absent, or present only in minor quantities. Except for one specimen

2/1690 all specimens come from the neighbourhood of Southern Cross, east of the town. From observations elsewhere in the field it is thought by Mr. H. A. Ellis that these specimens represent granitized greenstones. Lack of outcrops made it impossible to see any gradation between greenstones and granites, and so collect a suite of specimens, which showed the gradation from one rock to another.

G.S.W.A. No. 2/1821.—

In hand specimen this rock is fairly coarse grained, with elongated quartz grains, feldspar grains, which occasionally appear hypidiomorphic, and fairly abundant small flakes of muscovite, visible.

There are occasional elongated grains or wisps of biotite altered to chloritic material. In thin section only a few flakes of muscovite are seen. Oligoclase occurs as allotropic and hypidiomorphic grains, of medium size, usually quite turbid due to alteration. It is not certain that all the turbid grains are oligoclase, as in many no albite twinning can be seen. Orthoclase is seen as allotropic grains varying considerably in size, and quite fresh. Cleavage can frequently be seen. Microcline is also quite fresh, and the grains vary considerably in size. There is a suggestion that it may be replacing the turbid feldspar, as tongues of this are seen extending into the microcline grains. Quartz occurs in allotropic grains of varying size, and showing very slight strain shadows.

There is quite a considerable variation in grain size, with a large proportion of small feldspar and quartz grains. The normal order of crystallization is at least partially observed—orthoclase occurs normal to oligoclase, and microcline normal to biotite.

The rock differs from the gneisses previously examined in the following ways:—

- (1) The almost complete absence of biotite, and the relative abundance of muscovite, which is best seen in hand specimen.
- (2) The oligoclase is almost completely altered, and also perhaps some of the other feldspars. Fresh orthoclase and microcline are observed, and there is the suggestion that the microcline may be replacing the turbid feldspar.
- (3) The greater proportion of small quartz and feldspar grains, probably due to more intense crushing during consolidation.

Except for these features the rock resembles those rocks previously examined. It has been shown ²⁵ that, by the process of granitization, the tendency is to produce a rock of granitic composition from pre-existing rocks of any composition. This process has not been previously recognised in Geological Survey literature, nor has the writer examined

²⁵ Horwood, H. C., Granitization in the Cross Lake Region, Manitoba. Royal Society of Canada, Section IV., third series, Vol. XXX., May, 1936, pp. 99-117.

any suite of specimens from elsewhere which illustrate this process. It is desirable to search in the field for some place, from which it will be possible to collect a suite of specimens showing a gradual change. This is a point for consideration, when future field work is in progress.

G.S.W.A. No. 2/1817.—

This rock differs from 2/1821 and 2/1824 in the absence of muscovite and microcline. The feldspars are less altered. Both orthoclase and oligoclase are partly altered with the production of wisps of sericite (?). One small fragment of garnet was observed.

The Pegmatites and Aplites.

The rocks examined vary from fine grained aplites through medium grained pegmatitic and granitic rocks, to coarse grained pegmatites—the medium grained rocks being the more abundant.

The mineral composition is broadly similar to that of the granites and gneisses. Alotriomorphic quartz and orthoclase are present in all specimens. The plagioclase feldspar which is present in all except four rocks, is intermediate in composition between oligoclase and albite, usually closer to oligoclase, but perhaps in some rocks approaching closer to albite. Microcline is absent from thirteen of the rocks, but when present is usually quite abundant. The mode of occurrence of the quartz and the feldspars resembles that in the granites.

Biotite occurs far less frequently than in the granites and gneisses, and is generally not as abundant in individual specimens. In 2/1789, however, a black biotite, is the most conspicuous mineral, and forms flakes up to 1½ in. in length. It is also abundant in 2/1790 and 2/1791. These three specimens all come from the same locality. In thin section it occurs as hypidiomorphic elongated or tabular grains, with ragged ends, and with intense pleochroism from dark brown to light yellow brown. Inclusions of minute zircon (?), surrounded by a halo of dark coloured biotite, are common.

Muscovite, although it occurs quite frequently, is generally not conspicuous in the specimens examined. In 2/1648, however, from Nevoria, it occurs in quite a large mass with a radiating structure. This is observed elsewhere in the southern portion of the Yilgarn Goldfield, but specimens are generally too decomposed to collect.

The garnets vary in size from very small ($< .03$ c.m.) in 2/1659 up to a maximum of 1 c.m. in 2/1808. Numbers 2/1288 and 2/1710 contain garnets intermediate in size. In hand specimens all are reddish in colour, and more or less idiomorphic. Those seen in thin section vary from hypidiomorphic to idiomorphic, and are a very faint red brown in colour—almost colourless. There appears to be a slight variation in colour in different rocks. Garnets from two rocks have been analysed by the Government Mineralogist and Analyst and both

have been found to be manganeseiferous almandines. The analyses are given below:—

	G.S.W.A. 2/1508 (Lab. 1985).	G.S.W.A. 2/1659 (Lab. 1456).
SiO ₂	36·20	36·69
Al ₂ O ₃	20·76	20·72
Fe ₂ O ₃	1·08	trace
FeO	27·19	31·25
MnO	13·34	9·73
MgO	1·22	1·10
CaO	0·56	0·42
Alks ... ..	...	<i>nil</i>
TiO ₂ ... ..	...	<i>nil</i>
H ₂ O ± ... ..	...	0·02
	<hr style="width: 50%; margin: 0 auto;"/> 100·35	<hr style="width: 50%; margin: 0 auto;"/> 99·93
G.	4·20	4·27
Analyst ... ..	...	C. R. Le Mesurier.

Tourmaline occurs in four of the rocks and is fairly conspicuous in hand specimens. Variations in colour and pleochroism indicate differences in composition. The properties of the tourmaline in the four rocks are briefly summarised below:—

G.S.W.A. No. 2/1288.—

Usually allotriomorphic, but may be hypidiomorphic. Pleochroism from blue to almost colourless. Not very abundant in hand specimen.

G.S.W.A. No. 2/1311.—

Allotriomorphic. Pleochroism from brown to very light brown—almost colourless. Fairly abundant in hand specimen.

G.S.W.A. No. 2/1378.—

Allotriomorphic. Pleochroism from brown to light brown. Inclusions of quartz. Fairly abundant in hand specimen.

G.S.W.A. No. 2/1726.—

Allotriomorphic. Pleochroism from light green to almost colourless. Inclusions of quartz.

Other minerals observed are given in the mineral composition table. Only two of these call for any comment. Apatite is quite abundant in G.S.W.A. No. 2/1726, and is found in smaller quantities in other rocks. Magnetite is sometimes conspicuous in hand specimens.

The pegmatites and aplites are generally free from metamorphic effects, but a few show fairly pronounced cataclastic effects, such as defined strain shadows in quartz, bending of albite twinning lamellae, bending of muscovite flakes (G.S.W.A. No. 2/1277, 2/1360, 2/1771, 2/1400).

The mineral composition is set out in the table on page 110.

TABLE SHOWING TYPES OF PEGMATITES AND APLITES, AND THE MINERAL COMPOSITION OF EACH SPECIMEN.

Petrographic Type.	G.S.W.A. Registered Number.	Section Number.	Quartz.	Orthoclase.	Microcline.	Oligoclase.	Micropegmatite.	Biotite.	Muscovite.	Chlorite.	Hornblende.	Sphene.	Zircon.	Apatite.	Magnetite.	Garnet.	Epidote.	Tourmaline.	Ilmenite.	Leucoxene.	Spinel.	Cassiterite.
Aplites and pegmatites varying from fine to medium coarse-grained, and with garnets	2/1659	5984	†*	†	†	†	...	...	†	...	...	...	...	...	...	†	...	...	...	...	...	...
	2/1287	5854	†	†	†	†	...	†||	%	...	...	...	...	...	...	†	...	...	...	...	...	...
	2/1288	5855	†	†	†	†	...	...	†	...	...	...	...	...	...	†	...	†	...	...	...	...
	2/1508	5970	†	†	†	†	...	...	†	...	...	...	...	...	...	†	...	...	...	...	...	...
	2/1710	5999	†	†	†	†	...	...	†	...	...	...	...	...	...	†	...	...	...	...	...	...
	2/1732	6007	†	†	†	†	...	...	†	...	...	...	...	...	...	†	...	...	...	...	...	...
2/1808	6039	†	†	†	†	...	†‡	%	...	...	...	...	...	...	†	...	...	...	...	...	...
Medium coarse-grained pegmatites with tourmaline	2/1311	5875	†	†	...	††	...	...	...	...	...	...	...	...	...	...	...	†	...	...	...	...
	2/1378	5924	†	†	...	†	...	...	%	...	...	...	...	...	...	...	...	†	...	...	...	...
Medium-grained pegmatite with tourmaline and abundant apatite	2/1726	6004	†	†	...	†	...	...	...	...	...	...	...	†	...	...	...	†	...	...	...	...
Coarse-grained graphic pegmatites	2/1335	5893	†	†	...	...	...	%	†||	...	...	...	...	...	...	...	...	...	...	...	...	...
	2/1648	5982	†	†	...	...	...	%	†||	...	...	...	...	...	...	...	...	...	...	...	...	...
Medium-grained pegmatites without biotite	2/1277	5850	†	†	%	†	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	2/1815	6044	†	†	†	%	†	...	†	...	...	...	...	...	†	...	...	...	...	...	...	...
	2/1771	6019	†	†	†	†	...	...	†	...	...	...	...	...	...	...	...	...	...	...	...	...
Medium to coarse-grained pegmatites with biotite	2/1400	5935	†	†	...	...	...	†||	†||	...	...	...	...	...	...	...	...	...	...	...	...	...
	2/1582	5976	†	†	...	%	...	†||	†||	%	...	...	...	...	†||	...	...	...	...	...	...	...
	2/1707	5997	†	†	...	%	...	†||	†||	%	...	...	%	...	†||	...	...	...	...	...	...	†||
Medium-grained granitic rocks, and coarse-grained pegmatite (2/1789) with abundant biotite	2/1789	6025	†||	†	...	†	...	†	†||	...	...	...	...	...	†||	†||	...	...	...	...	...	...
	2/1790	6026	†	†	...	†	...	†	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	2/1791	6027	†	†	...	†	...	†	...	%	...	...	...	...	...	...	...	...	...	...	...	...

Acid Hypabyssal Rocks.

There is only one rock of this type.

G.S.W.A. No. 2/1679.—

In hand specimen this is a siliceous rock, with not very large phenocrysts of quartz, felspar and biotite.

In thin slice it is seen to consist of allotriomorphic to hypidiomorphic phenocrysts of quartz, and more or less idiomorphic phenocrysts of orthoclase in a fine grained crystalline ground-mass probably of quartz and felspar. The orthoclase phenocrysts frequently show zonal structure and carlsbad twinning. Biotite occurs in much decomposed phenocrysts. Occasional grains of pyrites are observed. The rock is determined as a quartz porphyry.

Rocks not Included in Previous Groups.

The only rock to be described here is one from close to Meier's Find, and about 2 miles south of Mt. Palmer.

G.S.W.A. No. 2/1770.—

In hand specimen, this is a massive rock consisting mainly of quartz grains in a light yellow brown ground-mass.

In thin slice, it consists of allotriomorphic grains of quartz of varying size in a ground-mass of aggregates of small flakes of white mica, with much decomposed remnants of probably biotite. The quartz grains generally have wavy extinction.

From field evidence it is considered that this rock has been produced by a process of granitization of greenstones. The rock is quite massive in the field and in hand specimen.

It differs from all other rocks examined, but shows some similarity in mineral composition to a suite of rocks (2/1819) collected from close to Southern Cross to illustrate granitization on a small scale. It has also striking differences—notably in grain size, mode of occurrence of the white mica and lack of schistosity.

Conclusions.

From examination of this suite of specimens the following conclusions may be drawn with regard to origin of the granite, and its associated gneisses and dyke rocks.

(1) That one granitic magma could have produced all the granites, the primary ortho gneisses, and the aplites and pegmatites, which frequently intrude the granites and gneisses. It could also have produced the pegmatites, which intrude the greenstones, and provided the solutions for any granitization,²⁶ which may have occurred.

(2) The granitic magma was intruded towards the end of the period of folding, and that subsequent movements, before consolidation was complete, resulted in the formation of gneissic rocks, and may also have produced the strain shadows noted in many of the granites.

²⁶ Horwood, H. C., op. cit., p. 113.

(3) Subsequent to the intrusion and consolidation of the pegmatites earth movements have been only local in extent, and have taken place under conditions of comparatively low temperature. They may have occurred some appreciable time after consolidation of the pegmatites and aplites.

THE RECENT DEPOSITS.

The recent geological age of the soil, alluvium, sand dunes and "cement" which occur in the Area can be accepted without question, but the age of some grits and ferruginous laterites which also cover some of the rocks is not so obvious. In the absence of definite evidence establishing the age of the grits and laterite, they are included here-under with the deposits of recent geological age.

Soil.

By far the greater portion of the area is covered with soil, the bulk of which appears to have been formed *in situ* by the weathering of the underlying rocks. The soils, including the sandy soils of the sand-plains have been discussed in Chapter I, page 36.

Alluvium.

There are no proved extensive deposits of alluvium. The various salt lakes carry a deposit of silt mixed with salt and gypsum crystals on their surfaces. Frequently this layer of silt can be seen to be only very thin, being underlain by a rock floor, and at present no information is available concerning the thickness of the alluvium in the lake beds. There are also very extensive topographical depressions covered with forest or scrub growth which may be occupied by alluvium but which reveal no indication of its presence. Bores are needed in these localities to determine whether or not alluvium capable of providing auriferous deep-leads exists in them.

Thin coverings of alluvium of very limited extent occur at the base of the more prominent greenstone hills and granite rocks, and in the vicinity of Southern Cross the bed of a short creek in New Zealand Gully has been worked for alluvial gold. Another patch of alluvium on the western shore of Lake Polaris immediately south-east of Southern Cross has also been worked for alluvial gold, and these two localities represent the only known auriferous deposits of alluvium.

Sand Dunes.

Sand dunes mostly of a reddish colour covered with eucalypt forest or scrub growth occur in several places throughout the Area. They are of limited extent, but provide irrefutable evidence of the influence of wind action in the cycle of erosion through which the land has passed in geologically recent times. These dunes are not forming at the present

time and the growth of vegetation on them prevents their migration. Good examples may be seen in the flat to undulating forest covered country from four to five miles north-east of Harris' Find; on the Parker's Range-Ravensthorpe Road just south of the Olga Group, and on the Moorine Rock-Mt. Hampton road south of Moorine Rock.

"Cement."

The low ridges and hills composed of rocks of the Whitestone Series are frequently capped by a layer of "cement." This formation consists of the fragmental weathering products of decomposing metamorphosed sedimentary rocks cemented *in situ* in a ferruginous and aluminous matrix. It has a characteristic fragmental appearance, but when examined carefully it frequently reveals the structure of the underlying rocks. Dragfolds, as well as strike and dip are sometimes discernable, and in many cases this is the only indication of any structure in an otherwise featureless outcrop.

Grits.

Thin layers of arkosic grits sometimes containing occasional small water-worn quartz pebbles are exposed in some of the railway and pipe line cuttings between Burracoppin and Koorarawalyee. They do not show distinct bedding and wherever they occur they overlie granite or gneiss. The surrounding country is always of the sand-plain type, and from the macroscopic appearance of the grits and the sandy nature of the sand-plain soil, it would seem a natural conclusion to consider that the sand-plains were formed from the breaking down of these grits. No fossils were found in them although they have not been examined microscopically for such organisms as sponge spicules, foraminifera, etc.

These grits may represent remnants of beds deposited during a marine invasion in Miocene times, proof of which has been found in the country to the south of the Area. It seems more likely, in the writer's opinion, that they are simply arkosic grits formed either *in situ* or very close to where they are now found during a cycle of arid erosion in geologically recent times.

The Ferruginous Laterite.

Detailed investigations into the origin and manner of occurrence of the lateritic material so widely distributed in the Area have not been carried out during the survey. The more obvious occurrences round the mining centres have been mapped and are shown on the 40 chains to the inch geological maps accompanying this report. No ideal sections showing the passage downwards from the laterite to the underlying rock were seen, and in view of the contentious nature of current geological thought on the question of the origin of this material only generalised remarks will be made here.

It was noted during the survey that the laterite occurred at numerous different levels on country underlain by greenstone, metamorphosed sediments, or gneiss. It appeared to be much the same in nature wherever found, consisting of angular or subangular pebbles composed of quartz grains set in a ferruginous and aluminous cement, the pebbles being themselves loosely or firmly held in a sandy, aluminous and ferruginous cement. In some cases, deposits of laterite clearly revealed the fact that they were formed of pebbles of a higher level laterite transported down a hill and recemented in a ferruginous cement. An excellent example of this type occurs on the western shore of Lake Polaris south of No. 3 shaft on the old Fraser's line of reef at Southern Cross.

Most of the laterite occurrences are on the higher parts of the ridges and hills, but exactly similar material can also be found on topographically lower country. The presence of laterite below much of the sandy soil of the extensive sand-plain areas has resulted in the more recent conception of the origin of much of the laterite of Western Australia as being a fossil B. horizon of an old soil profile.²⁷

²⁷ 1931. Prescott, J. A., *The Soils of Australia in relation to Vegetation and Climate*. Australia. Council for Scientific and Industrial Research. Bull. No. 52, pp. 45-51.

CHAPTER IV.

STRUCTURAL GEOLOGY.

	Page
The Broad Geological Structure	116
Nature of Folding	127
Faulting	131
Shearing	132
Jointing	134
The Broad Relation between Geological Structure and Gold Deposition ...	134

THE BROAD GEOLOGICAL STRUCTURE.

The processes by which the areal distribution of the rocks and their relation to one another have been determined are those governed by the principles of igneous intrusion and folding. These two geological processes are sufficient to account for the distribution of the various rock masses in the Area and large scale faulting has not been recognised. Thrust faulting on a large scale is often associated with the type of folding which the Yilgarn System has undergone, but in the chief area where these rocks occur, namely, the belt running south-south-east from Southern Cross to the southern limit of the goldfield, the distribution of the rocks can be accounted for by folding only. There is no evidence to be found in any of the other occurrences of the rocks of the Yilgarn System shown on Plate II. which suggests thrust-faulting on a major scale.

A broad conception of the geological structure is gained by picturing a thick series of originally horizontally disposed beds composed of lava flows, pyroclastic material and sediments very intensely folded along axes having a general N.N.W.-S.S.E. trend. This folding produced tight chevron types of *similar* folds and resulted in the formation of anticlinoria and synclinoria. Some of the anticlines and synclines on the limbs of these major structures are overturned and it is not unlikely that the major structures are themselves overturned and asymmetrical. Either subsequent to or coincident with this folding along a N.N.W. axis, another set of folds having an axial trend approximating to east by north, and classified as cross-folds was imposed on the folded rocks. This folding appears to be much less intense on the whole than the dominant N.N.W. folding, but it is of great importance in its influence on the relation between structure and gold deposition.

Granitic intrusion of a batholithic nature with associated granitic, pegmatitic and aplitic intrusive dykes and quartz veins was associated with this folding, and there were also some pre-granite basic intrusive rocks in the folded series. The magnitude of this granitic intrusion is not clear from field evidence, but granite out-

erops over widely separated localities in the Area, and the occurrence of migmatites and replacement gneisses of undoubted origin amongst the few outcrops found away from the folded series indicates an extensive influence exercised by the invading granite on the country invaded. Prior to erosion then, there would be a series of highly folded volcanic and sedimentary rocks, which, on account of cross-folding would be arranged as a series of northerly and southerly pitching anticlines and synclines forming complex dome and basin-shaped structures. The invading granite would have penetrated irregularly into these rocks and would have formed a zone of mixed rocks and replacement gneisses.

Elevation and subsequent peneplanation now reveals a roughly horizontal section of this complex of folded metamorphic and intrusive igneous rocks covered for the most part with a mantle of soil and erosion products of recent age. Many thousands of feet of rock have probably been removed from above the present surface and it is not difficult to visualise the control which the depth of erosion has had on the outcrop lines of the rocks forming this intricately folded system. In many respects the peneplaned nature of the main portion of the interior of Western Australia is a very serious drawback to the geologist, but in so far as it provides him with a roughly horizontal section through the rocks it is of great assistance in the interpretation of the structural geology.

Wherever the rocks of the Yilgarn System are found they represent the structural remnants of a once continuous series of folded rocks. On account of the very poor outcrop conditions the exact relation of these remnants to the surrounding rocks cannot be definitely stated. The Yilgarn System may itself be an horizon in a thick series of felspathic grits now converted to paragneisses. The few exposures of the rocks of granitic composition show that migmatites and replacement gneisses as well as granite do occur, but it is not possible to say definitely what happens to these remnants along and across their regional strike.

They could be converted into replacement gneisses by medium of invading solutions derived from the intrusive granite, or into migmatites by the intimate admixture of granitic magma with them. If they form an horizon in a felspathic grit series then cross folding could easily account for their disappearance along the strike. Unfortunately this very interesting and important problem cannot be completely solved, because of the almost complete lack of exposures.

In only very few instances can the undoubted granite be seen intruding the Yilgarn System, and then only on a very small scale as on the western shore of the lakes immediately south of Mt. Palmer. It is not advisable then to assume that the junction of the rocks of the Yilgarn System and the areas marked Gr/Gn on Plate II. represents an intrusive contact. It may do so in places, while in others, as in the

railway cutting $1\frac{1}{2}$ miles east of Yellowdine Railway Siding the rock of granitic composition can be seen to be a replacement gneiss. How far one is justified in assuming a similar marginal zone of replacement gneiss or migmatite flanking the remnants of the Yilgarn System throughout the Area is difficult to tell, since contacts and exposures are so few.

The structure of the recognisable remnants of the Yilgarn System can be best considered by dividing them into four belts as they occur in the field and then treating each in turn. For this purpose they can be divided as follows:—

- (a) The Southern Cross-Cheriton's Find Belt.
- (b) The Mount Holland-South Ironcap Belt.
- (c) The Boddalin-Sandalwood Rocks Belt.
- (d) The Holleton Belt.

Belt (b) is the southerly continuation of belt (a), while belts (c) and (d) are separated from (a) and (b) by an average width of about 20 miles of granitic and gneissic country, and occur near the western border of the goldfield. The two belts (c) and (d) do not appear to be structurally continuous, that is, they do not seem to belong to the same unit in the broad structure, though they still form portion of a once continuous structure.

There are other smaller remnants of the ancient rocks represented on Plate II. but they are omitted from the grouping outlined above. They reveal no useful structural information except an occasional north-west or north-north-west strike and a very steep dip.

(a) *The Southern Cross-Cheriton's Find Belt.*

This is the main gold-bearing belt and the one in which the structure can be most clearly indicated. Rocks belonging to the two series, namely, the Whitestone and Greenstone Series are found here in juxtaposition, and it is largely from their relative distribution as shown on Plate II. that the geological structure of this belt can be determined.

The occurrence of a jaspilite band in the Greenstone Series as exposed in this remnant plays a very important part in helping to unravel the structure, but it must be pointed out that the assumption has been made that this jaspilite band constitutes a stratigraphical horizon within the Greenstone Series. The wide distribution of this rock type and its peculiar characteristics points to a widespread uniformity of conditions during its deposition, and since it cannot be regarded as anything but of sedimentary origin, it is not unreasonable to regard it as a stratigraphical horizon.

Another more or less prominent rock type in the Greenstone Series characterised by being composed of anthophyllite with associated ironstone and cellular and banded secondary silica formations, has been traced along its strike for a considerable distance, and was found to be

a very useful member in places where the jaspilite band could not be located. The distribution of this rock is shown on the 40-chain geological maps, being too narrow to portray on the 4 mile to the inch plan. It occurs as either a sill or basic lava flow in the original unfolded series but now forms part of the highly folded rocks and is, in places, very highly schistose. It occupies a higher position in the Greenstone Series than the jaspilite, and providing this fact is appreciated it can be used in conjunction with the latter for structural purposes.

The proof that this band of anthophyllite schist forms part of the folded series is to be found in its distribution as shown north-west and south-east of Marvel Loch on Plate IV. This matter will be discussed in a later section of this chapter.

The outcrop line of either the jaspilite or anthophyllite schist can be traced from Southern Cross south-eastwards through Kennyville, Glendower, Lenneberg's Find, The May Queen Mine, Marvel Loch, Donovan's Find and Nevoria, a distance of about 30 miles. Throughout this distance the regional dip is at angles varying from 50° to 85° to the south-west and approaching Nevoria the strikes swing more to the east and the dips are steep to the south. From Nevoria the jaspilite can be traced through a somewhat disconnected line of outcrops in a north-north-east direction through Foundation Find, Vicker's Find, Meier's Find and Palmer's Find for a distance of about 12 miles. On this section dips are mostly vertical or steep to the west, and from some pillow lava facings on the lake shore east of Palmer's Find some of the beds are seen to be overturned to the east, *i.e.*, they face east and dip west. This feature can be proved for only a small exposure, but the mere fact of its existence is of importance when it is realised that the behaviour of minor structures is often a guide to that of the major structures of which they form a part.

The shape of this outcrop line together with the regional dips indicates that it represents the plan of a horizontal section through a southerly pitching antiline, the axis of which strikes north-north-west. Strong southerly pitches are to be seen in the dragfolds of the jaspilite and associated beds at Nevoria and east of Vicker's Find.

The next important outcrop line of the jaspilite is to be found to the south of that already described, and forms a partially completed oval shaped curve passing through Magowan's Find, Toomey's Hills, Parker's Range and then round through the Olga and Dulcie groups to just north of Cheriton's Find, a distance of some 23 miles. The longer axis of this curve trends north-north-west and the regional dip of the jaspilite on its western half is about 50° to the west. At Toomey's Hills and Magowan's Find on the short eastern portion it is 65° and 85° respectively to the east. Considering the northern half of this curve and the regional dip of the jaspilite, it also represents the horizontal section of a pitching antiline and the direction of pitch must be to the north.

The south-western portion of this jaspilite outcrop line swings gently round to the south-east from about the Olga Group to just north of Cheriton's Find, but the southerly extension of the eastern part from Magowan's Find could not be found. At Cheriton's Find, regional strikes approximating to east occur with steep southerly dips, and in some hills of the Whitestone Series situated some 3 miles west of Cheriton's Find, a quartzite band shows very intense folding with steep northerly pitching dragfolds indicating strong cross-folding in this vicinity. This partially completed oval shaped outcrop line and the regional dips associated with it can only result from the cross-folding of an anticlinal structure by another anticline.

Looking at the geological map on Plate II. it will be noted that the Greenstone Series is disposed along these two jaspilite outcrop lines and that flanking the Greenstone Series are remnants of the rocks of the Whitestone Series, the whole forming an hour-glass like arrangement of beds. The only way in which the regional dips, the two outcrop lines of the jaspilite, and the distribution of the Whitestone Series can be accounted for is by the cross-folding of an anticlinal structure by a syncline. This synclinal cross-fold must pass in a general easterly direction somewhere between Parker's Range and Nevoria, but consistent northerly pitches between Parker's Range and the Great Victoria Mine indicate that the axis of this cross-fold must be somewhere between this latter locality and Nevoria. The ore body in the Great Victoria Mine forms part of a steep northerly pitching dragfold and the various ore bodies at Nevoria form portions of steep southerly pitching dragfolds.

Returning now to the more southerly of the two jaspilite outcrop lines, it will be seen to be bounded to the north by a synclinal cross-fold, that its shape and regional dip demands that it be crossed nearly centrally by an anticlinal cross-fold, and that field evidence indicates that it is bounded to the south by a synclinal cross-fold. Considering only the nature of folding, i.e., that an anticline follows a syncline, and accepting the unquestionable existence of the strong Nevoria synclinal cross-fold, then the next major crossfold to the south must be anticlinal and the succeeding fold must be synclinal and so on. An anticlinal and synclinal cross-fold have been shown to exist to the south of the Nevoria cross-fold, and the major structure of this portion of the gold belt can be regarded as proved.

The Nevoria cross-fold is a very strong one as is also that to the south of Cheriton's Find, and it would appear that throughout this belt the synclinal cross-folds are more intense than those of an anticlinal nature. In indicating on the various maps the approximate position of the axis of the Nevoria syncline, the regional pitches show that it probably lies somewhere between Nevoria and a line passing through Burbidge and the Banker Group. The distribution of the Whitestone and Greenstone Series in this locality as shown on Plate V.

makes it very difficult to draw a geological section along the north-north-west anticlinal axis and still keep the axis of the synclinal cross-fold in the position where shown. There is some minor structure intervening here which the extremely poor outcrop conditions have prevented from being observed. The boundaries of the two rock series cannot be seen, and it is often difficult to say what rocks are underlying the forest and soil covered areas in this district.

The major structure of the Southern Cross-Cheriton's Find belt shows that the Whitestone Series must overlie the Greenstone Series, hence it must be younger in age, and not as previously thought, older than the Greenstone Series.

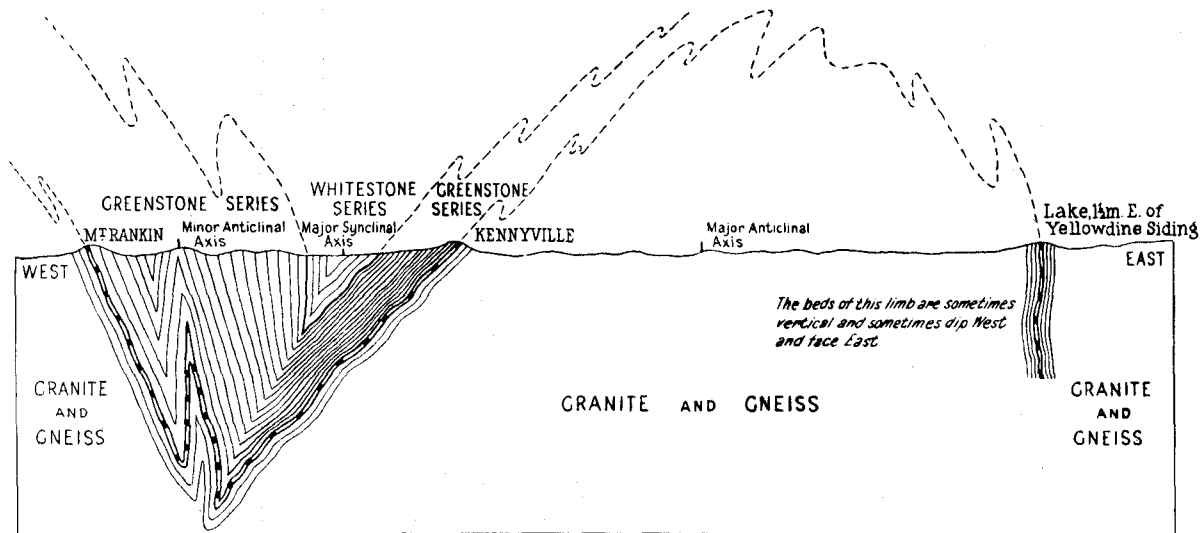
The structure from Southern Cross south-eastwards through Marvel Loch and Nevoria and then north-north-eastwards to Mt. Palmer has been shown to be a major anticline pitching to the south. This being the case, then the adjoining structures where remaining must be synclinal and normally can be expected to pitch to the south. To the east of the Mt. Palmer limb there are no recognisable remnants of the Yilgarn System, but flanking the western Marvel Loch—Southern Cross limb rocks of the Whitestone Series are shown on Plate II. occupying an area which gradually widens out to the south from a narrow strip near Southern Cross to a belt about 9 miles wide west of Marvel Loch. They are flanked on the west by rocks of the Greenstone Series and obviously form part of a southerly pitching syncline, the axis of which trends north-north-west and passes a little to the west of Southern Cross.

At Southern Cross the regional dip is steep to the west and the jaspilite band outcrops here in a number of parallel or sub-parallel ridges. This repetition of the jaspilite is caused by dragfolding on the western limb of the southerly pitching anticline (or the eastern limb of southerly pitching syncline) of which this jaspilite forms a part. It will be noticed that the Greenstone Series shows an appreciable thickening westwards from a little south of Southern Cross through Greenmount, Blackbourne's and Mt. Rankin, and that the jaspilite does not appear again until Mt. Rankin is reached. At this locality it outcrops as a long hog-back extending from the railway line near Keane Siding south-eastwards for about 6 miles, and has a steep regional dip to the north-east and a strong pitch to the south as indicated by many dragfolds in it.

Between Southern Cross and Mt. Rankin there is an arc of greenstone hills convex to the south, and although structural detail is lacking in them, it is not unlikely that they represent the outcrop line of a series of greenstone beds forming an anticline pitching to the south. This would be a minor anticlinal structure on the western limb of the major synclinal structure immediately west of Southern Cross.

Fig. 10

GEOLOGICAL SECTION
THROUGH MT RANKIN, KENNYVILLE AND LAKE 1½ M. EAST OF YELLOWDINE SIDING
YILGARN GOLDFIELD



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The geological cross section along a line passing eastwards through Mt. Rankin, Kennyville and the lake 2 miles east of Yellowdine Railway Siding shown in Fig. 10 indicates the probable nature of this synclinal and anticlinal folding along north-north-west axes in this locality.

The broad geological structure of this belt is reflected to a certain extent in the topography, as will be seen by referring to the section of this report dealing with The Ridges and Hills (Chapter II.). The ridges and hills composed of greenstone are disposed either as curves or straight lines according to their position in the folded complex, and those formed of rocks of the Whitestone Series behave similarly. The association between topography and structure is not very evident in the field on account of the general low relief and thick forest, and it frequently happens that the association is not appreciated until the structure has been worked out by other means. It is in this respect particularly that the lack of contoured topographical maps is felt.

Cross-folding.—The influence which cross-folding has had on the major structure of this belt has already been discussed, and two strong synclinal cross-folds at Nevoria and Cheriton's Find, with a less intense anticlinal cross-fold in between, have been recognised. Other cross-folds with axes at approximately right angles to those of the major anticlinal and synclinal structure are shown on the 40 chain to the inch geological maps, and convincing geological evidence in proof of at least three of these can be provided.

On Plate III. an anticlinal axis passes through Southern Cross in a general north-east by east direction. The drag-folds in the jaspilite north of this axis show a gradual increase in pitch to the north in a northerly direction and the shape of the outcrop line of the anthophyllite schist and the jaspilite approaching Southern Cross from the south indicates that a syncline is being crossed by an anticlinal fold. This crossfold is not a very strong one and is not the main cross-fold which causes the outcrop line of the jaspilite to swing round to the north and north-north-east in the area north of Bullfinch.

By studying the main band of anthophyllite schist shown on Plate III. running nearly north and south just west of Greenmount it will be noted that it is of a wavy nature, and the mere fact that it has such an irregular outcrop line indicates the existence of other minor anticlinal and synclinal cross-folds. It is impossible to locate the axes of these minor folds situated to the south of the main one at Southern Cross, since outcrops are very scarce east of the anthophyllite schist band.

An anticlinal cross-fold whose axis is depicted running a little north of east through Marvel Loch is shown on Plate IV. There is a slight bowing out to the south-west of the outcrop line of two bands of anthophyllite schist which traverse this map from the north-west to the south-east in the vicinity of Marvel Loch. As this portion of the struc-

ture is the western limb of a southerly pitching anticline and the regional dip is to the west, this slight bulge in the outcrop line can only be due to an anticlinal nose on this limb. It will be further noted that the outcrop lines of the two anthophyllite schist bands tend to converge as they approach Marvel Loch from the north-west and diverge after passing through that centre. This indicates that the two bands of anthophyllite schist are folded into a minor syncline. Confirmatory evidence of convergence of beds along the strike is to be found in the underground workings of the Marvel Loch Gold Development Mine at Marvel Loch, where two seemingly parallel bands of graphitic schist are cut in crosscuts at the south end of the workings. The western band can be traced to the north-west in several west crosscuts for a considerable distance, but the second band had not been encountered in any of the east crosscuts, although these had extended a long way past the point at which the east band could be expected to occur if it remained parallel to the western band.

In the neighbourhood of Donovan's Find this minor synclinal structure is shown by the opposed dips of beds adjacent to the two anthophyllite schist bands. To the north-west of Marvel Loch as far as Glendower, the two bands of anthophyllite schist outcrop as a chain of discontinuous occurrences about three-quarters of a mile apart and show no sign of influence by any strong cross-folding (the outcrop line is straight or nearly so). The May Queen Mine is situated in this minor syncline as is also the Propatria Mine at Donovan's Find.

The next cross-fold whose existence is suggested by the shape of a jaspilite outcrop line, occurs at Palmer's Find, and on Plate VI. an anticlinal axis has been shown passing through this centre in an east by north direction largely on account of the eastward bowing out of the jaspilite outcrop in this locality. The main mine here occurs in a minor syncline on the major anticlinal cross-fold. A prolongation of the anticlinal axis shown at Marvel Loch passes approximately through Palmer's Find, but there is no evidence to show that there is any connection between these two structures.

Where cross-folds other than those already mentioned are shown on the maps, the geological evidence is not convincing, but what evidence there is will be found on the various maps.

(b) *The Mt. Holland-South Ironcap Belt.*

This is a large remnant of rocks of the Yilgarn System extending from Cheriton's Find in a southerly direction to the southern border of the goldfield. It is shown on Plate II. as being mainly composed of rocks of the Whitestone Series in which there are some bands of greenstone. Whether these bands form part of the Greenstone Series or are only beds in the Whitestone Series, cannot be stated.

Throughout this belt, exposures capable of being used for structural purposes are extremely scarce, and the means of access in it are

also poor. Mt. Holland and the North, Middle and South Ironcaps provide the only small exposures on which strikes and dips can be obtained over a short distance. Occasional outcrops of amphibolite schist or quartz mica schist seen in other parts of this remnant show that the beds are very closely folded, strike mostly north-west, and have vertical or nearly vertical dips. The jaspilite bed occurs at Mt. Holland and the three Ironcaps, but its outcrop line is limited to a few chains only in each instance, and there is no possibility of tracing it away from these points. At Mt. Holland the jaspilite forms a short ridge, strikes nearly north, and dips at about 15° to the east. Some dragfolds in it pitch at 15° to the south-east and this particular outcrop forms the eastern limb of a south-easterly pitching anticline. About 3 miles to the south of Mt. Holland the jaspilite bed is exposed again crossing the track. It strikes north here and has steep east and west dips. It is both underlain and overlain by greenstones. There appears to have been an increase in the sedimentary phase in the Greenstone Series in a southerly direction, and this has increased the difficulty of structural interpretation.

The North Ironcap is a low gently rounded hill composed of jaspilite having an average strike of north-west and a dip to the north-east of from 45° to 50° . It is intensely folded, so much so that a limb structure diagnosis could not be made from the folds. The granite appears to come right up to its western and southern slopes and there are some rugged cliffs on the western fall.

The Middle Ironcap is a rounded hill composed mainly of jaspilite rising to about 200 feet above the general level of the surrounding country. The jaspilite is highly folded and the pitches of the folds are N. 20° - 30° W. at from 30° to 35° . This particular outcrop may be the western limb of a northerly pitching anticline. No definite strike or dip could be obtained though a probable strike is N. 70° W. The only sure structural information available here is that the dragfolds pitch to the north at from 30° to 35° in several places fairly close together where observed. The rocks flanking this jaspilite to the east and west are probably members of the Whitestone Series; occasional fragments of rock found in the soil and scrub covered country in this vicinity suggest this to be the case.

The South Ironcap presents an asymmetrically rounded outline with the steeper slope to the west when viewed from the south, and its highest part is occupied by a jaspilite band. In the eastern slope the strike of the jaspilite is N. 60° W. and the dip is 50° to the south-west. The band is highly folded and reversals in dip are frequent, but the predominant dip of the main outcrop along about half a mile of ridge appears to be at from 45° to 80° to the south-west. The pitch of the dragfolds varied from 15° to 50° to the south-east, and no reversals of pitch were noted. An excellent large dragfold on the west side of the north end of the ridge indicated that the

enclosing jaspilite bed formed the west limb of an anticline pitching at S. 20° E.

At the Forrestonia Mining Group (abandoned when visited in March 1936) the regional strike of some gneiss in which the quartz reefs occur appears to be N. 55° W., and the regional dip steep to the north. The dragfolds at the Middle Ironcap have a consistent northerly pitch while those at the South Ironcap pitch to the south. An antilinal crossfold with an axis trending E. 30° N. or thereabouts passing somewhere between the Middle and South Ironcaps through Forrestonia may exist, but the evidence is too poor to enable more than a suggestion being made that this may be the case.

Elsewhere in this belt the outcrop conditions are so poor that nothing further about the broad structure can be obtained. The increase in the sedimentary phase of the Greenstone Series suspected of having taken place southwards from Cheriton's Find also greatly complicates the problem when dealing with a highly folded system in which the component series cannot be definitely recognised. The structural evidence found in the Mt. Holland-South Ironcap belt merely substantiates that noted in the Southern Cross-Cheriton's Find belt. The existence of tight folding along an axis having a general north-westerly to northerly trend is shown by widely separated strikes in this direction and steep opposed dips. Crossfolding in a direction approximately at right angles to this folding is evidenced by the occurrence of dragfolds pitching both to the north-north-west and south-south-east at varying angles.

Forrestonia is the only centre at which gold occurs in or near this belt and detailed work of a similar nature to that carried out in the Southern Cross-Cheriton's Find belt was not undertaken here. Further useful structural details could no doubt be obtained by an intense geological survey, but it would take a long time and would be very costly to do this class of work in this belt.

(c) *The Boddalin-Sandalwood Rocks Belt.*

On Plate II. a narrow belt of the Greenstone Series is shown extending south-eastwards from Boddalin to near Sandalwood Rocks. Isolated outcrops of the jaspilite band occur in the southern half of this belt, and widely separated determinations of strikes and dip along the length of the belt show strikes varying from N. 45° W. to N. 70° W. and dips of from 70° N.E. to 85° S.W. This indicates very close folding along axes approximating to a north-westerly direction, but it was not found possible to assign to this belt a definite limb structure in the general folding system. The regional dip cannot be ascertained and there is no field evidence available by which it can be correlated with the structure in the Greenstone Series to the east. The intervening country consists of granite and gneiss and is covered by extensive sand-plains in which there are only occasional outcrops of granite.

At the southern end of the belt at Felstead's Find, several steep southerly pitching dragfolds were seen in very weathered outcrops of a band of metamorphosed sediments in the Greenstone Series. This is the only evidence of cross-folding which could be observed, but the very bad outcrop conditions throughout the whole of this belt may be successfully hiding other evidence. Detailed traverses were not made in this belt, and some considerable effort was required to trace it along the strike in a reconnaissance survey of this part of the Area.

(d) *The Holleton Belt.*

The extreme scarcity of outcrops and the diversity of direction and dip of the comparatively few exposures seen in this belt have prevented any major structural interpretation of the Greenstone Series occurring here being made. The jaspilite band outcrops as a short contorted exposure in some low undulating scrub covered country on a road $6\frac{1}{2}$ miles east of the 55-mile peg on the Rabbit Proof Fence, but could not be found elsewhere. The greenstone belt as a whole maps as though it may be the northern end of a pitching fold, but no other geological evidence in support of this conception can be offered. Under the topographical and vegetational conditions existing at Holleton, it is absolutely essential to be able to trace a recognisable bed in order to arrive at some conception of the broad structure. The mine workings examined by Mr. Hobson were few in number and are concentrated into the northern part of the belt. They reveal no consistent minor structure which could give a clue to the broad geological structure.

The marked diversity in the several strikes and dips observed indicates cross-folding, and the entire belt is probably a very complex system of pitching folds. The regional strike cannot be ascertained, but it may be more nearly in an easterly than northerly direction, since the belt has an extension to the west, beyond the boundary of the goldfield, not determined in this survey.

NATURE OF FOLDING.

The major structure of the Southern Cross-Cheriton's Find belt has proved beyond doubt the existence of two sets of folds which have exercised a dominating influence of the distribution of the rock types. Of these two sets of folds, that which took place along an axis having a general north-north-west trend is the more prominent, and has resulted in the production of a series of parallel or sub-parallel major and minor anticlines, the limbs of which are compressed into a very tightly folded complex. The minor anticlines and synclines are often drawn out up or down the axial plane and the occurrence of frequently opposed, very steep dips seen in practically any reasonably good exposure of the folded beds, is strong evidence of this type of folding.

The folds are seldom, if ever, symmetrical, and the main type of fold, the chevron variety, occurs as asymmetrical anticlines and synclines, and even as recumbent folds in some instances. The overturning of limbs of the folds is naturally frequent, and unless some means of obtaining a facing of the beds is available, it is practically impossible to determine their position on a limb. For structural purposes, any regional dip of 45° or under was assumed to be a normal dip, but dips in excess of this value were regarded with suspicion as being possibly overturned.

The minor folds of this series persist for long distances along the strike of the axial plane in the Southern Cross-Cheriton's Find Belt, as is demonstrated by the outcrop lines of both the jaspilite and anthophyllite schist bands. The folding is not made hopelessly complex in this belt by the influence of numerous strong cross-folds. Minor dragfolds seen at various isolated localities in the area were far too few in number to be of any service in helping to elucidate the major structure. They served as a guide to the regional pitch and the existence of minor cross-folds, but throughout this survey, made as it was under such poor outcrop conditions, the distribution of the rock types and the outcrop lines of recognisable beds, proved of most value. Both the pitch and shape of the dragfolds in any bed are of structural value only when applied to the beds immediately above and below them, and structural interpretations made from one dragfold cannot be applied in the absence of other evidence to beds some distance above or below those containing the dragfold. Field experience has shown that the effective use of dragfolds in any structural problem, demands that there be good exposures, that they be more or less continuous, and that most important of all, there be plenty of dragfolds. These conditions will very seldom be encountered in the Pre-Cambrian metamorphic rocks of Western Australia.

The repetition of beds by dragfolding on a major scale when seen in a subsequent exposure on a horizontal plane, accounts for the several parallel lines of jaspilite at Southern Cross, and for the duplication of the anthophyllite schist bed north-west and south-east of Marvel Loch.

Localities in which relatively small exposures reveal the types of folding mentioned above are the railway cutting west of the lake, situated about $1\frac{1}{2}$ miles east of Yellowdine Railway Siding, and the western shore of the same lake system immediately east of Vicker's Find, south of Mt. Palmer.

The other set of folds, less prominent than those just described, have axes trending more or less at right angles to the north-north-west series and are responsible for the convergence and divergence of outcrop lines of the various beds. These crossfolds are directly responsible for the pitch of the main anticlines and synclines, and a direct measure of their intensity is the angle at which the minor dragfolds pitch. Throughout the Area cross-folds resulting in both very high and very

low opposed pitches in minor and major dragfolds are to be observed. It seems that there are some cross-folds which have greatly influenced the general rock structure, such as those at Nevoria and Cheriton's Find, and that others such as the anticlinal cross-folds at Southern Cross and Marvel Loch, which although able to be recognised, have not exercised as prominent an influence.

There is evidence of the existence of a number of cross-folds either parallel or sub-parallel to these main ones which must be regarded as minor flexures or dragfolds on the limbs of the major cross-folds. The existence of very steeply pitching dragfolds in minor structures at localities far removed from the strongly cross-folded areas, and which have no reflection in the major structure in their vicinity, indicates that some of these minor cross-folds are intense but of small extent. An example of this type of cross-fold is that shown on Plate IV. near the north-west corner where three roads join. The sharp convergence of strike lines immediately north of the axis where depicted, and the occurrence of steep northerly pitching dragfolds to the south of it, unquestionably indicates a synclinal cross-fold of considerable strength. Producing the axis of this cross-fold to the east it will be noted that the outcrop lines of the jaspilite and anthophyllite schist are not noticeably affected. A possible explanation of this may be that the cross-fold pitches steeply to the west and as a consequence the beds further to the east have not been disturbed by it.

No evidence having a bearing on the general nature of the cross-folds could be obtained on account of poor outcrop conditions. They are probably asymmetrical and have varying pitches. If two reasonably distinctive rock series can be found under good outcrop conditions in an area which has been folded along two directions approximately at right angles to each other it would be possible to ascertain some of the characteristics of the cross-folds. Under existing West Australian goldfields conditions there is very little hope of ever finding these favourable occurrences.

The steep southerly pitch of the major dragfolds at Nevoria coupled with the steep northerly pitch of the major dragfold which constitutes the Great Victoria Mine suggests that either the Nevoria cross-fold is extremely intense, or that the fold is less intense but is exposed in its lower portions.

It is very important from an economic point of view to be able to recognise cross-folding in the field, since in the southern portion of the Yilgarn goldfield at least, it has been found to be closely associated with gold deposition. Under field conditions on the West Australian goldfields the major cross-folds will be indicated by the outcrop lines of the jaspilite where these occur. Failing these, then the present state of our knowledge of the stratigraphical sequence in the Pre-Cambrian metamorphic rocks will have to be used in conjunction with their

distribution in any district. A correlation of the Pre-Cambrian rocks of Western Australia has recently been made by the Government Geologist, Mr. F. G. Forman.²⁸

Whether gold deposition is, or is not, associated with cross-folding in other goldfields can only be ascertained by recognising these structures, and in any case, the more fully the geological structure is understood, the more easily can the structural features of the various gold occurrences be explained.

Recognition of minor cross-folds is more difficult, and particularly so when dips are steep as they nearly always are, and outcrops may be limited to as low as 5 per cent. of the area being investigated. In this case minor dragfolds are of great value if they can be found giving opposed pitches or showing changes of pitch in one direction. The greatest care is needed in mapping as many strikes and dips of schistosity or bedding (when this latter feature occasionally occurs) as possible. Convergence or divergence of strike lines towards or away from any centre is a sure indication of cross-folding even though the degree of convergence or divergence be very little. An analysis of the outcrop lines of any bed subjected to folding in two directions at a marked angle to each other and a consideration of the dips of the beds will determine the nature of both sets of folding, whether anticlinal or synclinal.

When portions of the greenstone belts are mapped on a scale of 20 chains to an inch, these features tend to become distinct in the mapping, but on the scale of 40 chains to an inch they are either only faintly discernible or are totally absent. It frequently happens that no distinctive rocks can be recognised in a locality, but the behaviour of the strike lines of even very steeply dipping schistosity will give some clue as to whether or not there is any cross-folding. Sometimes ore bodies occur in relatively large dragfolds, and if sufficient work has been done on them the direction of pitch of the ore body reveals the pitch of the structure with which it is associated.

If a cross-fold of either synclinal or anticlinal nature can be shown to exist at any locality, then the next succeeding cross-fold must be opposite in nature to the one whose existence is already established. Conclusive evidence sufficient to enable the trace of the axial plane on the existing ground surface to be indicated accurately on a plan will seldom if ever be found, but scattered and fragmentary evidence of cross-folding will frequently be seen, and if a definite structure is known for a particular locality then very useful conclusions can be drawn about the adjoining structure. Hence it pays to spend some considerable time in attempting to work out a local structure from which full use may be made of fragmentary structural data obtainable

²⁸ 1937. Forman, F. G., A Contribution to Our Knowledge of the Pre-Cambrian Succession in Some Parts of Western Australia. *Journal of The Royal Society of Western Australia*, Vol. XXIII., p. xxv.

in adjoining areas. In the field work undertaken in connection with this survey, full use was made of the principles outlined above, with, it is hoped, as demonstrated on the various plans some measure of success.

Several instances were noted in which another feature of cross-folding, namely, the disappearance of beds along the strike was to be observed. The manner in which this can be caused has already been described on page 54 (see Ridges and Hills, Chapter II.) and should be constantly watched for as a sure indication of cross-folding.

FAULTING.

Large scale faulting was not detected, although the severity of the folding along the N.N.W. axes suggests that it is most probable that faults of some considerable magnitude must exist somewhere in the folded rocks. In view of the very poor outcrop conditions existing over the whole area, it is impossible to detect any but the most conspicuous rock types, such as the jaspilite and anthophyllite schist, and then only imperfectly, since only discontinuous outcrops of these beds can be found.

In the numerous underground workings examined by Messrs. Hobson and Matheson, plans and sections of some of which appear in the Geological Survey of W.A. Bulletins Nos. 98 and 99, minor faulting was found to be of wide and frequent occurrence. The nature of the folding which the Yilgarn System has undergone would suggest that much of the faulting should be of the reverse type, and that normal faulting would be much less frequent. Such faults as could be examined underground, showed that normal faulting was more frequent than reverse faulting, and that strike faults were perhaps more numerous than dip faults.

In most instances, the dip of the fault plane was low, and the displacement of the faulted sections of the reefs seldom amounted to more than a few feet. Pegmatite dykes were almost invariably found occupying the fault planes, and the thickness of these dykes varied from an inch or less, to as much as twenty or thirty feet. Even when a thick dyke was found to be cutting the reef, it was not uncommon to find that only a very small lateral displacement of the reef had taken place.

The very frequent association of pegmatite dykes with faulting, as observed in the mines, and the occurrence of many outcrops of pegmatite in districts far removed from known mining centres, suggests that minor faulting with low dipping fault planes, is very widespread in the Yilgarn System throughout the Area. This also suggests the possible existence of thrust faulting on a large scale, although this structural feature cannot be proved to exist here. An excellent locality in which to view a general distribution of thin and thick pegmatite dykes intruded along flatly dipping planes, is along the western shores

of the lake system south of Mt. Palmer. Faulting cannot be obviously detected here, but many of the planes along which the pegmatite has been intruded are probably fault planes.

Some of the faults shown on the 40 chains to the inch geological plans, have been mapped from the obvious lateral displacement of recognisable beds; for example, on Plate III., those immediately west of Southern Cross where the jaspilite bands outcrop. Similarly, along the Mt. Rankin jaspilite outcrop, the several faults where shown, can be detected from the visible lateral displacement of the jaspilite. The strike of many of the larger faults mapped on surface evidence, varies between north-east and east, the directions coinciding with the general strike of the axial planes of the cross-folds. Barren quartz reefs frequently occur occupying the fault planes of these easterly trending faults, and since recognisable faults with this strike are nearly always associated with quartz reefs, faults have been drawn on the maps where only easterly trending quartz reefs could be seen. This, it is thought, is a reasonable inference, necessitated by an almost complete absence of outcrops whereby substantiating evidence could be obtained.

In mapping the various faults shown on the geological plans, the possibilities of repetition due to drag folding were constantly kept in view, and when dealing with the outcrop lines of the jaspilite, it was particularly necessary to constantly bear in mind the fact that cross folding and drag folding can produce a distribution of outcrops which could be mistakenly associated with faulting.

SHEARING.

The type of shearing which occurs most frequently is probably that caused by differential movement within a rock mass in directions parallel to the schistosity (flow cleavage) of the affected rocks. The evidence from which the existence of shearing is postulated, lies in the nature of occurrence of the many gold bearing quartz formations seen in the underground workings of the numerous small mines of the Area. With very few exceptions, these are found to have strikes and dips coincident with the strikes and dips of the schistosity of the enclosing schistose rocks. The necessity for the formation of some line of weakness, if not for the occurrence of actual openings, in which quartz deposition can take place, and the finding of this quartz deposition in planes parallel to the planes of schistosity of the enclosing rock, is taken as *prima facie* evidence of differential movement parallel to these planes.

In no instance was it found possible to determine the relation between schistosity and bedding in any of the workings examined, nor could fracture cleavage be definitely recognised. It is not unlikely however that fracture cleavage and schistosity are nearly coincident on the limbs of the major folds, and in that case shearing can be said to have taken place along planes parallel to the fracture cleavage.

Away from the underground workings it is not possible to recognise shearing in the general mass of schistose rock, but it is not unlikely that sheared zones, apart from those in which quartz reefs occur, do exist. From the distribution of the gold mining centres (see Plate 1) it can be inferred that there is a distribution of shearing in directions conforming to the outcrop lines of the beds of the Greenstone and Whitestone Series. In a series of rocks folded into similar folds, there is a strong tendency for shearing to take place along the attenuated limbs of the numerous anticlines and synclines, which, if sufficiently strongly exercised, results in a stretch thrust fault being formed when the folds are overturned. It has already been shown that the limbs of the major folds of the rocks comprising the Yilgarn System are intensely drag-folded and overturned, and it seems most probable that a belt of drag-folded strata exists in association with the jaspilite of the Greenstone Series in which shearing has been particularly strongly developed. This suggestion is strengthened by the occurrence of very many of the mines in a relatively narrow belt flanking and including the jaspilite.

By far the greater proportion of the gold-bearing quartz reefs occur as a series of parallel or sub-parallel ore bodies following closely the trend of the regional schistosity, both along the strike, and down the dip. They may be more or less tabular bodies, or they may occupy the limbs of pitching folds, or drag folds with horizontal axes. In nearly every instance the shearing which is presumed to have provided the lines of weakness permitting entry of gold-bearing solutions, must have followed the direction of schistosity imposed on the rocks in the zone of rock flowage. None of the ore bodies examined produced clear instances of spur veins and other structures associated with a shear-tension pattern of deformation under a shearing movement.

At Donovan's Find south-east of Marvel Loch there are some small quartz reefs being worked on the "New Democrat," "Outsider," and "Mussolini" leases, the strikes of which are oblique to the schistosity of the surrounding country rock. The exposures here, both on the surface and underground, do not permit of the making of a proper diagnosis of the structure with which these reefs are associated. They may occupy fault planes, or on the other hand they may represent tension fissures associated with a shear-tension pattern. If the latter is the case, then the north-west shearing is not evident, since there are no workings in quartz reefs close by which might lie in a north-west shear. Somewhat similar oblique quartz reefs occur in the "Battler" lease 8 miles south-east of Southern Cross, and here the rocks with which they are associated are pillow lavas flanked by very schistose amphibolite rocks, the strike of the schistosity of which is about north-west. These quartz reefs dip to the north, and the formation of the fissures in which they occur may be directly associated with a strong synclinal cross-fold shown on Plate IV. some four to five miles south-west of the "Battler" lease.

JOINTING.

Jointing due to varied causes is frequent in all the rocks of the Area, but no detailed analysis was made of the various classes of joints. Most of the underground workings show numerous "greasy heads" and fracture surfaces, and while some of these can be definitely associated with faulting, being more numerous in the vicinity of faults, others are present where no faulting exists.

The granite "rocks" are seldom obviously jointed, and then only on a big scale. In some of the granite exposures in which pegmatite or aplite dykes occur, the distribution of the dykes suggests that they have entered along a roughly rectangular series of intersecting joints, probably formed as tension joints when the granitic mass was cooling.

A combination of jointing, schistosity (flow cleavage) and fracture cleavage in moderately or steeply dipping greenstone beds, results in a peculiar spear-head arrangement of outcropping jointed rock in which the lines of intersection of the planes represented by flow and fracture cleavage, together with these planes, form the edges and sides respectively of a parallelepiped. These parallelepipeds are always weathered into spear-head like structures, but are nearly always inclined at an angle from the vertical. The direction and degree of their pitch is a measure of the direction and degree of pitch of the fold with which they are associated. The nearer the cross-section of these parallelepipeds approaches to a rectangle, the closer are the rocks in which they occur to the nose of a fold. Good examples of these pitching "spear-head" structures are to be seen on the Yellowdine-Parker's Range Road near the 16-mile peg on the west side of the road.

In several other localities, notably in the jaspilite band west of the 15 mile peg on the Yellowdine-Parker's Range Road and in a very small exposure of conglomerate with quartz pebbles on the western margin of Burbidge townsite, fracture cleavage can be observed crossing the schistosity (flow cleavage) obliquely.

THE BROAD RELATION BETWEEN GEOLOGICAL STRUCTURE AND
GOLD DEPOSITION.

The occurrence of gold in certain localities and its non-occurrence in others is dependent mainly on three factors, all of which must be present together before gold deposition can take place. The essentials of these three factors are as follows:—

- (a) There must be a source of supply.
- (b) There must be suitable pre-existing rock-structure, such as fracture zones or other lines of weakness in which the gold and its associated gangue minerals can be deposited.
- (c) There must be suitable rock types, in which essential precipitants of gold, such as iron compounds, freely occur, favourably situated with respect to the source of supply and the geological structure.

Factor (a) is, of course, a fundamental necessity, but the size and quality of a gold deposit is very largely determined by the extent to which factors (b) and (c) are present. In the Yilgarn goldfield south of the Great Eastern Railway, no evidence pointing to any other source for the gold than that of an intrusive granitic magma could be found. It has not been found possible to establish any fundamental petrological or age differences in the various granite outcrops of the Area, but the field evidence relating to the distribution of the gold-mining centres, seems to point to the conclusion that either granite or zones affected by granitic intrusion lie not very distant (mostly under one mile) from the gold reefs. There is no information available concerning the depth to the granite or granite affected zone below the gold bearing country, and this lack of knowledge about the underground distribution of the source of supply is an important missing link in any investigation into why the gold is found where it is.

Some interesting facts concerning factor (b) were brought to light as a result of the survey, and the relation which many of the gold centres bear to geological structure in this portion of the Yilgarn goldfield may prove to be of use in the future investigations in other goldfields.

No detailed investigations concerning the effect of wall-rock on gold deposition in any mine were carried out, but the principle of selectivity in gold—deposition in rocks of widely different chemical composition in a zone of gold deposition was noted in several of the smaller mines. Factor (c) is amply supplied by the rocks of the Greenstone Series which consist mainly of schistose lavas and pyroclastic rocks mostly of basic composition, and which are the chief host rocks of the various gold reefs. It is of interest to note here that the rocks of the Whitestone Series which consist mostly of metamorphosed sediments, contain only very few gold reefs when compared to those of the Greenstone Series. It will be seen from the geological map on Plate II. that this series is presumably in contact with the granite in many places, but very little gold deposition has taken place in it. The question immediately arises as to whether the right type of gold source granite exists near the contact. Unfortunately this question cannot be definitely answered, although in the absence of evidence to the contrary, it may be presumed that the granite in contact with both the Greenstone and Whitestone Series is of a similar type. The beds of the Whitestone Series are quite capable of being formed into structures suitable for the deposition of gold in the areas where they junction with the granite, but in those places where they form the synclinal portion of folds, they are underlain by the Greenstone Series, and the latter is therefore closer to the underlying granite and would probably intercept and precipitate any migratory gold solutions coming from the granite at depth, provided, of course, that the Greenstone Series had not been absorbed in the granite.

There is a line of gold deposition along a synclinal axis of a tightly folded portion of the Whitestone Series, extending south-south-eastwards from a little to the west of Southern Cross (see Plate III.). This structure is southerly pitching, and is crossed by a cross anticline in the vicinity of Southern Cross. The Greenstone Series should underlie these beds here at no great depth, and gold bearing solutions have been able to reach the beds of the Whitestone Series. There is no lack of quartz reefs both large and small in the Whitestone Series wherever it occurs, and it is difficult to account for the absence of gold bearing quartz in it unless it is presumed that the rock types forming it were not capable of supplying factor (c) above. This would imply that solutions carrying gold did at one time have access to the beds of the Whitestone Series but passed out of them without forming gold reefs. There are numerous bands of rocks composed mainly of ferromagnesian minerals in the Whitestone Series but these do not appear to have helped gold deposition.

It may not be unreasonable to presume that the gold-bearing solutions did not have access to the beds of the Whitestone Series, and when it is seen that the Greenstone Series (which underlies the Whitestone Series) must come between the Whitestone Series and the invading granitic magma and solutions, it is not at all unlikely that the chemical balance of the magmas and solutions may have been sufficiently disturbed to prevent the introduction of much gold bearing quartz into the Whitestone Series. Had the relative order of deposition of the two series been reversed it is quite probable that the gold would have been formed in the Whitestone Series, and not in the Greenstone Series.

As far as is known, the Greenstone Series is the oldest of the recognisable Pre-Cambrian rocks in the Yilgarn goldfield, and beds of a similar nature to those of the Greenstone Series, though referred to by other series names in West Australian Pre-Cambrian geology, occupy the lowest stratigraphical horizon of the Pre-Cambrian rocks in the districts where they occur. The rocks of this lowest recognised stratigraphical horizon naturally tend to form the barrier to granitic invasion a long time before those higher up in the stratigraphical succession do, hence they have the best chances of containing gold reefs.

The mines occurring in the rocks of the Whitestone Series are:— The "Transvaal" ("Jupiter") and other small gold occurrences in the vicinity of the synclinal axial plane of the Whitestone Series south-west of Southern Cross, the "Mountain Queen" near Marvel Loch, the "Great Victoria" at Burbidge, the mines at Edward's Find, and the small mines at Harris' Find south-east of Nevoria. They all have a definite association with some prominent geological structure which has also influenced the rocks of the Greenstone Series nearby in which gold deposition has also taken place. Considered as a whole, by far the most frequent occurrence of gold reefs is in the Greenstone Series distributed in a manner which will now be discussed.

The Distribution of the Gold Mining Centres Within the Greenstone Series.

A study of the various 40 chains to the inch geological maps discloses the fact that the gold occurrences in the rocks of the Greenstone Series lie along lines which closely follow the outcrop lines of the jaspilite and anthophyllite schist bands, the latter being parallel to and close to the jaspilite band from Southern Cross south-eastwards to Nevoria.

There is a distribution of gold reefs in more or less isolated centres, commencing with Southern Cross, and proceeding south-eastwards through Kennyville, Glendower, Lenneberg's Find, May Queen and Xantippe Groups, Marvel Loch, Donovan's Find and Nevoria. From Nevoria the outcrop line of the jaspilite swings sharply round to the north-north-east, and along this section occur Foundation Find, Vieker's Find, Meier's Find and Mt. Palmer, all very closely associated with the Greenstone Series in the vicinity of the jaspilite. Some of these gold reefs are in the jaspilite, viz., some at Kennyville, Nevoria, Glendower, and Lenneberg's Find, but most of them are in the greenstones at an horizon which seems to be stratigraphically above the jaspilite.

South of Nevoria, there exists another chain of gold mining centres closely associated with the outcrop line of the jaspilite and distributed along an incomplete oval shaped structure, commencing with Magowan's Find east of Parker's Range, and continuing north-westwards to Toomey's Hills, then swinging round in a south-south-westerly direction through Parker's Range to the Olga Group, where the structure curves round to the south-east through the Dulcie Group to Cheriton's Find.

In this distribution of gold reefs, there are two obvious facts which need explaining if the very important problem of the structural control of gold deposition, as it applies to this area, is to be partially understood. It will be necessary to know why the gold-line follows the outcrop line of the jaspilite, and why gold-deposition along that line is localised in more or less isolated centres.

The Gold Lines.—Dealing first with those gold occurrences known to follow the outcrop lines of the jaspilite, it will be necessary to recall to mind the broad geological structure. It has been shown in an earlier section of this chapter, that the outcropping portions of the Greenstone Series constitute remnants of a once extensive and highly folded series, the folds of which are of the similar type, and are frequently overturned. Drag folding on a minor and major scale exists, as is shown by frequent reversals in dip of steeply dipping beds across the strike; by the folding of the anthophyllite schist band between Southern Cross and Donovan's Find into a tight synclinal fold; and by the repetition of the jaspilite band at Southern Cross, Nevoria, Palmer's Find and Parker's Range.

Evidence of intense folding of the Greenstone Series resulting in the production of tight folds parallel to the outcrop lines of the jaspilite and anthophyllite schist band, can be found throughout the rocks of the Greenstone Series.

The gold bearing quartz reefs have been found to occur within the tightly folded zone, and in the section of this chapter dealing with Shearing, it has been explained why such structures are favourable to the formation of lines of weakness in which gold bearing quartz can be formed. It would appear then, that there is a drag-folded zone in the vicinity of and including the jaspilite band within the Greenstone Series, which coincides with the regional distribution of the jaspilite band as determined by the major geological structure. The detailed structure of this major drag-folded zone cannot be worked out, but there are several gold mining centres which throw some light on portion of its structure.

That portion of the Greenstone Series exposed at Southern Cross which includes the various jaspilite bands and the Fraser's line of gold reefs, comprises a drag-folded zone on the western limb of a southerly pitching anticline, namely, the major pitching anticlinal structure extending south-eastwards through Marvel Loch and Nevoria and then north-north-eastwards through Palmer's Find. The most easterly outcrop of the jaspilite band at Southern Cross is at Gravel Reserve 10033 a short distance to the north of the township where it dips steeply to the west. It next outcrops in a series of ridges west of the Fraser's gold line and has a regional dip to the west. The reefs in the old Fraser's mine dip to the west also and it is not unlikely that the greenstones outcropping between these two jaspilite bands form portion of a tight fold with the gold reefs of the Fraser's gold line occupying a position somewhere close to the axial plane or in the western limb of the minor fold. There is no evidence to show whether this fold is anticlinal or synclinal, and all that can be said about it is, that its axis trends north-west parallel to the line of gold reefs in Fraser's mines and that it is overturned to the east, i.e., that its axial plane dips westwards. The several other gold lines parallel to and situated westwards of the Fraser's gold line are all situated either in axial planes of tight folds, or in the limbs of closely folded anticlines and synclines: under existing outcrop conditions, it is impossible to state definitely which they are. (See Plate III.)

The Jupiter (old Transvaal) gold line occupies the position actually in or very close to the axial plane of the major southerly pitching syncline occupied by the beds of the Whitestone Series southwards of Southern Cross. (See Plate III.)

Another centre in which some detail of the folding in the main drag-folded zone can be shown to exist, is at Marvel Loch, where it has already been shown that the Marvel Loch Gold Development Company's mines, as well as the old Marvel Loch mines, are situated on or near the synclinal axis of a pronounced north-westerly trending syncline,

which forms part of a zone of rocks tightly folded along axes trending in this direction. There are several parallel gold lines at this centre, and at the Mountain Queen Mine, drag-folds in the large open cut, indicate that the line of gold deposition took place in and adjacent to the axial plane of a very tightly folded syncline. The other parallel gold lines at this centre occur either in axial planes or in the limbs of the tightly folded rocks of the Greenstone and Whitestone Series.

The May Queen gold mine, situated some 5 miles N.W. of Marvel Loch, occurs either in or apparently very close to the axial plane of the synclinal fold between two bands of anthophyllite schist. This is the north-westerly continuation of the syncline in which is situated the main producing mine at Marvel Loch, namely, the Marvel Loch Gold Development Company's mine. This synclinal structure can be traced south-eastwards from Marvel Loch towards Nevoria, and the group of small mines at Donovan's Find is closely associated with it. Of these mines the "Pro Patria" appears to occupy a position close to the axial plane of the fold, while the others, namely, the "Bohemia" Group, the "Francis Furness," the "Salvation," the "Outsider" and "New Democrat," appear to be associated with its north-easterly dipping western limb.

At Nevoria the main mine (the Nevoria Gold Mining Company's mine) is situated in a drag-folded portion of the jaspilite band, and in this instance the gold deposition is associated with quartz veins and mineralisation (mainly pyrrhotite) in a fracture system within the jaspilite. As far as can be ascertained the jaspilite here forms a limb of a strong synclinal cross-fold, the Nevoria cross-fold. Parallel gold lines have not been found here, but a thick mantle of soil north and south of the main line effectively hides all of the country rock for long distances, and it is not unlikely that other lines do exist in the greenstone under this soil covering, particularly to the south of the main line at Nevoria.

Continuing along the outcrop line of the jaspilite north-north-eastwards from Nevoria towards Mt. Palmer, there are several localities where gold has been found in proximity to the jaspilite, but not in it. Of these, only that at Palmer's Find at Mt. Palmer has proved to be of any size. Here, the rich quartz reefs of the Yellowdine Gold Development Company's mine occur in drag-folds near the axial plane of an overturned syncline in the Greenstone Series striking north-north-east. This is a strong synclinal structure running parallel to the outcrop line of the jaspilite bands in this locality, and it can be found again in the Greenstone Series north of the railway line about $1\frac{1}{2}$ miles east of Yellowdine Siding. (See Pl. XIX., Bull. 98.)

The Great Victoria Mine at Burbidge, the Banker Group and the smaller mines at Harris' Find are in northerly pitching drag-folded structures on the limbs of a major antiline pitching north. At these

localities there are fewer parallel gold lines than at those associated with the drag-folded zone in proximity to the jaspilite.

The occurrence of numerous small gold reefs both in the jaspilite and in the greenstones containing it in the Magowan's Find, Toomey's Hills, Parker's Range, Olga, Dulcie and Cheriton's Groups outcrop-line of the jaspilite, is again illustrative of the manner in which gold deposition has taken place in the rocks forming a tightly folded zone in proximity to the jaspilite. Gold deposition in nearly all of these localities has taken place in two or more parallel lines, but always in a manner such that the quartz reefs conform in strike and dip to the planes of schistosity in the enclosing rocks. Unfortunately, at all of the gold centres in this partially completed oval-shaped gold-line, outcrop conditions are so poor and the mines so shallow, that even the broader details of the folding associated with the gold deposition cannot be ascertained.

The Localisation of Gold Deposition.—The distribution of gold-mining centres in more or less isolated groups along the known gold-bearing horizon, particularly in the case of the rocks of the Greenstone Series, needs explaining if the attempt in this chapter to account for the distribution of gold occurrences on a geological structural basis is to be partially successful.

In the main greenstone belt of the Area, namely, that extending from Southern Cross in the north, to Cheriton's Find in the south, the existence of a gold bearing horizon within the Greenstone Series has been established, and a perusal of the various 40 chain to the inch geological plans, discloses the fact that the known gold mining localities occur as more or less compact groups within that horizon and are separated by intervals of country in which no gold reefs have as yet been found.

It has already been shown (page 118, The Southern Cross-Cheriton's Find Belt) that cross-folding of the general north-westerly trending major anticlinal and synclinal folds is a dominating factor in the geological structure of the Yilgarn System, and in the occurrences of these cross-folds as discussed below, it will be seen that there is some relation between cross-folding and gold deposition.

It is necessary to point out that in discussing this probable relation, the assumption has been made that the country along the main gold line between the known centres does not contain gold reefs. It is frequently the case that this intervening country is flat and soil-covered and possesses few outcrops, but not universally so, and it may be presumed that prospectors have examined this country carefully, being situated as it is on the gold line. Throughout the Greenstone Series, particularly in the Parker's Range district, it is noticeable that wherever the jaspilite band and associated greenstones outcrop, there is a group of small mines. It has been difficult to obtain any direct

evidence pointing to the reasons for the disappearance of greenstone and jaspilite outcrops along their strike, but it is easily accounted for if the influence of cross-folding on an already tightly folded series of rocks is taken into consideration. (See page 54, Ridges and Hills.)

It becomes necessary to enquire why the deposition of gold has not been continuous along a known gold bearing horizon. Considering only the three essential factors necessary for gold deposition, namely, a source of supply, a suitable structure, and a suitable host rock, the wide distribution of granite and the prevalence of ample supplies of suitable host rock in the Greenstone Series seems to imply that two at least of these factors have been present over very wide areas. In the case of the area under discussion, very little is known about the characteristics of these two latter factors, but from evidence shortly to be discussed, it would appear that the presence or absence of suitable structures dependant on the presence of absence of cross-folding is of paramount importance in determining the localities of gold deposition.

Unfortunately, in only a comparatively few instances can conclusive evidence be found establishing this connection; in others only portions of the evidence are available, and in still others, outcrop and mining conditions are of such a nature that it has not been found possible to discern the principal structural features controlling the localisation of gold deposition, although in these cases an intelligent guess can be made. The gold mining centres at which conclusive evidence of the existence of cross-folding has been found are Southern Cross, Marvel Loch, Nevoria and Burbidge, Mt. Palmer, and Cheriton's Find.

The regional distribution of the Whitestone Series southwards from Southern Cross, the shape of the outcrop line of the anthophyllitic schist band west of Greenmount, and that of the jaspilite band running south-eastwards from Southern Cross shows that the structure is pitching in a southerly direction. (See Plate III.). North-westwards along the outcrop lines of the jaspilite bands, commencing a little to the south-west of No. 3 shaft on the Fraser's line of reefs, there is a gradually increasing northerly pitch in the drag-folds, showing that there has been a reversal in pitch of the structure. To the south of No. 3 shaft, several small southerly pitching drag-folds can be seen near the lake edge, but these are only confirmatory and the reversal in pitch of the major structure as determined by the criteria quoted above can be accepted. Thus an anticlinal cross fold exists at Southern Cross and the orientation of its axis is probably north-east.

The nature of the cross folding at Marvel Loch has been described on page 123 (Cross folding). Confirmatory evidence of the existence of an anticlinal cross-fold here is possibly to be found in the open cut of the old Mountain Queen Mine, where drag folds at the northern end pitch to the north and those at the southern end pitch to the south.

The anticlinal structure in this open cut may be only of local significance, but in any case its occurrence is not necessary for the establishment of the existence of the main anticlinal cross-fold here.

Ample evidence in support of the existence of the strong Nevoria synclinal cross-fold has been supplied in previous pages, and the occurrence of gold at Nevoria, Donovan's Find, Burbidge, and Harris' Find, localities directly influenced by this structure, is significant.

At Mt. Palmer, the ore body in the Yellowdine Gold Development Company's mine, the only producing mine at this centre, is a gold bearing quartz formation occupying a drag-fold which has been folded by a minor synclinal cross-fold. The shape of the eastern outcrop line of the jaspilite for some distance north and south of the mine suggests that it owes this shape to an anticlinal cross-fold, causing a local outward bowing of the jaspilite outcrop. (See Plate VI.) Gold deposition in this case then has taken place in a minor drag-fold crossed by a minor synclinal cross-fold, the whole minor structure being situated near the axial plane of a larger anticlinal cross-fold.

At Cheriton's Find near the southern end of Parker's Range, the regional strike is a little west of north and the dip steep to the south. A few small drag-folds can be found in this locality pitching steeply to the south also, and the general south-easterly swing of the jaspilite from Parker's Range through the Olga and Dulcie groups indicates that a synclinal cross-fold is being approached. Ore deposition at Cheriton's Find has not proved to be extensive, but gold bearing quartz veins have been found here and a strong synclinal cross-fold does exist in this locality.

Dealing now with those gold centres in which the evidence for the association of gold deposition with cross folding is not conclusive, as it is above, but in which it is very suggestive, we can consider the following localities:—Edward's Find, Felstead's Find and the Glendower and Battler Groups east of the 8 mile peg on the Southern Cross-Marvel Loch Road. At Edward's Find the ore bodies are quartz reefs in drag-folds in the Whitestone Series, but insufficient work had been done on them at the time of the survey to determine their direction of pitch from mine workings. About 20 chains north-east of the most southerly workings on G.M.L. 13 P.P. (The Cricket Lease) there are some small drag-folds in a poorly exposed band of metamorphosed sediments which pitch steeply to the north-west. In the country immediately east, north-east, and south-east of Edward's Find, exposures are very scarce, but as shown on Plate II., several strikes and dips obtained here suggest the existence of a synclinal structure with an axis trending east by north. Continuing the axis of the proved Nevoria synclinal cross-fold in a westerly direction, it would pass in the vicinity of Edward's Find, and the evidence outlined above is suggestive of the continuation of this fold, a very strong one structurally, this far westwards.

At Felstead's Find, situated some 16 miles west by south from Edward's Find, a narrow belt of greenstone of the Greenstone Series outcrops. This forms the south-easterly continuation of the Westonia-Boddalin gold belt, and until recently gold had not been found in it south of Boddalin. The gold occurrence at Felstead's Find is only very small, being confined to small quartz reefs in highly folded greenstone beds. At one locality near the southern end of the belt, steep southerly pitches were seen in a small quartz formation. The occurrence of gold in this so far isolated locality in the only definite patch of greenstone known to exist west of Edward's Find in this part of the goldfield, and the existence of steeply pitching drag-folds in association with it, is significant. The continuation of the axis of the strong Nevoria synclinal cross-fold westerly from Edward's Find, would pass in the vicinity of Felstead's Find, but the only evidence for presuming the influence of this cross-fold at Felstead's Find is a strong southerly pitch in the minor folds near the southern limit of the recognisable greenstone country. Outcrop conditions at Felstead's Find are particularly bad.

There is a strong suggestion that the "Glendower" and "Battler" groups, situated about 4 miles and half a mile respectively east of the 8 mile peg of the Southern Cross-Marvel Loch Road, are influenced structurally by a strong synclinal crossfold. This is shown on Plate IV. near the north-west corner of the map and its existence is supported by conclusive geological evidence, details of which appear on this section of the map. It is difficult to imagine that the structure at these two groups could not have been affected by this minor cross-fold, but no substantial evidence can be found in any of the mines examined in these groups supporting the conception of cross-folding influence. Outcrop conditions in the vicinity of the mines and the surrounding country are extremely poor. The absence of outcrops of antophyllite schist and jaspilite north westwards of Glendower may indicate their down folding in this direction, and the nature of the quartz reefs in the "Battler" mines, where they tend to be formed in fractures transverse to the regional schistosity, and dip steeply northwards, may indicate their association with cross-folding.

In the attempt to correlate gold deposition with cross-folding, the possible association outlined in the several paragraphs below is entirely conjectural, and the suggestions which will be made cannot be supported by any evidence.

Let us accept the influence of the minor synclinal cross-fold on gold deposition for the "Glendower" and "Battler" groups. (See Plate IV.) In the gold belt south-east of these groups the following groups of mines occur in the following geographical order:—Going south-east from the Glendower Group we have Lenneberg's, May Queen and Xantippe, and Marvel Loch. An anticlinal cross-fold has been shown to exist at Marvel Loch, so starting with this structure and proceeding north-westwards and realising that a syncline follows an anti-

cline, the Xantippe and May Queen Groups may be associated with a synclinal cross-fold, and the Lenneberg Group with an anticlinal cross-fold. The next cross-fold would need to be synclinal to follow the order, and this would bring us back to the postulated syncline affecting the Glendower Group. There is some suggestion of regularity in the occurrence of the various gold mining centres along the gold line between Southern Cross and Nevoria and this might have some connection with the periodicity of the cross-folding.

The distribution of the mining centres in the Parker's Range district, namely, Magowan's Find, Toomey's Hills, Parker's Range, The Olga Group and the Dulcie Group, suggests that the cross folding may have been associated with gold deposition. Opposed pitching drag-folds do occur in the vicinity of the Olga Group and some of the ore bodies have strong northerly or southerly pitches, but the shallow mines and very poor outcrop conditions of this part of the goldfield did not permit of the obtaining of anything but fragmental evidence to support this conception.

Extending the conception of the association of gold deposition with cross-folding to widely separated areas, it seems that there may be more than a coincidence in the fact that a prolongation of the axis of the Cheriton's Group synclinal cross-fold (Plate III.) in a westerly direction passes through Holleton. The Greenstone Series at Holleton maps as a mass convex to the north, near the northern margin of which are situated the main mines. Near the 48-mile peg on the rabbit-proof fence, some of the greenstone strikes west and dips vertically. There is no structural feature associated with the mines that may be considered indicative of cross-folding, but the few available strikes and dips in the poorly exposed rocks of the Holleton district suggest that it is an intensely folded occurrence of beds of the Greenstone Series.

The Forrestonia Group, near the southern boundary of the gold-field, may be associated with an anticlinal cross-fold, which is postulated as existing between the Middle and South Ironcaps. There is certainly a reversal of pitch in the structures of which the Middle and South Ironcaps form a part, but there is no direct evidence at the Forrestonia gold centre by which the occurrence of gold there can be associated with this cross-fold.

The axis of the anticlinal cross-fold shown passing through Southern Cross on Plate II. when produced in a westerly direction, passes through the northern end of the greenstone band running north-west from Mt. Rankin to the railway line at Keane Siding. At this point of intersection, there is a reversal of pitch in the drag-folds in the jaspilite, the pitch changing from south to north. Continuing this axial line beyond this point at which it demonstrably exists, it passes through Boddalin, and produced still further westwards, it would pass in the vicinity of Burgess' Find about 10 miles

south of Burracoppin, just outside the western margin of the gold-field. At Boddalin and Burgess' Find the line crosses small greenstone belts and at both localities gold reefs have been found. Whether the Southern Cross anticlinal cross-fold influenced the geological structure westwards beyond Keane Siding cannot be proved, because at both Boddalin and Burgess' Find, it is difficult to find any outcrops, let alone determine the minor structure in which the gold reefs occur.

General Remarks.—If the evidence submitted above can be regarded as sufficient to establish a general relation between cross-folding and gold deposition, then there are obviously some features of the cross-folding, viz., the dip of the axial planes and the pitch of the folds, about which no information has so far been obtained. Prospects of being able to secure this additional information are not good, on account of the lack of suitable exposures in most of our gold belts. The regional dip no doubt exercises a strong influence on the pitch of a cross-fold, but there are a number of reversals in direction of dip in the beds forming any limb of a major structure and it is not yet known if there is any selectivity of gold deposition based on the direction of dip of the beds in these minor folds. As a result of mine inspection carried out by Messrs. Hobson and Matheson, it can be stated that most of the ore bodies in the western limbs of anticlinal structures dip to the west when the regional dip is to the west, although there are instances of easterly dipping ore bodies in easterly dipping beds within these major western limbs of anticlinal structures. The eastern limbs of anticlinal structures do not carry nearly as many ore bodies as the western limbs do, and in some instances these eastern limbs of anticlinal structures are overturned to the east, or are practically vertical.

The evidence collected during the survey showed that many of the ore bodies occurred in drag-folds in the Greenstone and White-stone Series and that there was a tendency for ore bodies to be arranged *en échelon*. This latter arrangement appears to be the natural distribution of ore bodies formed in steeply pitching drag-folds distributed across an incompetent zone and finally exposed in a more or less horizontal surface. A perusal of the various pitches of the numerous ore bodies examined does not show a uniformity in direction of pitch controlled by the regional pitch of the major geological structure. Rather does it indicate that the pitch of any individual ore body is determined by the pitch of the minor folds in the country rock in its immediate vicinity. The regional pitch does control the pitch of those ore bodies occurring in major drag-folds when these occur near the axes of strong cross-folds, e.g., Nevoria and Burbidge. The direction of pitch of ore bodies occurring in major drag-folds on the limbs of structures influenced by strong cross-folding, but located some distance away from the axis of the cross-fold, may be determined by the direction of regional

pitch. No good examples of this type of control can, however, be quoted unless the Marvel Loch Gold Development Company's Mine at Marvel Loch proves in development at depth to have a southerly pitch.

In the Annual Report of the Geological Survey for 1935 (p. 21), the writer set out what he then thought to be the succession of folding which had influenced the rocks of the Yilgarn System. This conception of the order of folding was made at an early stage in the survey when the distribution of the rock types and the structures were imperfectly known. It now appears that although the main periods of folding were recognised in that report, their probable succession was incorrectly stated.

Throughout this chapter on structural geology, only two periods of folding have been recognised, namely, that along a north-west axis and the other in a direction approximately at right angles, classified as cross-folding. The evidence for the existence of a third period of folding has not been strong, being confined to one definite locality only. Other evidence in support of a third period of folding may exist in the area, but if so, it was not noted during the course of the field work. The locality where this evidence does occur is in a bluff immediately west of the Mountain Queen Mine at Marvel Loch. Here a very steeply pitching drag-fold consisting of many minor folds is exposed in plan and cross section on two joint faces of decomposed rock. The bed in which it occurs is itself drag-folded in a gentle, fairly large fold, the axis of which is nearly horizontal. This indicates that this particular bed has undergone three periods of folding. The axis of this fold of the third period strikes north-west and coincides with the direction of the axis of the major folds.

The influence which this period of folding has had on gold deposition throughout the gold belt has not been definitely recognised in most of the mine workings, if it can be assumed to have had a wide-spread influence. The peculiar behaviour of the gold bearing quartz reefs in the small mines at the Olga Group (see Bull. 99) suggests that the shape of the ore bodies is probably determined by this third period of folding. Mr. R. S. Matheson, who investigated these mines, drew the writer's attention to the fact that the quartz reefs in the "Black Cat," G.M.L. 3716, the "Miner's Dream," G.M.L. 3757, the "Manita," G.M.L. 3717 and the late "King of The Range," G.M.L. 2606, were occurring in southerly pitching drag-folds, that the stope length rapidly diminished in depth, and that the dip flattened in the lowest levels. This leads to the suggestion that a repetition of the structure in which the downward diminishing quartz lenses occur, may be expected below the point at which quartz deposition apparently ceased, and that such recurrences will be found in the direction of pitch. The shape of the ore bodies in the "Bohemia" Mine, G.M.L. 3393, at Donovan's Find, also suggests the influence of this third period of folding.

In conclusion it can be stated that in the area investigated, the distribution of the gold lines and the localisation of gold deposition along these gold lines have been found to be intimately associated with geological structure and that this structure has been largely determined by the principles controlling the deformation of rocks by folding.

CHAPTER V.

ECONOMIC GEOLOGY.

	Page
Introduction	148
The Gold Deposits	148
(a) Nature and Mode of Occurrence of the Auriferous Deposits	149
(b) The Mineral Associations of the Auriferous Quartz	154
Minerals other than Gold	158
Prospecting Recommendations	158

INTRODUCTION.

In this chapter only the broad features of the economic geology of the Area will be dealt with. All of the mines both large and small which were operating during the years 1935 and 1936 were examined by Messrs. Hobson and Matheson during these years, and their reports on the detailed economic geology of the Area are contained in G.S.W.A. Bulletins Nos. 98 and 99. Much of the information contained in this chapter is the result of their work.

THE GOLD DEPOSITS.

Gold is the only mineral which has been extensively mined in the Area and is also the only one so far known to occur in payable quantities. It has been found associated with quartz in the free state, and also with metallic sulphides such as arsenopyrite, pyrite and pyrrhotite in quartz reefs in the rocks of the Yilgarn System.

Only a very small quantity of gold has been obtained from alluvium and this is the more remarkable when the wide distribution of the auriferous quartz reefs is taken into consideration. Up to the end of 1936 a total production of 546,999 ounces of fine gold represented the yield from this part of the Yilgarn Goldfield, and of this, only 2,965.3 fine ounces came from doliied, alluvial and specimen gold, the balance being obtained from amalgamation and cyanidation of 1,309,636 tons of ore mined from auriferous quartz reefs. (For Production Figures see Chap. I., page 23.)

The deepest workings of any mine do not exceed 480 feet vertical depth, and much of the mining activity has been confined to depths seldom exceeding or even reaching 200 feet below the surface. A great number of the quartz reefs are of a small, lenticular nature, and the auriferous belts have a liberal distribution of old abandoned workings in them. Gold reefs have been found in some portion of almost every belt of country formed of rocks of the Yilgarn System, and in one instance, at Forresteria, gold reefs occur in a granitic gneiss.

The origin of the mineralised quartz reefs is assumed to be intimately connected with a granitic magma which has intruded the folded rocks of the Yilgarn System as batholiths, and which outcrops as bare isolated hills in the country adjacent to the gold belts.

The average grade of the gold-ore mined to date is low (8.3 dwt. per ton) though occasional smaller rich reefs occur in which values of one ounce and more per ton are obtained. The two largest mines in the district are situated at Southern Cross and Marvel Loch, and the largest present producer of gold is the Yellowdine Gold Development Company's mine at Mt. Palmer. No mine is treating more than 6,000 tons of ore per month, and with the exception of the main mine at Mt. Palmer continuation of production from the larger mines is dependent on the maintenance of the enhanced price of gold which has been ruling over the last few years. The average grade of the ore mined by the Yellowdine Gold Development Company at Mt. Palmer has been about 15 dwt. per ton, and with the exception of the small mines at Edward's Find and the "May Queen" mine, is the highest grade ore being worked in the Area.

(a) *Nature and Mode of Occurrence of the Auriferous Deposits.*

(1) *The Alluvial Deposits.*—Only 2,965 ounces of gold have been reported as coming from alluvial deposits, and of this amount approximately 1,614 ounces were obtained from a small patch of alluvium on the western shore of the salt lake immediately east of the main mine at Mt. Palmer. The material from which this gold was obtained is not, in a strict geological sense, alluvium since it consists of unsorted angular fragments of greenstone and quartz of varying dimensions forming a scree-slope deposit on and at the foot of the eastern slope of a hill. Old alluvial workings on the western shore of Lake Polaris south-east of Southern Cross have a similar origin, and most of the other localities where the balance of the alluvial gold production must have come from are of a similar nature. The old workings in New Zealand Gully south-west of Southern Cross were in true alluvium, where the dry bed of a short shallow water course has been worked. There do not seem to have been any areas of any size which have been worked by "dry-blowers" or "shakers."

At Marvel Loch and Burbidge gold appears to have been found in lateritic formations overlying decomposed beds of vertical dipping metamorphic sediments at the old Mountain Queen Mine and at the Great Victoria Mine respectively. This must have been detrital gold, but no information is available now as to the manner of occurrence of the gold in the lateritic material.

(2) *The Reef and Lode Deposits.*—The Reefs are lenticular masses of quartz enclosed by rocks of either the Greenstone or Whitestone Series, and in one instance by a gneiss of granitic composition. The gold occurs in the quartz either in the free state or in association with

such mineral sulphides as pyrite, pyrrhotite arsenopyrite and galena. In the majority of mines so far worked, both large and small, the gold has been recovered almost entirely by amalgamation processes only, showing that most of the gold occurs in the free state. The values within any ore body are not uniform, but occur in shoots of varying dimensions, and frequently pitch either flatly or steeply in the direction of the strike. The dimensions of the quartz bodies vary from a few inches in thickness to as much as 20 and more feet, but this latter width is exceptional, and most of the reefs seldom attain a thickness of 6 feet. They are lenticular both along the strike and in the direction of the dip, and some ore bodies consist of successive lenses of quartz separated by short stretches of country in which only a thin stringer of quartz occurs.

Several ore-bodies which are exposed only in the oxidised zone have the characteristics of lodes, *i.e.*, they represent shear zones in which a considerable width of the country rock appears to have been mineralised by gold-bearing solutions, enabling the decomposed rock to be mined as an ore.

In most instances of this type it was noted that the rock being mined was more or less veined with a network of parallel or anastomosing veinlets of quartz. Sometimes the veinlets were so thin as to be easily missed on casual examination, but the universal presence of quartz in either greater or less amount in all material being mined as gold-ore leads to a conclusion which can be arrived at in few words, namely, "No quartz, no gold."

It is in these lode formations that the influence of enrichment by circulating meteoric waters is particularly noticeable in the oxidised zone. There is an erratic distribution of values within them, and the occurrence of "paint-gold" deposited in joint surfaces and minor fault planes is indicative of the secondary nature of this gold. Most of the ore-bodies occurring in the jaspilite bands can be classified as lodes, and in every instance where these formations are being worked quartz stringers and veinlets are found to be present.

The manner in which the gold-bearing quartz has been introduced into the host rocks has not been investigated. How much of it represents the infilling of pre-existing openings, or to what extent the quartz reefs have been formed by the metasomatic replacement of the country rock is a problem which would entail much petrological and chemical research. The ore-body in the old Fraser's Mine at Southern Cross shows some evidence of the formation of the quartz reefs by the metasomatic replacement of a hornblende schist, and the occurrence of "horses" of mullock in other reefs may suggest a similar origin for them. It has not been possible to investigate the so-called lode formations below the oxidised zone since none of them have been worked below that zone. Investigations into the occurrence of primary gold deposition in the country rock with the absence of quartz veinlets have

not been practicable on this account, and the distribution of gold in kaolinitic material in the decomposed lode formations has been attributed to solution and redeposition of primary gold contained in the quartz.

In the hard schistose greenstone rocks, the ore bodies are mainly quartz reefs, but in the metamorphosed sedimentary bands interbedded with the greenstones or in the beds of the Whitestone Series, the ore bodies are frequently zones of decomposed schistose rock such as biotite schist, graphitic schist, etc., liberally impregnated with thin quartz veins.

Quartz reefs also occur under these circumstances, but are much less frequent in occurrence than the lode type.

The factors influencing the distribution and localisation of auriferous quartz deposition have been discussed in Chapter IV. where it will be seen that geological structure has played an important part in determining both the shape and manner of occurrence of the quartz reefs. Broadly, the reefs and lodes are found near the axial planes of the folds in tightly folded schistose greenstones or metamorphosed sedimentary beds, or occur in drag-folded structures associated with the folding. With few exceptions they have a strike and dip coincident with that of the enclosing schistose rock, and their pitch, when they occupy dragfolds is the same as that of the dragfold. Occasionally, quartz reefs whose strike is oblique to that of the regional schistosity have been mined, but this type of ore-body has been definitely recognised in only two small mines.

Each small mine has its own peculiar structural features and no generalised statement applicable to all ore-occurrences can be made. It can be said, however, that investigations into the geological structure of the southern portion of the Yilgarn Goldfield show that the shape and distribution of the ore-bodies are entirely controlled by the principles of folding, and that theoretically, under these conditions, parallel or sub-parallel gold-lines can be expected to occur. The repetition of folded structures in depth can also be anticipated in general, but whether or not these repeated structures carry quartz veins can only be ascertained by exploratory boring.

In the table on page 152 the various types of ore-bodies occurring in the Greenstone Series, the Whitestone Series, and in gneiss are set out.

The reefs and lodes of the Greenstone Series are confined mainly to an horizon of incompetent greenstone beds with which is associated one or more beds of jaspilite, and occur mostly within one mile of the junction of the greenstone with either granite or gneissic rocks of a granitic composition. The deposits in the Whitestone Series are confined to those portions of the rocks which have been involved in cross-folding of a fairly intense order, or where they occur along or near the axial planes of major folds.

TABLE SHOWING CLASSIFICATION ACCORDING TO MANNER OF OCCURRENCE OF TYPICAL ORE BODIES FOUND IN THE YILGARN SYSTEM.

Rocks in which Ore-Body Occurs.	Nature of Ore Body.	Locality.
<p>GREENSTONE SERIES (mainly schistose and massive amphibolite rocks with bands of metamorphosed erosion sediments)</p>	<p>Quartz reefs in schistose greenstone showing some evidence of formation by metasomatic replacement; strike and dip of reef coincident with that of schistosity</p>	<p>Fraser's Reef, Southern Cross.</p>
	<p>Quartz reefs in schistose greenstone; strike and dip coincident with schistosity</p>	<p>May Queen Mine (near Marvel Loch).</p>
	<p>Quartz reefs in massive greenstone; strike oblique to the regional schistosity</p>	<p>"Battler" G.M.L. 3667, South-East of Southern Cross.</p>
	<p>Quartz reefs in schistose greenstone; strike oblique to schistosity</p>	<p>"Mussolini" G.M.L. 3434, Donovan's Find.</p>
	<p>Quartz reefs in greenstone at the junction of greenstone and metamorphosed sedimentary band; strike coincident with schistosity</p>	<p>"Gentle Annie" G.M.L. 3472, Marvel Loch.</p>
	<p>Quartz reefs in dragfolds in schistose greenstone. Reef assumes shape of dragfold</p>	<p>Yellowdine Gold Development, Ltd., Mt. Palmer.</p>
	<p>Lode material with quartz stringers in schistose greenstone; strike and dip coincident with schistosity</p>	<p>Marvel Loch Gold Development N.L., Marvel Loch.</p>
	<p>Lode material with quartz stringers in metamorphosed sedimentary beds interbedded with schistose greenstone; strike and dip coincident with schistosity</p>	<p>Late "L.S.D." Lease, Parker's Range.</p>
	<p>Lode material with quartz stringers at the junction of greenstone and metamorphosed sedimentary bands; strike and dip coincident with schistosity</p>	<p>Marvel Loch Gold Development N.L., Marvel Loch.</p>
	<p>Lode material with quartz stringers in contorted jaspilite bands; strike and dip coincident with schistosity</p>	<p>Nevoria Gold Mines, Ltd., Nevoria.</p>

<p>WHITESTONE SERIES (mainly metamorphosed erosion sediments with bands of greenstone)</p>	<p>Quartz reefs in metamorphosed sedimentary bands ; strike and dip coincident with schistosity Quartz reefs in greenstone bands ; strike and dip coincident with schistosity Lode material with quartz stringers in metamorphosed sedimentary band ; strike and dip coincident with schistosity Lode material and quartz stringers in thin interbedded greenstone and metamorphosed sedimentary bands ; strike and dip coincident with schistosity Lode material with quartz stringers forming dragfolds in a band of metamorphosed sediments ; the lode assumes the shape of the dragfold</p>	<p>“Jaccoletti South” G.M.L. 3542 Marvel Loch. G.M.L. 12 P.P., Edwards’ Find. Old Mountain Queen Mine, Marvel Loch. Old Transvaal Mine, Greenmount. Great Victoria Mine, Burbidge.</p>
<p>GNEISS (of doubtful origin but of granitic composition)</p>	<p>Quartz reefs in granitic gneiss ; strike and dip coincident with gneissosity</p>	<p>Forrestonia.</p>

The structural features of the various reefs and lodes examined in the Area are discussed in G.S.W.A. Bulletins Nos. 98 and 99, and suggestions are made there for the future prospecting of the various ore-bodies.

(b) *The Mineral Associations of the Auriferous Quartz.*

In most of the mines examined, mining operations were confined to the oxidised zone, but in those mines in which unoxidised country rock could be examined it was noted that there was no noticeable introduction of carbonates or iron sulphides into the wall rocks associated with quartz reefs, nor was there any bleaching of these rocks. The chief alteration was the development of biotite mica in the amphibolite schists near the margins of the quartz bodies, and the introduction of veinlets of silica.

No detailed chemical or petrological investigations into the progressive alteration in the country rock in the vicinity of quartz reefs was undertaken, but every endeavour was made during the survey to secure information about the nature of the mineral sulphides and other metallic minerals associated with the auriferous quartz. With the exception of one instance (The "Transvaal") none of the ore-bodies seen below the oxidised zone could be classified as pyritic ore-bodies, the sulphides in all cases constituting only a very minor part of the ore, the greater portion being massive quartz.

In the hope of contributing some facts having a bearing on the distribution of associated metallic minerals with respect to geological conditions the following tabulated information concerning the mineral associations of some of the auriferous ore-bodies of the Area is given. In the table the mining groups are arranged as near as possible in geographical order from north to south. (See table pages 155-157.)

Many scattered references to minerals associated with gold reefs in the Yilgarn Goldfield are contained in G.S.W.A. Bulletins Nos. 49, 63 and 71. The information available concerning the associated minerals is not sufficiently complete to enable an analysis of the occurrences to be made, but it may be significant that as far as the mines which were examined in the southern part of the Yilgarn Goldfield were concerned, the presence of arsenopyrite in small quantities in the quartz usually denoted a fairly high concentration of free gold in the quartz. The quartz reefs at Edward's Find and Mt. Palmer contain arsenopyrite, and the ore bodies at these two centres are considerably higher in grade than those at any other centre in the Area. In the main mine at Marvel Loch the presence of tourmaline in the quartz frequently indicates a high gold content. The presence of arsenopyrite in the ore body, however, does not always indicate a high gold content, since at the "Transvaal" mine near Southern Cross a highly pyritic ore body containing much arsenopyrite is only a low grade gold ore.

Pyrite and pyrrhotite appear to be the chief sulphides with the widest distribution, being associated with auriferous quartz in practically every ore body exposed below the zone of oxidation.

TABLE SHOWING SOME MINERAL ASSOCIATIONS OF AURIFEROUS QUARTZ IN SOME OF THE MINES OF THE YILGARN GOLDFIELD SOUTH OF THE GREAT EASTERN RAILWAY.

Group.	Mining Tenement.	Type of Ore Body.	Mineral Associations.
Southern Cross	Late "Fraser's" G.M. ...	Quartz and lode material in greenstone	Iron oxides, pyrrhotite and pyrites.
Southern Cross	"Three Boys" G.M.L. 3444...	Jaspilite lode material with quartz stringers	Chalcopyrite, biotite, actinolite.
New Zealand Gully	"Queen Ann" G.M.L. 3473 ...	Quartz reef in greenstone near junction with metamorphosed sedimentary band	Pyrite or pyrrhotite.
New Zealand Gully	"Tarcoola" G.M.L. 3802 ...	Quartz reef in greenstone	Pyrite or pyrrhotite.
Greenmount	Late "Transvaal" G.M. ...	Lode material with quartz stringers in thinly interbedded greenstone and metamorphosed sediments	Arsenopyrite.
Kennyville	P.A. 4682	Jaspilite lode with quartz stringers	Hematite.
Blackbourne's Find	P.A. 4428	Quartz reef in greenstone	Iron sulphides.
Mt. Rankin	"No Trumps" G.M.L. 3555 ...	Jaspilite lode material with quartz stringers	Iron oxides.
Battler	"Battler" G.M.L. 3667 ...	Quartz reef in greenstone	Pyrite.
Glendower	"Evelyn Molly" G.M.L. 3512	Jaspilite lode material with quartz stringers	Iron oxides.

TABLE SHOWING SOME MINERAL ASSOCIATIONS OF AURIFEROUS QUARTZ IN SOME OF THE MINES OF THE YILGARN GOLDFIELD SOUTH OF THE GREAT EASTERN RAILWAY—*continued*.

Group.	Mining Tenement.	Type of Ore Body.	Mineral Associations.
May Queen	" May Queen " G.M.L. 3459 ...	Quartz reef in greenstone	Arsenopyrite, pyrite and chalcopyrite (?).
Palmer's Find	Yellowdine Gold Dev., N.L. ...	Quartz reef in greenstone	Arsenopyrite, pyrrhotite, pyrite.
Marvel Loch	" Alexander " G.M.L. 3642 ...	Lode material in greenstone	Chromite, magnetite, ilmenite limonite.
Marvel Loch	Marvel Loch Gold Dev., N.L.	Quartz and lode material in greenstone	Tourmaline, chalcopyrite, pyrite, arsenopyrite and pyrrhotite (?).
Jaccolletti	" Gentle Annie " G.M.L. 3472	Quartz reef in greenstone near junction with metamorphosed sedimentary band	Jarosite.
Jaccolletti	" Lenodo " G.M.L. 3431 ...	Quartz reef in greenstone	Pyrrhotite, arsenopyrite.
Jaccolletti	Late " Mountain Queen " mine	Lode material with quartz stringers in metamorphosed sediments	Garnet, pyrrhotite, graphite.
Donovan's Find	" Mussolini " G.M.L. 3434 ...	Quartz reef in greenstone	Sulphides reported.
Donovan's Find	" Salvation " G.M.L. 3382 ...	Quartz reef in greenstone	Sulphides including arsenopyrite.
Donovan's Find	" Bohemia " G.M.L. 3393 ...	Quartz reef in greenstone	Sulphides including arsenopyrite.
Nevoria	Nevoria G.M. Company ...	Jaspilite lode material with quartz stringers	Pyrrhotite, garnet.

Burbidge	"Great Victoria" G.M.L. 3480	Lode material in metamorphosed sedimentary band	Limonite, marcasite.
Edward's Find	"Sunshine" G.M.L. 12 P.P....	Quartz reefs in greenstone ...	Sulphides including arsenopyrite.
Harris' Find	"New Hope" G.M.L. 3702 ...	Quartz with lode material in greenstone	Iron sulphides.
Harris' Find	Voided P.A., 35 chains north of G.M.L. 3702	Quartz reef in greenstone	Arsenopyrite.
Centenary	"Centenary" G.M.L. 3520 ...	Quartz reefs in greenstone ...	Vanadinite, some biotite and orthoclase.
Olga	"Miner's Dream" G.M.L. 3757	Quartz reef in greenstone	Pyrite and probably other sulphides.
Holleton	P.A. 4579	Quartz and lode material in greenstone	Pyrrhotite and pyrite.
Holleton	"North End Exd.,"	Quartz reef in massive greenstone	Pyrite (?).

MINERALS OTHER THAN GOLD.

Small quantities of arsenical concentrates and tin-oxide have been produced from the Transvaal Mine near Southern Cross and from Holleton respectively, but no official records of the quantities are available. These are the only two metallic minerals other than gold which have so far been found in payable quantities, and gold is the only mineral being mined for at the present time (August 1937). Travertinous limestone deposits have been worked in the past on leases situated about 2 miles south-east of Southern Cross.

During 1935 an attempt was made by some private persons to make bricks from a clay derived from weathered amphibolite schist, graphitic schist and phyllite bands obtained in a pit north of the old dam-site in New Zealand Gully. The quality of the bricks did not come up to expectations and the venture was soon abandoned.

There are no known workable deposits of magnesite in the Area, although there is a considerable quantity of this material scattered about the bouldery greenstone hills to the south of Southern Cross.

On the western shore of the salt lake system east of the 13 mile peg on the Yellowdine-Parker's Range Road there are thin deposits of detrital andalusite gravels resting on exposed andalusite schists in which numerous large crystals of andalusite can be seen. The andalusite can be collected by scraping it together with a shovel, and considerable quantities of the mineral could be obtained by treating the weathered andalusite schists by crushing and concentration. Andalusite is essentially an aluminium silicate with a high melting point, and could be used for purposes where a high grade refractory material was required.

The numerous outcrops of jaspilite are potential iron ores of varying purity, at least as far as their outcrop portions are concerned. Their nature in depth has not been ascertained except in one instance, when the iron content appeared to have materially diminished. The Mount Caudan Lode at Parker's Range outcrops as a hill of limonite (goethite) with an admixture of manganese oxide. Bores revealed the presence of a pyritic ore body below this outcrop some 70 feet in width consisting mainly of pyrrhotite. This occurrence constitutes a potential source of sulphur ore. Detailed particulars of the outcrop, assays, bore-logs, etc., of the Mt. Caudan Lode are contained in G.S.W.A. Bulletin No. 63.

PROSPECTING RECOMMENDATIONS.

The well known fact that the greenstone belts are the chief host rocks of the auriferous quartz reefs and lodes throughout the Eastern Goldfields of Western Australia has been amply substantiated in its application to the gold occurrences in the southern portion of the Yilgarn Goldfield. The other well established fact, that the auriferous deposits also occur in these greenstones at distances of up to one mile or more from the contact of the greenstones with either granite or

gneissic rocks of a granitic composition is also true in this Area. A general recommendation can therefore be made that auriferous deposits are most likely to be found in the greenstone belts of the Area within the limits outlined above, and that all greenstone belts are possible carriers of gold reefs.

The structural control of ore deposition as outlined in previous sections of this Bulletin makes it possible to strongly recommend the procedure of lateral prospecting both on the surface and underground from known ore bodies. In the case of a new "find," it is advisable to seek for new ore-bodies in a direction at right angles to the strike as well as along the gold line.

A useful guide to the probable pitch of an ore-body is to be found in the pitch of minor folds which may be observed in the wall rocks in the initial stages of opening up a mine. Recognition of this probable relation should greatly aid the setting out of a development programme for any new mine where these pitching folds can be seen.

Auriferous deposits have been found in the metamorphosed sedimentary beds of the Whitestone Series, and these rocks are therefore also potential sources of gold deposits. The most likely localities in which to look for gold in the rocks of this series are where they are traversed by the axes of the major folds shown on Plate II.

The exact nature of much of the country underlain by the sand plains is not known, and it is suggested that any drainage channels found in these areas should be carefully examined for detrital gold.

Surface prospecting operations on this field must be very largely confined to methods involving the extensive use of loaming, and in most of the localities suggested below, it will be found the only practicable means of testing. The following localities are suggested as being those most favourably situated for the possible occurrence of gold:—

- (1) The country south-westwards from Lenneberg's Find between that locality and the old Southern Cross—Marvel Loch Road.
- (2) The country for half a mile west of the 15½ mile position on the Yellowdine-Parker's Range Road. The most southerly turning point of the Nevoria Jaspilite should be situated somewhere in this vicinity, but a thick mantle of soil covers the flat country here.
- (3) The northern end of the belt of mica schists, etc., in which Harris' Find (Mundy Hills) is situated.
- (4) The country between Nevoria and Burbidge adjacent to the axis of the Nevoria Synclinal cross-fold shown on Plate II.
- (5) The jaspilite band occurring at Parker's Range, Toomey's Hills and Magowan's Find must curve round in an anti-clinal nose somewhere about 1 to 2 miles east of the 20

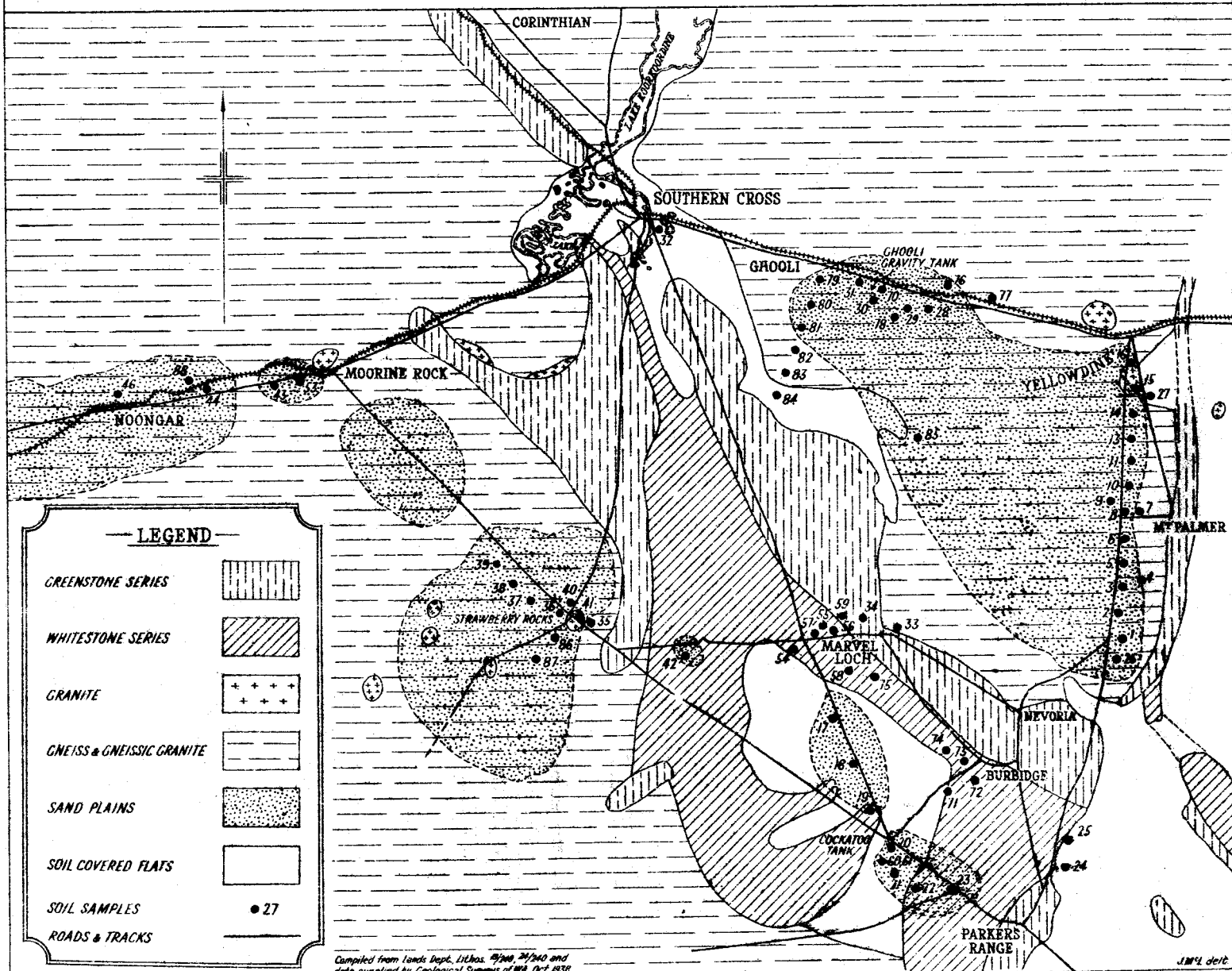
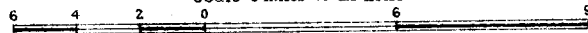
mile peg on the Yellowdine-Parker's Range Road, and this flat soil covered area is worth prospecting in this locality.

- (6) At about one mile south from the Main Parker's Range dam a track turns east from the main road, and after crossing some lake country a short distance in, follows a general easterly direction across heavily forested, flat, red sandy soil-covered country. At from 13 to 14 miles in along this track the south easterly continuation of the Harris' Find country is encountered, and this belt is worthy of prospecting in this vicinity and to the south-east.
- (7) The country for one mile west and parallel to the Olga and Dulcie lines of leases, south of Parker's Range.
- (8) The narrow belt of greenstone running from Boddalin south-eastwards to Sandalwood Rocks, a length of some 25 miles. This is a difficult belt to trace and guides to its occurrence may be found in the following places:—
 - (a) Near the S.W. corner of Location 492. (Lands Department Litho 23/80.)
 - (b) Near the N.W. corner of Location 340. (Lands Department Litho 23/80.)
 - (c) Near the S.W. corner of Location 334. (Lands Department Litho 23/80.)
 - (d) Near the S.E. corner of Location 498. (Lands Department Litho 23/80.)
 - (e) Near the S.E. corner of Location 516. (Lands Department Litho 23/80.)
- (9) Locations 473 and 474 on Lands Department Litho 23/80 consist largely of greenstone, and as this is a newly mapped patch of possible gold bearing country it should be worth investigating.
- (10) There is some evidence to support the conception that the axis of an anticlinal cross fold passes through Kennyville in a S.W. by westerly direction a little to the south of Greenmount. The country adjacent to a line drawn through Kennyville and say the old Government Dam on the Southern Cross-Strawberry Rocks Road should be prospected.

In G.S.W.A. Bulletins Nos. 98 and 99, Messrs. Hobson and Matheson have, whenever possible, made suggestions for the further prospecting of ore deposits in the mines which are dealt with in their reports.

GEOLOGICAL MAP
OF
SOUTH CENTRAL PORTION OF YILGARN GOLDFIELD
Showing Approximate Distribution of Sand Plains & Positions of Soil Samples Examined

Scale 6 miles to an inch



APPENDIX.

SAND-PLAIN SOILS FROM THE YILGARN GOLDFIELD.

By Dorothy Carroll, Ph.D., D.I.C., Department of Geology,
University of Western Australia.

CONTENTS.

	Page
Introduction	161
Topography and Geology—	
Topography	162
Geology :	
Basement Rocks	163
Superficial Deposits and Soils	164
Examination of the Sand-Plain Soils—	
Mechanical Analysis	164
Mineralogical Examination	166
Mineralogy of the Soils	166
Description of the Individual Minerals	
A. Heavy Fraction	167
B. Light Fraction	171
Source of the Heavy Residues	173
Significance of Results of Investigation	175
Acknowledgments	180

SAND-PLAIN SOILS FROM THE YILGARN GOLDFIELD.

INTRODUCTION.

In the south-west of Western Australia there are many flat expanses covered with sandy soils to which the name "sand-plain" is generally applied. These plains are of two distinct types—inland and coastal. Inland sand-plains usually occur on the higher portions of the gently undulating tableland which forms the "Great Plateau of Western Australia."¹ Their origin has been variously explained: some observers consider them to be the remains of sand dunes now levelled by the wind; others, that they are soils derived from granite—whence it comes that large areas south of Lat. 28° S. have been coloured as "granite and gneiss" on geological maps of the State; others again, consider that these sand-plains are the remains of soils of the podsol type, which were formed in some previous epoch.

It occurred to me that study of the heavy minerals (those with a specific gravity of 2.9 or more) contained in the soils might help in the geological mapping of sand-plain areas and throw some light on their origin.

This investigation places on record the results of examining soils from the inland type of sand-plain from the Yilgarn goldfield of which Southern Cross (119° 20' E. 31° 15' S.) is the economic centre. Samples representative of about 1,000 square miles (*Text figure 11*)

¹ J. T. Jutson, *The Physiography of Western Australia*, Bull. 95, W.A. Geol. Survey, p. 3. 1934.

were collected from the southern portion of goldfield with the co-operation of officers of the Geological Survey, particularly Messrs. H. A. Ellis and R. A. Hobson.

In order to get representative samples a series of traverses across several large sand-plains was made, and soils were collected* at intervals of one mile along the tracks which cross the plains. As these plains are covered with thick scrub, from 3 to 10 feet high collecting away from tracks was extremely difficult.

TOPOGRAPHY AND GEOLOGY.

Topography.

As mentioned above the Yilgarn goldfield is part of the "Great Plateau of Western Australia" which here is gently undulating and stands at a height of about 1,200 feet above sea-level. The main topographic units of the area are:—

- (1) The lowest part of the country occupied by strings of salt lakes, during the greater part of the year bare clay flats covered with a thin sheet of salt but containing a shallow sheet of water after exceptionally heavy rain. They are, in places, bordered by cliffs up to 30 feet in height.
- (2) A broad belt of slightly higher country running through Southern Cross between Parker's Range in the south and Bullfinch in the north.
- (3) The highest ground, lying east and west of this belt of slightly higher country, occupied by almost level sand-plains.

Owing to lack of a topographic survey, generalisations as to height are a little uncertain but some idea of the range in level may be obtained from the numerous spot-heights which are available for the parts crossed by railways or by the pipe-lines connected with the Mundaring Reservoir. Southern Cross, 1,163 feet may be taken as the level of the salt-lake depressions; Corinthian, 1,306 feet the average height of the belt of slightly higher country; and 1,350 to 1,380 feet the range in height of the sand-plain areas. From these figures it is seen that, although the sand-plains are correctly stated to occupy the highest ground, the difference in level is small, the slopes are gentle, and the topography very "subdued."

The area is generally regarded as an old upraised peneplain which since elevation has had very little chance of renewed erosion, for the rainfall is so scanty that there are no permanent rivers, and the few intermittent streams, although transporting a fair amount of material after rain, cannot effect much change in the general level of the country except to fill the wide shallow valleys slowly with alluvial material from the more elevated parts. Clarke² has suggested that this part of the great plateau owes its plain character to a Miocene submergence

* All samples examined were from the upper 6 inches of the soil profile.

² E. de C. Clarke, A.N.Z.A.A.S. Vol. XXII., 1935, p. 466.

during which aggradation reduced the irregularities whose remains are now the strings of salt lakes representing old partly filled river channels.

Geology.

In describing the mineralogy of the soils of any area it is necessary to consider the geology and to try to determine the relationship between rocks and soils. This is particularly necessary when dealing with a problem such as the sand-plains, for these soils cover large areas which are devoid of rock outcrops, or contain only very few outcrops, so that field occurrence gives practically no clue to their origin.

The Basement Rocks—of the Yilgarn goldfield are of Pre-Cambrian age³ and have been divided as follows:—

Yilgarn System	{	4. Granite, intrusive	
		3. Whitestone Series	Meta-sediments including andalusite- and garnet-schists, slates, conglomerates.
		2. Greenstone Series	Amphibole schists of sedimentary origin, subordinate epidiorites.
		1. Gneiss	A thick series of coarse sediments now changed to gneiss. It appears to form the lowest part of the Yilgarn System.

The Greenstone and Whitestone Series are interbedded and are a conformable series of ancient sediments with a minor development of basic igneous rocks. They are also probably conformable with the gneiss which underlies them but the field relationships are not clear. The gneiss has in many places been intruded by granitic magma; the Greenstones and Whitestones have also been attacked to a small extent by this magma, but it is the gneiss, as the basal member of the system, which has suffered most, being converted in many areas to migmatite. Whether there has been more than one period of granitic intrusion it is not possible to say at present, but the results of this granitisation are similar to those observed in Finland and Norway.⁴

The major structure of the area is a series of folds which strike N.N.W. and pitch S. and have been thrown into cross-folds at right angles to the first folds. The geological map (*Text-Figure 11*) shows that the gneisses form the cores of the antiforms, and there is no haphazard distribution of gneiss as was indicated on the earlier geological maps. The patches of granite, appearing as large "pimples" are the intrusive granite and represent the invading granitic magma. Barth⁴

³ F. G. Forman, *Pres. Add. Royal Soc. W.A.*, Vol. XXIII., 1936-37.

H. A. Ellis, *Ann. Prog. Rep. G.S.W.A.* for 1936, p. 31.

⁴ J. J. Sederholm, *Bull. Comm. Geol. Finland*, Nos. 58, 77, 107.

T. W. Barth, *The large Pre-Cambrian intrusive bodies in the southern part of Norway*, *Geophysic. Lab. Carnegie Instit. Wash.*, paper No. 887, 1936.

has described a similar occurrence as follows: "The areas of solid black on the map, indicating pure granite look much like blots; indeed, the gneiss area may be likened to blotting paper that has sucked up all the granitic juices from below." The areas of granite in the Yilgarn gold-field appear to be of this nature, and are generally of lower elevation than the main part of the country in which they occur. They appear to have been "unroofed" by erosion.

Superficial Deposits and Soils.—Thin beds of grits with small pebbles of quartz and occasionally of felspar have been noticed in places in this area overlying the worn surface of the Pre-Cambrians, chiefly the gneiss.

Other superficial deposits are laterite, nodular travertine, and gypsum.

Ferruginous gravel (laterite) is of frequent occurrence, most usually as a horizontal layer 6 inches to 2 feet below the surface of the sand-plains. It sometimes overlies greenstone, and is then of a different composition, being much more ferruginous and less sandy, but apparently it never directly overlies granite, although it does occur with the grits overlying the gneiss. Nodular travertine, known as "cement" is found in some parts, and is forming under the present climatic conditions above weathered greenstone containing much lime.

Seed gypsum is present on the dry lake surfaces, Lake Seabrook having large and pure deposits.

The *Soils* of this district fall roughly into three groups:—

Red and brown soils in the wide flat valleys.

Pinkish brown sandy loams demonstrably resulting from the weathering of granite.

Yellow sands to sandy loams typical of the sand-plains.

This investigation deals primarily with the sand-plain soils, but several soils of other types were also examined for comparison.

From the point of view of origin soils may primarily be divided into sedentary and transported. Mineralogy of the soils can help in deciphering the obscured rocks only if the soils are sedentary. A consideration of the evidence given below establishes the sedentary character of the sand-plain soils.

EXAMINATION OF THE SAND-PLAIN SOILS.

Mechanical analysis.

Mechanical analyses were made of typical samples by sieving with Tyler screens giving the grade sizes of the Wentworth scale,⁵ i.e., nos. 5, 9, 16, 32, 60, 115, 250.

⁵ C. K. Wentworth, Jour. Geol., Vol. XXX., pp. 377-392, 1922.

The results are plotted as *Text-figure 12* from the following figures:

Grade.	Screen Openings.	Sample Number.					
		17.	22.	24.	2.	42.	39.
	mm.	%	%	%	%	%	%
+5	3.96	...	1.91	0.45	...	1.67	...
+9	1.98	0.05	3.85	2.35	0.56	3.69	0.05
+16	0.99	2.78	3.70	12.93	6.10	1.18	3.27
+32	0.49	20.89	6.88	15.54	22.54	22.90	25.72
+60	0.24	35.95	26.77	24.81	39.35	21.18	32.67
+115	0.12	25.98	34.20	23.58	21.00	25.30	21.50
+250	0.06	10.03	14.82	11.42	6.47	18.37	9.55
-250	...	4.32	7.87	8.92	3.98	5.71	7.26

Note.—Sample 24 is a soil from near Parker's Range, the others are sand-plain soils.

+ Retained on.

These soils are poorly sorted when compared with dune sands or beach sands (*Text-figure 12*) although the bulk of the sand lies between grades 32 and 115. The curves obtained do not fall into any natural

Figure 12

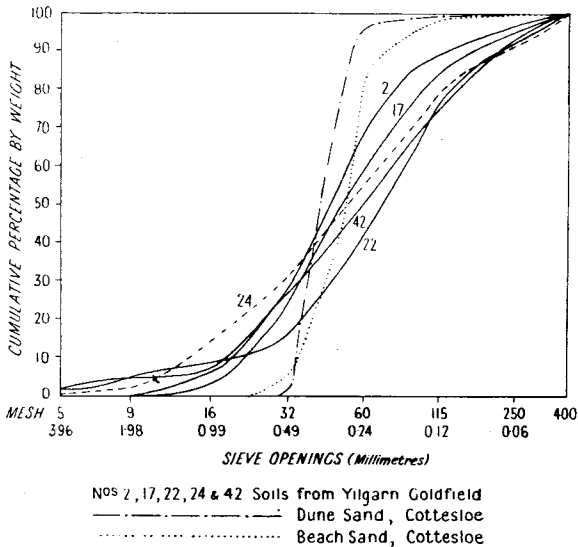


Fig. 12.—Mechanical analyses of some soils from the Yilgarn goldfield. A dune and a beach sand from Cottesloe are added for comparison.

group when compared with Udden's analyses⁶, and this precludes the possibility that the sand-piains are flattened sand dunes, for dunes from any locality have a definite grade of sand grains, that is, they contain only those grains which are easily moved by the average winds⁷.

The small amount of *sorting* which these sands do show is due to the fact that many of them are derived from the ancient metamorphosed sediments the material of which had been sorted during or prior to the deposition which formed these sediments. The occasional *rounding* of quartz grains is satisfactorily explained in the same way.

Mineralogical Examinations.

Mineralogical examinations were made of the finer material, that passing the 60 mesh sieve. Each sample was first washed thoroughly to remove the clay and silt grades, and then boiled for a few minutes in 1 : 1 conc. HCl to remove the colouring matter which obscures the grains and so makes microscopic identification difficult. The grains examined were between 0.24 and 0.12 mm. in diameter, and this size is referred to subsequently as the *Fine Sand*.

The cleaned fine sands were then placed in bromoform to obtain the heavy minerals, i.e., those sinking in the liquid, which are employed for diagnostic purposes. For a number of samples the quantity of "heavy" and "light" minerals was found by weighing. The per cent. by weight of heavy minerals is known as the *Index Figure*. The results are as follows:—

Sample No.	23	76	77	78	79	80	81	82	83	84	85	86	87	88
Index Figure	0.83	0.46	0.15	0.06	0.12	0.12	0.12	0.34	0.30	3.36	0.26	0.28	0.19	0.07

From this it will be seen that, except in sample 84, the quantity of heavy fraction is very small.

The soils being sedentary the vast majority of their heavy minerals will have been derived from the underlying rocks. It was therefore, necessary to know the characteristics of the heavy minerals of the base-ment rocks. To this end a number of representative types were crushed and the heavy minerals separated out with bromoform. By this means a "background" of geology and mineralogy was obtained, for in investigations of this type the examination of the soil mineralogy must go hand in hand with that of the country rocks to attain the most profitable and reliable results.

Mineralogy of the Soils.—A glance at the particulars regarding the heavy fractions obtained shows that more or less the same minerals are to be found in all the soils examined. A closer inspection shows,

⁶ J. A. Udden. Bull. Geol. Soc. Amer., Vol. 25, p. 655, 1914.

⁷ R. A. Bagnold, Geog. Jour. 85, p. 342, 1935; and 89, p. 409, 1937.

however, that the mineralogy of individual soils varies in two important respects: first, the number of grains of each mineral varies from soil to soil; and secondly, the minerals themselves often exhibit characteristic forms and colours. Examples of this variation, known as "poly-varietalism," are found most noticeably in zircon, tourmaline, garnet, and amphibole; less so in andalusite, staurolite, and spinel.

It was found that both the amount and the varieties of the minerals gave important clues as to the origin of these soils.

The following heavy minerals were identified in the fine sands:— ilmenite, magnetite, limonite (labelled opaque grains and not differentiated in the descriptions), various types of amphibole, zircon, tourmaline, rutile, sphene, monazite, and epidote; and the metamorphic minerals, andalusite, staurolite, sillimanite, kyanite, garnet, spinel.

The "key" minerals of these residues, those which are of the most significance when determining the origin of a soil, are andalusite, staurolite, tourmaline, garnet, zircon, rutile, and amphibole; thus:—

Abundance of andalusite and staurolite, with subordinate tourmaline and zircon, and with small though constant amounts of spinel indicate derivation from the Whitestone Series.

Zircon prominent, with rutile, garnet, and amphibole indicates derivation from gneisses or granites. (Gneiss and granite here refers to the areas of undifferentiated gneiss and granite on the map.)

Abundance of amphibole with or without an increased amount of opaque grains, including an increase in magnetite, and subordinate or no andalusite and tourmaline indicates derivation from the Greenstone Series.

The relative abundance of the minerals of the heavy fraction was obtained by counting the numbers of grains of each mineral present in the mounts and expressing the result as a percentage. Usually about 10 to 12 microscope fields, involving about 300 grains, were counted for each sample. The advantages and disadvantages of this method of counting and expressing results have been discussed recently.⁸

Description of the Individual Minerals.

A. Heavy Minerals.

Opaque grains include ilmenite, limonite, magnetite and possibly leucoxene. Of these, ilmenite and limonite are the most abundant. No attempt was made to distinguish between the amounts of the various opaque minerals with the exception of magnetite which was removed with a small electro-magnet. It is usually present only in very small amounts in the sand-plain soils, but in soils clearly overlying greenstone it is much more abundant. Soils overlying greenstone at Marvel Loch were examined in order to make a comparison of the mineralogy

⁸ D. Carroll, Jour. Sed. Petrol., Vol. 8, No. 1, p. 3, 1938.

of the main types of soil in the district. Usually, in any soil examined, opaque minerals make up a large part of the heavy fraction, but in the sand-plain soils the opaques fall to a small figure in comparison with other soils, *e.g.* the fine sand of sample 23, a typical sand-plain soil, contained 24% opaque grains, whereas sample 56, overlying greenstone, contained 81% opaque grains. This variation in percentage of opaque grains is definitely related to origin as has been shown when describing other soils from the neighbourhood of Southern Cross.⁹

Amphibole: In the sand-plain soils amphibole is a very subordinate mineral, but in the soils derived from greenstone it may rise to as much as 50% in the heavy fraction of the fine sand. The amphibole group contains a large number of different varieties of this mineral which differ in chemical composition and optical properties. In the soils of this district, as in the rocks, there are several distinct varieties of amphibole. The most noticeable and that of the widest occurrence is the bluish-green strongly pleochroic variety, with $Z \wedge c = 17 - 22^\circ$, $Z =$ dark green, X and $Y =$ dark bluish green. This can be referred to the pargasite group and is a member of the hornblende series, although the blue coloration indicates glaucophanic tendencies. There are two types of pale green to almost colourless amphibole, one with a small extinction, $Z \wedge c = 13^\circ$ which belongs to the cummingtonite group; and another, with a larger extinction, up to 20° which is a member of the tremolite-actinolite series. Anthophyllite has been noted in some of the soils. Simpson has described anthophyllite and kupfferite (cummingtonite group) from the rocks of this district.¹⁰ All these are types of amphibole which occur in metamorphic rocks. One or two grains of a brownish green amphibole were noted in some of the samples. From the small amount of amphibole in the sand-plain soils it is evident that the Greenstone Series contributed little, if any, material to their formation.

Zircon is a mineral of great diagnostic significance in these soils for if the amount in any soil increases noticeably it is certain that gneiss or granite is at no great distance. It is a conspicuous mineral in many of the residues and occurs in several well-marked habits: small rounded prismatic grains; clear zoned grains; rather squarish grains with inclusions; brownish to purplish zoned grains with many inclusions. From the Range Table (*Text-figure 14*) the amount of zircon is seen to vary considerably, those soils overlying granite containing the most. A heavy fraction of this type of soil is pictured in *B* of *Text-figure 15*. It should be noted, however, that the type of gneiss containing pink garnet contains very little zircon. Soils derived from greenstones and meta-sediments yield only insignificant amounts of zircon in the heavy fraction.

⁹ D. Carroll, *Geol. Mag.*, 1936, p. 503.

¹⁰ E. S. Simpson, *Jour. Royal Soc. W.A.*, Vol. XXIII, 1936-37, p. 19.

Tourmaline is commonly present in all these soils in small amounts. The two most prominent varieties are a medium brown, and a bright blue, dravite and indicolite respectively. Both occur as unworn prismatic grains, although occasional rounded grains have also been recorded. The distribution of tourmaline in the rocks of this district is not completely known, and it is not a plentiful mineral although prospectors have found large rough crystals of schorl. The gneiss and meta-sediments often contain microscopic prisms. In the schist it is probably of metamorphic origin and indicates the effects of emanations from a granitic magma or from a pegmatite. Blue tourmaline appears only to be in the sand-plain soils, and its presence in the heavy residue of a highly weathered slaty rock at the "Great Victoria" confirms its origin in members of the Whitestone Series. Mauve grains and rounded grey grains are found in some soils.

Rutile is usually present in small amounts in these residues in either pale yellow or deep reddish brown grains. It was found that the pale grains were contributed by the gneisses and some types of meta-sediments. Rutile is not a constituent of the greenstones to any marked extent, and this is accounted for by the fact that the majority of these greenstones are metamorphosed basic sediments, thus differing from a number of the Kalgoorlie greenstones which are metamorphosed igneous rocks and do contain rutile. The deep reddish brown grains have the appearance of much abrasion and most probably were detrital grains in the sediments which have now been incorporated in the Whitestone and Gneiss Series.

Sphene is usually in colourless to pale brown angular grains. It is a minor mineral in most of the heavy residues except in one or two samples, *e.g.*, No. 35 from near Strawberry Rocks. It is present in the majority of the granites and gneisses of the district.

Monazite is of sporadic occurrence in these residues. It is in pale yellowish green rounded grains. Monazite has been identified as an accessory mineral of a number of gneisses in the district, particularly in the gneiss outcropping at Southern Cross.

Epidote is also of sporadic occurrence and is never a prominent constituent of the residues. The grains have the usual optical characters.

The Metamorphic Minerals are strongly represented in these soils, *andalusite* being the most prominent. Andalusite is present in nearly every soil examined, and often makes up to 40 to 50% of the heavy fraction of the fine sand. The greatest amount is, as would be expected, in soils overlying andalusite schists and slates, and from this it is certain that those sand-plain soils containing large amounts of andalusite must also be derived from these schists and slates. Andalusite is a minor constituent of some of the gneisses, and hence it is liable to

occur in any of the soils of the district. It is an important "key" mineral for this suite of soils, although its wide-spread distribution in the country rocks somewhat reduces its diagnostic value. Andalusite occurs in colourless prismatic grains a large proportion of which are pleochroic; inclusions are commonly present, and some grains, which have very abundant black carbonaceous inclusions arranged as a core or scattered irregularly within the grain may be referred to chiastolite. All types are prismatic and show no signs of wear.

Staurolite is another prominent member of this metamorphic suite, but is never as plentiful as andalusite. The amount rises to 12% in one heavy residue, but in most of the soils containing this mineral there is 5 to 10%. It occurs in the typical pale yellow-brown strongly pleochroic grains, and sometimes in darker brownish pink grains with sharp angular margins. A rock containing staurolite is a grey graphitic slate outcropping about 1 mile west of Marvel Loch where it is associated with andalusite,¹¹ but from its constant association with andalusite in the soils of the district there must be many more staurolite-bearing schists and slates which up to the present have not been found outcropping.

Sillimanite and *kyanite*, with the usual features of detrital grains, are found in some of the soils but are never plentiful. Sillimanite is in excess of kyanite.

Garnet is of sporadic occurrence, the greatest quantity being in sample 33, a soil directly overlying gneiss with garnetiferous pegmatite intrusions. This soil contains 20% of garnet in the heavy residue. There are two other sources for garnet in this district, (1) the garnetiferous aplites; and (2) the garnetiferous slates and schists. The types of garnet from these rocks have recently been analysed by Simpson.¹² In the slates the garnet is an unstable variety easily altered by weathering, for the weathered slate has a "pock-marked" appearance. It is the garnet from the gneiss and pegmatite, and that from the aplites which persists in the soils. The most striking grains of garnet are those occurring as small euhedra, bright pink in colour, with a brownish interior. This type has previously been recorded by me from soils and gneiss near Hope's Hill, north of Southern Cross. It is evidently of wide-spread occurrence in the gneisses of this district.

Spinel was identified in a number of soils from sand-plains and is of two colours which may indicate two distinct varieties, but the amount of material available is not sufficient for a chemical analysis. These grains may be either deep green and somewhat rounded, or pale bluish green grains. The former is the typical ceylonite or pleonaste found in many sediments, whereas the paler grains may be gahnite, the

¹¹ E. S. Simpson, Ann. Report Chem. Branch Mines Dept. for 1936, p. 10.

¹² E. S. Simpson, Jour. Royal Soc. W.A., Vol. XXIII., p. 17, 1936-37.

zinc spinel. Gahnite has been recorded from Nevada.¹³ It has also been found in schists in one area of similar Pre-Cambrian rocks in Western Australia, viz., the Goyamin Pool area about 40 miles north-east of Perth,¹⁴ and although the spinel obtained in these soils has a similar appearance, it cannot be definitely identified as gahnite without an analysis.

B. Minerals of the Light Fraction.

Quartz is the predominant mineral in this fraction. The grains are angular to rounded in shape, the angular type being in the majority. Some soils have quartz grains with many inclusions, the most conspicuous being rutile and sericite rods, pepper-dust opaque particles, probably iron ores, sometimes air bubbles and minute zircons. The type of inclusions points definitely to metamorphic rock parentage for these grains.

The degree of roundness was worked out for five samples according to the method given by Burt¹⁵ with the following results:—

Sample.	Class.					Total No. of Grains.	Coeff. of Roundness.
	Round.	Sub-round.	Half-round.	Sub-angular.	Angular.		
No. 70	No. 62	No. 45	No. 50	No. 88	No.	245	40.82
No. 18	2	9	41	236	8	296	4.5
No. 42	10	36	83	138	....	267	12.63
No. 1	22	27	85	140	....	274	16.93
No. 64	16	58	91	85	....	250	19.21
Esperance sand-plain	124	156	358	108	9	755	31.72
Dune sand, Bunbury	42	41	147	88	7	325	24.19
Granitic soil, Peak Charles	6	28	109	144	78	375	7.74
Oolitic sand, Nevada	....	....	....	....	....	....	66.10
Dune sand, South California	....	....	....	....	....	....	47.77

The analyses of the dune sands and granitic soil are added for comparison. In order to estimate the degree of rounding the quartz grains are examined under a microscope and grouped into different classes of roundness. The total number of grains of each class is then multiplied by 128, 32, 8, 2, and 1 respectively (after Burt's method), the products added, and then divided by the total number of grains examined. From this table it can be seen that the average roundness of the quartz of the sand plain soil varies, in the fine sand grade, between sub-angular to nearly half-way between sub-rounded and round. Figures between 4 and 20 indicate the degree of roundness to be expected from sedentary soils overlying the parent rock. Over 20 indicates a certain amount of wear and/or sorting in this grade of material. It is noticeable that sample 70 has a very much greater degree of roundness than the other samples from the Yilgarn gold-

¹³ E. S. Simpson, Jour. Royal Soc. W.A., Vol. XVI., p. 31, 1930-31.

¹⁴ E. S. Simpson, Ann. Prog. Report Chem. Branch Mines Dept. for 1936, p. 10.

¹⁵ F. A. Burt, Jour. of Geol., Vol. 35, p. 668, 1927.

field. In the field it was seen to be a drift sand or soil and was one of two or three sand-plain soils which had suffered from wind action.

Considering, however, the fact that some gneisses in this area contain perfectly spherical grains of quartz, it is not altogether justifiable to say that, with the exception of sample 70, the rounding observed in sand grains in these soils was caused by wear and transport while the sand-plains were being formed. The rounding may have been done before the grains were incorporated in Pre-Cambrian times in the sediments which were afterwards metamorphosed, and these grains released by weathering in Kainozoic or later times. Similar types of sandy gneisses of Pre-Cambrian age have been described from America¹⁶, and in the Yilgarn goldfield there are many rocks in which the metamorphism has not been so intense as to destroy the outlines of the original quartz grains; for example, rounded grains surrounded by a rim of new quartz occur in a number of the greenstones, notably from Bullfinch.

Felspar: is a minor constituent of the sands examined and is absent from a number of the samples. The grains are all somewhat altered by weathering and may be coated with a brownish material which is difficult to remove. The refractive index of the felspar is below 1.53 and twin lamellae are not present. Therefore the felspar may be referred to orthoclase. Microcline was not seen, nor was microperthite which is often plentiful in inland West Australian soils.

Clay material: The clay grade of material was washed out of these soils during the preparation of the samples for microscopic examination. A glance at the table of mechanical analyses will show that there is very little clay in these soils. Yellowish brown semi-opaque often rounded grains in the fine sand represent the largest grains of the clay fraction. The refractive index of these grains is much higher than 1.53, probably in the vicinity of 1.60 to 1.63, which indicates that the main constituent of these grains is nontronite. In the finer parts of the soils there are many small angular clear grains of a clay mineral which has a rather lower refractive index and may belong nearer the beidellite end of the nontronite-beidellite series. An interesting feature of the largest grains of this material, i.e., the so-called nontronite, is the presence of numbers of small colourless to pale yellow crystals within the grains. These are exactly similar to the rutile and anatase grains which are found in altered biotite or in chlorite, and their presence here suggests that these clay grains have been formed from the original biotite of the rocks by weathering and soil forming processes.

¹⁶ R. A. Wilson, Sedimentary gneisses of the Salmon River Region near Shoup, Idaho. Jour. Geol., Vol. 45, p. 193, 1937.

Source of the Heavy Residues.—All the heavy minerals found in the sand-plain soils of this district occur also in one or more of its basement rocks. No one mineral is confined to one rock type, e.g., zircon and rutile are found both in gneisses and in meta-sediments; andalusite is in both the meta-sediments and to a smaller extent in the gneisses. It is likely, however, that certain varieties of particular minerals are characteristic of particular rock types, and therefore the "varietalism" of minerals is important in attempting to determine the rock which has yielded the soil of a certain part of the plain—in other words, to determine what rock underlies that part of the plain.

The heavy mineral assemblages of the sand-plain soils are characterised by:—

1. The abundance of andalusite and staurolite, with minor amounts of sillimanite and kyanite.
2. The relatively small quantity of amphiboles, and, in some soils, of the iron ore minerals (opaques).
3. The constant presence of tourmaline, rutile, and zircon; and the sporadic occurrence of garnet, epidote, monazite, and sphene.

Many of these soils occur in situations in which no evidence as to parentage can be obtained, in which, indeed, it is quite uncertain, so far as field evidence goes, whether the soils are sedentary or transported; but a consideration of the various aspects of the mineralogy of these soils shows, in the first place, that these soils are sedentary and, in the second place gives a very definite indication as to the underlying rocks from which the soils have been formed. As was stated earlier in this paper, the presence of abundant andalusite, accompanied as it nearly always is by staurolite, indicates underlying meta-sediments of the Whitestone Series. Where the percentage of zircon has noticeably increased, e.g., from 1% to 10 to 12% it is reasonable to conclude that gneisses and/or granite are the parent rocks of that soil.*

With these points in mind, and realising that there can be no hard and fast line of demarcation between the minerals yielded by some types of the country rocks, I decided to make an easily interpreted diagram of the results of this examination. The heavy minerals were divided on a percentage basis into three groups as follows:—

- A. *Meta-sedimentary minerals* comprising andalusite, staurolite, sillimanite, kyanite, and spinel.
- B. *Greenstone minerals* comprising amphiboles and epidote.
- C. *Granitic and gneissic minerals*, comprising zircon, rutile, garnet, sphene, tourmaline, monazite.

* This statement is true for all the soils of the district, although this paper is primarily concerned with sand-plain soils.

Some of the species in C may actually belong to group A, but their most pronounced occurrence, except perhaps for tourmaline, is in the gneisses or granite.

In this arrangement it will be noted that there is no provision for the opaque grains. In this suite of soils the opaque minerals are less in amount in the soils presumably derived from the meta-sediments and greatest in the soils (not from the sand-plains) overlying greenstones, where this greenstone is not of the amphibole schist type. Bearing this in mind and knowing that opaque minerals occur in all the soils examined, I thought it best to ignore them in making the diagram, so as not to obscure the issue between the minerals of more definite diagnostic value.

The original percentage results had to be re-calculated omitting the opaque minerals, and the new figures were plotted in a triangular diagram with A, B and C (the groups given above) as the poles (*Text-figure 13*). This diagram clearly shows the variation in mineralogy, and through this, the variation in parentage of the sand-plain soils of this part of the Yilgarn goldfield, meta-sediments and gneiss or granite being the end-points of the range.

In order to show the variation in mineral composition of soils across the various sand-plains a Range Table (*Text-figure 14*) was constructed from the percentage results, which, for this purpose, were replaced by Frequency Numbers as used by the Burmah Oil Company.¹⁷

<i>Percentage.</i>	<i>Frequency Number.</i>
90—100	8+
75—89	8
60—74	8—
45—59	7+
35—44	7
28—34	7—
23—27	6+
18—22	6
14—17	6—
7—13	5
4—6	4
2—3	3
1—2	2
½—1	1
one grain only	1*

The Range Table gives diagrammatically the mineralogy of the samples arranged according to the traverses along which the soils were collected. Each soil is represented by a vertical line, and each is, in field occurrence, one mile from the next. As in the triangular diagram (*Text-figure 13*), the soils show a marked variation in mineralogy, and hence in parentage.

¹⁷ Evans, Hayman, and Majeed, Proc. World Petrol. Congress, 1933, vol. 1, p. 251.

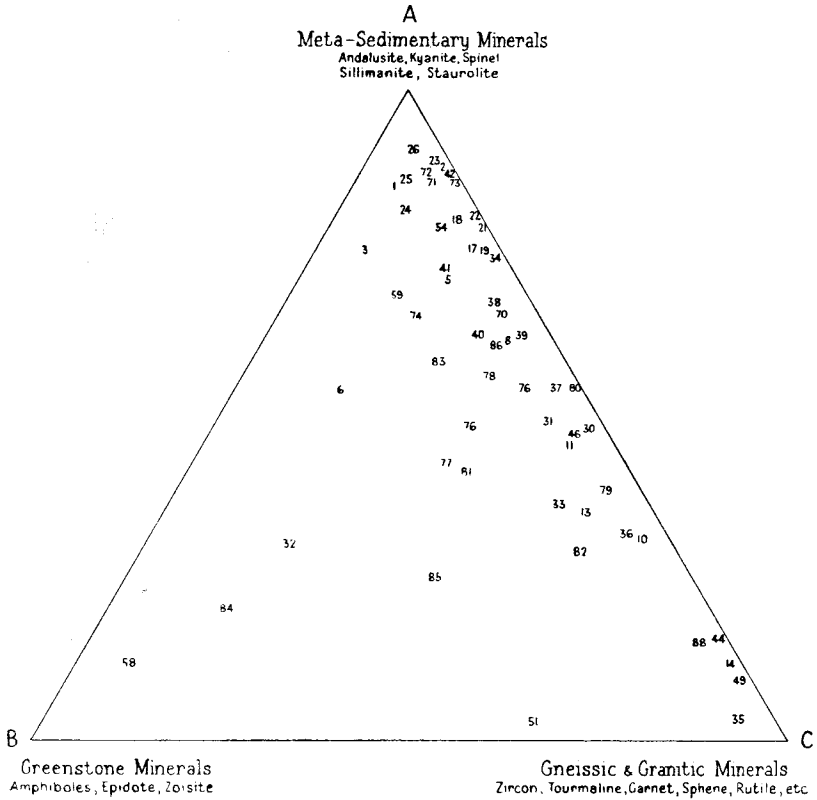


Figure 13

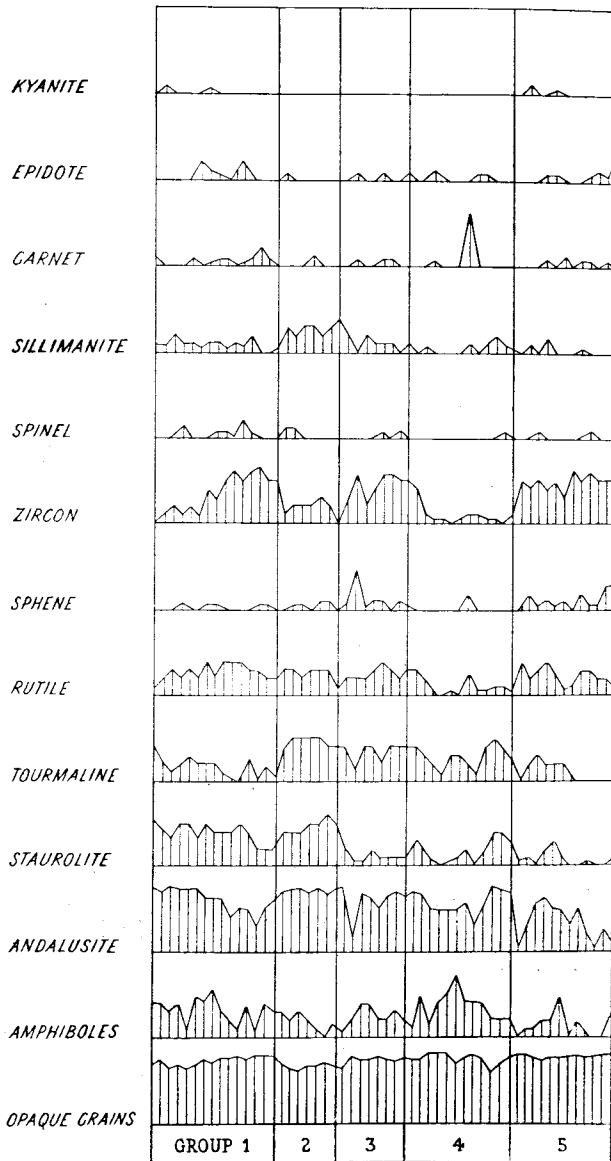
Fig. 13.—Representation of percentage composition of the heavy mineral assemblages of soils from the Yilgarn goldfield. The opaque grains have been excluded from these figures and the remaining heavy minerals calculated to 100%. This triangular diagram shows the range in type of heavy mineral assemblage and hence the range of the rocks contributing to soil formation. For positions of samples see map (fig. 11). Groups of soils from various localities are:—Parker's Range to Yellowdine siding, 24, 25, 26, 1, 2, 3, 5, 6, 8, 10, 11, 13, 14, 15, 16; Marvel Loch to Parker's Range via Cockatoo Tank, 54, 17, 18, 19, 21, 22, 23; Strawberry Rocks area, 42, 35, 41, 40, 86, 87, 36, 37, 38, 39; Marvel Loch to Burbidge, 34, 59, 55, 56, 57, 58, 33, 75, 74, 73, 72, 71; between Ghooli and Burracoppin, 28, 29, 30, 70, 76, 77, 78, 31, 32, 44, 46, 49, 52, 53, 51, 88; between Ghooli and Marvel Loch on Pipe-line, 79, 80, 81, 82, 83, 84.

SIGNIFICANCE OF RESULTS OF INVESTIGATION.

This mineralogical examination of the heavy residues of sand-plain soils reveals first, the fact that the majority of the soils are sedentary, and second, that there are two distinct types in the Yilgarn goldfield:—

1. with a predominant metamorphic assemblage of heavy minerals;

Figure 14
 RANGE TABLE SHOWING VARIATION IN PERCENTAGE COMPOSITION
 OF HEAVY MINERAL ASSEMBLAGES
 Samples Arranged According to Locality



Explanation.—In this Range-Table the percentage of each mineral in each heavy fraction is shown as a frequency number, and each of these numbers is represented by one-tenth of the distance between the horizontal lines. Each vertical line represents a soil sample. The groups are soils along a particular traverse, thus:—Group 1 (reading from left to right): Samples 25, 26, 20, 1, 2, 3, 5, 6, 8, 10, 11, 13, 14, 15, 16. From Parker's Range to Yellowdine Siding. Group 2: Samples 54, 17, 18, 19, 21, 22, 23. Marvel Loch to Parker's Range via Cockatoo Tank. Group 3: Samples 42, 35, 41, 40, 36, 37, 38, 39. Strawberry Rocks Area. Group 4: Samples 34, 59, 55, 56, 57, 58, 33, 75, 74, 73, 72, 71. Marvel Loch to Burrbridge. Group 5: Samples 28, 29, 30, 70, 31, 32, 44, 46, 49, 52, 53, 51. Between Ghooli and Burracoppin.

2. with a predominant granitic and/or gneissic assemblage of heavy minerals.

These two types are illustrated by *A and B of Text-figure 15*, photomicrographs of samples 23 and 88 respectively. (The position of every sample is shown on the map, *Text-figure 11*.)

Samples 1, 2, 5, 8, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 34, 38, 39, 40, 41, 42, 54, 70, 71, 72, 73, 78, 86 belong to group 1.

Samples 10, 11, 13, 14, 30, 33, 35, 36, 37, 44, 46, 49, 51, 80, 82, 87, 88, belong to group 2.

The sample-numbers omitted from these lists are those of greenstone soils or of soils of rather intermediate "mixed" parentage. Several of the latter type were collected for comparison.

As stated in the *INTRODUCTION* this work was undertaken with two objects—first to help in mapping; second, to determine the origin of the sand-plains.

If one consults the map (*Text-figure 11*) it is apparent that, from the position where samples of these two types of sand-plain were collected, considerable additional information is available for the completion of the geological map, for the heavy minerals indicate that either the Whitestone series or granite and/or gneiss underlies these plains. From this information many areas, as for example, that between Cockatoo Tank and Parker's Range, or the large area between the road to Strawberry Rocks and Cockatoo Tank, can be filled in with the Whitestone series. These areas are at present left blank on the geological map, and these are the areas in which, from structural evidence, one would expect to find just those types of rock whose presence beneath the plains is revealed by this investigation. Therefore the structural lines can be extended across these plains with certainty, and this enables the rocks beneath the plains to be added to the now incomplete geological map.

That there are some drift sands and soils cannot be denied, but that many red soils, not occurring on sand-plains (e.g. no. 54), and white to yellowish brown sand-plain soils have been derived from the same series of rocks is evident from the heavy residues.

And now we come to the second object of this investigation: the proving of the nature and origin of these sand-plains in the Yilgaru goldfield. From field evidence it appears that the sand-plains are true sandy soils of a fossil or residual character, owing their formation to some process not now in operation. The difficulty of explaining the formation of these soils under arid conditions was first recognised by Prescott¹⁸, who realised that the lateritic layer below the sandy soil gives the evidence that these soils are podsoils which developed in a damp climate.

¹⁸ J. A. Prescott, Bull. 52, C.S.I.R. (Austr.), 1931.

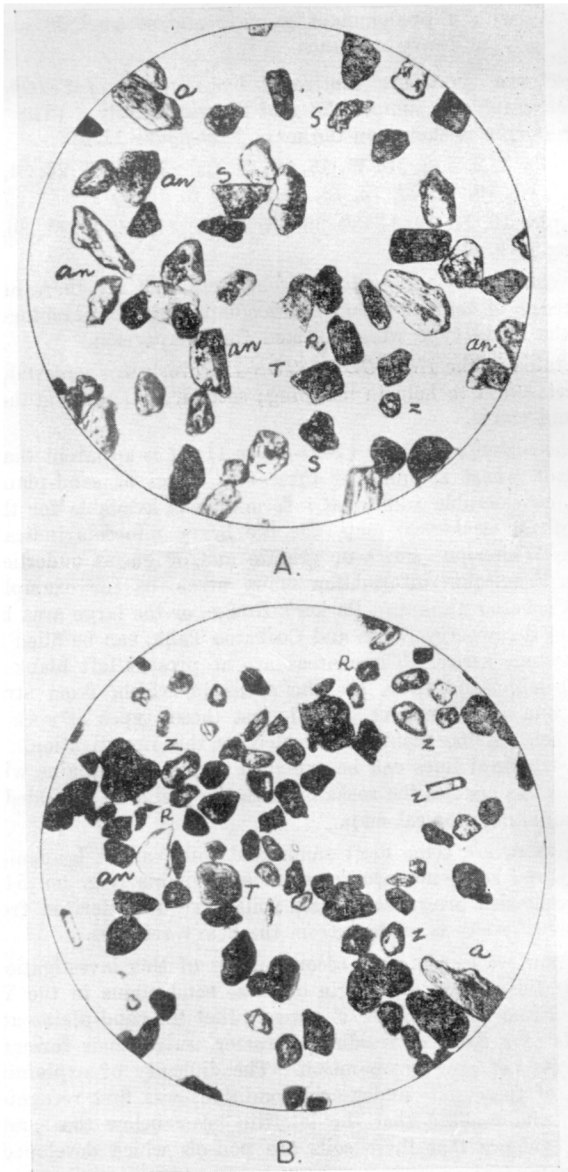


Fig. 15.—Heavy mineral assemblages of typical sandplain soils, Yilgarn Gold-field. A—Heavy mineral assemblage of fine sand of sample 23, a sandplain overlying the Whitestone Series. B—Heavy mineral assemblage of fine sand of sample 88, a sandplain overlying gneissic granite. An, andalusite; A, amphibole; S, staurolite; T, tourmaline; Z, zircon; R, rutile. Opaque grains are either ilmenite or limonite. Ordinary light, $\times 55$.

Therefore in this part of Western Australia there are two distinct periods of soil formation: present-day soils, normal red to reddish brown loams and clays in the more low-lying parts formed by weathering *in situ* of the country rocks (some of these soils have suffered slight local transport); and old soils—the yellow to pale brown sands of the plains containing a lateritic layer which the other soils do not. The sand-plains are residual and are preserved to-day because of the low relief and scanty rainfall of this part of the country. The equivalent of the sand-plain on the Greenstone Series is the heavy lateritic type of semi-scrub plain of small extent, a typical example of which can be seen on the road between Marvel Loch and Burbidge. All the heavy lateritic cappings, not so abundant in this district as in some parts of the goldfields, apparently belong to the same geological time as the formation of the sand-plain soils.

Of the suggestions mentioned in the *INTRODUCTION* to account for the origin of sand-plains it is seen that the first of these, that the plains are residual dune sand deposits was dismissed when considering the mechanical analyses of typical soils from these plains. Field evidence is also opposed to this origin, for in only two instances did I see anything suggestive of dune origin, and the monotonous flatness, which has to be seen to be believed, is, to my mind, much more in keeping with a re-elevated peneplain, than with an area which has been subjected to prolonged wind action. The lack of rounding of the quartz grains, except in a soil known to have been transported, also is against the possibility of dune origin, although this criterion has to be used with caution.

The idea that the sand-plains are soils overlying granite has been widely accepted and has much more foundation, for granite and gneiss do underlie many parts of these plains; and until a mineralogical examination had been made no one who believed in the sedentary character of the sand-plains had suggested that any other rock but granite might give rise to a sand-plain. Modern soils developing in the more low-lying parts of the district vary according to the underlying rock. Occasionally in some of the sand-plain areas we find granite outcrops surrounded by newly formed pinkish brown soils. These soils are not at all similar to the yellow soils of the sand-plains themselves, and this suggests that the normal weathering of a uniform expanse of granite could not, under the present climatic conditions, give rise to the typical sand-plain. Another feature of importance is the absence of a lateritic layer in the modern soils, whereas it is a constant feature of the sand-plain soils. The sand-plain soils must therefore be residual and the second suggestion, that they are normal granitic soils, is also dismissed, leaving only the third possibility (fossil soils) which has been proved to be correct by the result of this investigation.

ACKNOWLEDGMENTS.

This investigation was undertaken as one of the projects of the Commonwealth Research Grant to the University of Western Australia. The work was done in the Department of Geology under the direction of Professor Clarke whom I wish to thank for discussions and invaluable suggestions. Mr. F. G. Forman, Government Geologist, made the necessary field-work and collecting possible by allowing me to accompany officers of the Survey during their survey of the southern part of the Yilgarn goldfield. Sympathetic co-operation and discussions were given by Messrs. H. A. Ellis and R. A. Hobson with whom I did the field-work.

INDEX.

The principal references are indicated by heavy type.

Acid dykes	...	...	...	...	...	...	...	...	85
Acknowledgments	...	...	...	...	...	...	...	...	16
Actinolite	...	...	...	...	...	...	...	74, 81,	84
Aerial photographs	...	...	...	...	...	...	...	...	16
Agricultural pursuits	...	...	...	...	...	...	...	...	36
Albite	...	...	...	...	...	...	...	89, 99, 101, 108,	109
"Alexander" lease, G.M.L. 3642	...	...	...	...	...	...	...	...	84
Alluvium	...	...	...	...	...	...	...	62, 113,	148
Alluvial gold	...	...	...	...	...	...	...	...	22, 113
Almandine	...	...	...	...	...	...	...	...	72
" manganiferous	...	...	...	...	...	...	...	...	109
Amphibole	...	...	...	...	...	...	...	84, 85,	168
Amphibolite	...	...	...	...	...	...	...	...	75, 93
Amphibolites, coarse grained	...	...	...	...	...	...	...	...	66
Amphibolite rock	...	...	...	...	...	...	...	70, 76, 77,	84
" rocks, massive	...	...	...	...	...	...	...	...	74, 76
" schistose	...	...	...	...	...	...	...	...	73
Analysis, rock	...	...	...	...	...	...	...	...	80
" mineral	...	...	...	...	...	...	...	...	74, 109
Andalusite	...	...	...	...	...	...	...	68, 72, 73,	158, 169
Andradite	...	...	...	...	...	...	...	...	73
Anthophyllite	...	...	...	...	...	...	...	...	79
" schist (<i>see</i> Schist, anthophyllite).	...	...	...	...	...	...	...	...
Anticlinoria	...	...	...	...	...	...	...	...	116
Apatite	...	...	...	...	...	...	...	93, 99, 101, 103,	109
Aplite	...	...	...	...	...	...	...	57, 86, 89 , 91, 112,	116, 134
Aplites, petrological description of	...	...	...	...	...	...	...	...	108
" table showing types and mineral composition of	...	...	...	...	...	...	...	...	110
Area, definition of	...	...	...	...	...	...	...	...	10
" investigated	...	...	...	...	...	...	...	...	9
" " general description of	...	...	...	...	...	...	...	...	10
Arkosic grit	...	...	...	...	...	...	...	56, 59, 62,	114
Arsenical concentrates	...	...	...	...	...	...	...	...	22, 158
Arsenopyrite	...	...	...	...	...	...	...	148, 150,	154
Augite	...	...	...	...	...	...	...	...	75, 81, 85
Bagnold, R. A.	...	...	...	...	...	...	...	...	166
Banker Group	...	...	...	...	...	...	...	76, 120,	139
Barth, T. W.	...	...	...	...	...	...	...	...	163
Basement rocks	...	...	...	...	...	...	...	...	64, 67, 92
Basic intrusive rocks	...	...	...	...	...	...	...	14, 18, 63, 66, 70, 83 ,	86, 89, 116
Battler Group	...	...	...	...	...	...	...	...	142, 143
"Battler" lease	...	...	...	...	...	...	...	...	133
Biotite	...	...	...	...	...	...	...	88, 93, <i>frequently</i>	99-112
" development of, near ore bodies	...	...	...	...	...	...	...	...	154
Bismuth	...	...	...	...	...	...	...	...	93
Blackbourne's	...	...	...	...	...	...	...	...	121
"Black Cat," G.M.L. 3716	...	...	...	...	...	...	...	...	146
Blatchford, T.	...	...	...	...	...	...	...	...	16
Boddalin	...	...	...	...	...	...	...	126, 143, 144,	145
" prospecting recommendations, vicinity of	...	...	...	...	...	...	...	...	160
Boddalin—Sandalwood Rocks Belt, structure of	...	...	...	...	...	...	...	...	118, 126
Bohemia lease	...	...	...	...	...	...	...	...	76, 88, 139, 146

INDEX—*continued.*

Bowley, B. M.	47
Breccias, volcanic	75, 76
Bricks, attempt to make	158
Bullfinch	123
Burbidge	136, 139, 142, 159
" conglomerate at	71, 134
" cross-folding at	141
" gold in lateritic formations at	149
" prospecting recommendations, vicinity of	159
" water supply at	44
" Whitestone Series at	70
Burgess' Find	144
Burt, F. A.	171
Canada	10
Carrol, Dorothy	4, 41, 167, 168
Cassiterite (<i>see also</i> Tin, Tin oxide)	89, 93
"Cement"	62, 114
Central Ironcap	50
Cheriton's Find	55, 82, 124, 137, 140
" " amygdaloidal lavas at	75
" " auriferous quartz veins at	142
" " cross-folding at	120, 123, 129, 141, 142, 144
Chiastolite	68, 72
Chlorite	99, 101, 106, 107
Chromite	66, 80
Clarke, E. de C.	162
Classification of rocks	64
Clay material in soils	172
Climate	24
Comet G.M.	73, 87, 88, 90, 91
Condarnin Rock	57, 90
Conglomerate	70, 71, 134
" schistose	69
Correlation of rocks	64, 65
"Cricket," G.M.L., 13 P.P.	88, 142
Cronin's Lagoon	46
Cross-folding (<i>see also</i> Cross-folds)	14, 117, 120, 123, 126, 127, 131, 132
" relation to gold deposition	140-145
Cross-folds (<i>see also</i> cross-folding) 116, 123, 124, 126, 128, 129, 130, 128-130	
Cross Lake Region, Manitoba	82
Deep leads	113
Deepest workings in Area	148
Depressions, topographical	59
Diopside	84, 85
Dolerite dykes	85
Donovan's Find	119, 137, 142
" " barren quartz reefs cutting through auriferous quartz reefs at	87
" " erosion sediments in Greenstone Series at	76
" " pegmatite dykes at	88
" " quartz reefs oblique to schistosity at	133
" " structure at	124, 139
" " third period of folding at	146
Dragfolds	120, 123, 125, 126, 127, 128, 129, 132, 133, 138, 142, 145
" use of	128
Drag folding	82, 137

INDEX—*continued.*

Geological maps, general description of	...	...	...	...	17
" structure, broad	...	...	...	...	116
" " relation between geological structure and gold	...	...	...	...
deposition	...	...	...	...	134
Glendower Group	...	...	77, 81, 90, 119, 124, 137, 142, 143, 144		
Gneiss	18, 58, 63, 85, 87, 88, 90, 93, 103, 112, 126, 148, 149, 151, 163, 172, 173				
" augen	...	...	...	...	69, 106
" biotite	...	...	...	...	69, 90, 92
" injection	...	...	...	...	63
" orthogneiss	...	...	...	63, 90, 91, 103, 112	
" paragneiss	...	...	...	...	63, 64, 106, 117
" quartz felspar	...	...	...	...	90, 92
" quartz muscovite	...	...	...	...	106
" replacement	...	...	14, 63, 78, 82, 90, 117, 118		
" of doubtful origin	...	...	...	...	106
" table showing types and mineral composition of	...	...	...	...	104-105
" types of ore bodies in	...	...	...	...	151, 152
Gneisses, petrological description	...	...	...	...	103
Goethite	...	...	...	...	158
Gold, discovery of	...	...	...	...	20
" source of	...	...	...	...	135
" deposits	...	...	...	...	48
" alluvial	...	...	...	...	149
" nature of	...	...	...	...	149
" mode of occurrence	...	...	...	...	149
" reef and lode	...	...	...	...	149
" deposition, factors influencing	...	...	...	134, 141, 151	
" localisation of	...	...	...	...	140
" relation of cross-folding to	...	...	...	...	140-145
" lines	...	...	...	...	14, 137
Granite (s)	14, 56, 62, 63, 78, 83, 85, 87, 88, 89, 91, 92, 93, 99, 112, 116, 117, 125, 126, 135, 151, 163, 164				
Granites, petrological description of	...	...	...	...	99
" table showing types and mineral composition of	...	...	...	...	100
Granite "Rocks"	...	...	11, 14, 18, 51, 53, 56, 89, 90, 134		
Granitic, gneissic and pegmatitic rocks, petrological report	...	...	...	...	93
" intrusions, periods of	...	...	...	...	91
" magma	...	...	...	90, 112, 149	
Granitisation	14, 18, 63, 64, 78, 82, 87, 90, 91, 107, 112, 163				
Granitised rocks (<i>see also</i> Granitisation)	...	...	...	...	82
Gravel reserve 10033, jaspilite at	...	...	...	...	138
Great Western Australian Plateau	...	...	...	...	59, 161
" Victoria G.M.	...	...	70, 120, 129, 136, 139, 149		
Greenmount	...	...	44, 69, 84, 121, 141		
" prospecting recommendations, vicinity of	...	...	...	...	160
Greenstone, definition of	...	...	...	...	74
" Series	13, 14, 18, 58, 63, 64, 65, 69, 74, 83, 84, 85, 88, 89, 91, 92, 118, 120, 121, 124, 126, 127, 135, 136, 137, 138, 139, 140, 143, 145, 149, 151, 163				
" distribution of gold mining centres within	...	...	...	...	137
" erosion sediments in	...	...	63, 74, 75, 76, 91, 127		
" existence of belt of drag folded strata in	...	...	...	...	133, 151
" relative age of	...	...	13, 63, 64, 67, 74, 121		
" soils of	...	...	...	...	38, 39
" types of ore bodies in	...	...	...	...	151, 152
Greywacke	...	...	69, 74, 75, 76, 77		
Grits	...	...	...	...	164
" arkosic	...	...	56, 59, 62, 114		

INDEX—*continued.*

Marvel Loch, greenstone soils at	167
" " mines in the Whitestone Series at	136
" " orthogneiss at	90
" " pegmatite dykes at	88
" " staurolite, andalusite, and almandine, in vicinity of	72
" " staurolite west of	170
" " structure at ... 119, 121, 123, 124, 129, 138, 141, 143, 146	146
" " two periods of gold deposition at	91
" " water supply at	44
" " Whitestone Series, vicinity of	69
" " Gold Development	76, 124, 138, 139, 146
" " Mine	76, 138
Matheson, R. S.	3, 15, 17, 86, 131, 145, 146, 148, 160
May Queen Gold Mine	77, 79, 84, 119, 124, 139, 149
" " Group	143, 144
Mechanical analysis	164, 165
Meier's Find	79, 112, 119, 137
Metamorphic minerals	72, 169
Metamorphism, regional	67
Meta-sediments	163, 173
Metasomatic replacement	150
Microcline	frequently 99-112
Middle Ironcap	55, 82, 125, 126, 144
Migmatites	14, 56, 57, 63, 64, 78, 86, 87, 88, 90, 91, 92, 117, 118
Mineralogical examination, method of (soils)	166
Mineralogy of soils	166
Mineral production	22
Minerals, description of individual (soils)	167
" " identified in soils	167
"Miner's Dream," G.M.L. 3757	146
Mining, history of, in area	20
" " timber	43
Miocene submergence	52, 163
Monazite	109
Moorine Rock	40, 59, 60, 61
" " —Mt. Hampton Road	114
Morrel	33
Mountain Queen Mine, exposures of Whitestone Series, in vicinity of	69, 71, 136
" " " gold in lateritic formations at	149
" " " manganiferous almandine at	73
" " " staurolite west of	15
" " " tuffs and volcanic breccias, south-east of	76
" " " structure at	139, 141, 146
Mt. Bailey	57
Mt. Caudan Lode	158
Mt. Hampton	50, 51, 57
Mt. Holland	33, 50, 51, 55, 60, 78, 82, 89, 125
" " —South Ironcap Belt, structure of	118, 124
Mt. Palmer (<i>see also</i> Palmer's Find)	55, 137, 139, 149
" " anthophyllite at	79
" " arsenopyrite at	154
" " barren quartz reefs at	87
" " cross-folding at	141, 142
" " granite intrusive into Greenstone Series at	89
" " granitisation, vicinity of	90
" " jaspilite at	76

INDEX—*continued.*

Mt. Palmer, pegmatite at	...	...	...	...	...	88, 132
" " water supply at	...	...	...	...	...	44
Mt. Rankin	...	...	...	54, 76, 82, 121, 123, 132, 144	...	
Muscovite	...	...	...	88, 93, 99, 102, 106, 107, 108, 109, 112	...	
" Mussolini " lease	...	...	...	...	...	133
Nepheline	...	...	...	...	...	85
Nevoria	...	...	...	55, 78, 136, 144, 145, 159	...	
" cross-folding, vicinity of	...	...	...	120, 123, 129, 139, 141, 142	...	
" jaspilite at	...	...	...	...	76, 81, 82	
" pegmatite dykes at	...	...	...	...	88, 108	
" prospecting recommendations, vicinity of	...	...	...	...	159	
" structure at	...	...	...	119, 120, 123, 129, 137, 138, 141, 142	...	
" water supply at	...	...	...	...	44	
" Gold Mining Co.	...	...	...	...	139	
" —Parker's Range Road	...	...	...	...	70	
" New Democrat " lease	...	...	...	...	133, 139	
New Zealand Gully	...	...	...	76, 78, 84, 85, 113, 149, 158	...	
North America	...	...	...	...	62, 66	
" Ironcap	...	...	...	...	50, 53, 82, 125	
Nontronite	...	...	...	...	172	
Olga Group	...	...	...	67, 78, 114, 137, 142, 160	...	
" " gold reefs at	...	...	...	...	140	
" " granitisation, vicinity of	...	...	...	...	83, 90	
" " phonolite at	...	...	...	...	15, 67, 85	
" " prospecting recommendations, vicinity of	...	...	...	...	160	
" " structure at	...	...	...	119, 120, 137, 144, 146	...	
Oligoclase	...	...	...	...	89, frequently 99-112	
Opaque grains	...	...	...	...	167, 168, 174	
Ore, average grade of	...	...	...	...	149	
" bodies in Yilgarn System, table showing classification	...	...	...	...	152, 153	
" " <i>en echelon</i> , arrangement of	...	...	...	...	145	
Origin of sand plains	...	...	...	...	177, 179	
Orthoclase	...	...	...	...	85, frequently 99-112	
" Outsider " lease	...	...	...	...	133, 139	
Palace Hotel	...	...	...	...	83	
Palmer's Find (<i>see also</i> Mt. Palmer)	...	...	...	78, 83, 119, 124, 137, 138, 139	...	
" " discovery of	...	...	...	...	21	
Parker's Range	...	...	...	55, 60, 85, 159, 162	...	
" " jaspilite at	...	...	...	...	76, 82	
" " mechanical analysis of soil from	...	...	...	...	165	
" " structural information	...	...	...	119, 120, 137, 140, 142, 144	...	
" " water supply at	...	...	...	...	44	
" " —Ravensthorpe Road	...	...	...	...	114	
Pegmatite(s)	57, 63, 66, 67, 71, 73, 76, 85, 87, 88, 89, 91, 93, 108,	112, 116	131, 134	92, 93	...	
Pegmatite, albite	...	...	...	...	84	
" basic	...	...	...	...	88	
" dykes (<i>see also</i> Pegmatite)	...	...	...	...	101, 106	
" micro	...	...	...	...	92	
" tin bearing	...	...	...	...	108	
Pegmatites, petrological description of	...	...	...	...	110	
" table showing types and mineral composition of	...	...	...	...	162	
Peneplain	...	...	...	...	173, 174	
Percentage results (soils)	...	...	...	...	179	
Periods of soil formation	...	...	...	...	...

INDEX—*continued.*

Southern Cross, basic intrusive rocks, vicinity of	84
" " cross-folding at	123, 129, 136, 141
" " faulting at	132
" " granite at	89
" " granitisation, vicinity of	83
" " jaspilite at	76, 137, 138
" " outcrops of Whitestone Series, vicinity of	69
" " pegmatite dykes at	88
" " structure at	138
" " water supply at	44
" " Rifle Range	69
" " —Cheriton's Find Belt, structure of	118, 127, 128
" " " " " cross-folding in	123
" " Parker's Range Road	69, 70, 75, 76
" " Strawberry Rocks Road	69, 78
" " " " " " prospecting recommendations, vicinity of	160
South Africa	62, 66
" Ironcap	50, 53, 82, 125, 126, 144
Sorting of sands	165, 166
"Spear head" structure	134
Spessartite	73
Sphene	99, 102, 169
Spinel	93, 170
Staurolite	15, 68, 72, 170
Strain shadows (<i>see also</i> Wavy extinction)	101, 103, 106, 109
Strawberry Rocks	51, 57, 75
Structural Geology	116, 163
Superficial deposits and soils	164
Synclinoria	116
Tantalite	92, 93
Temperature	24
" " data at Southern Cross, table giving	26
"Three Queens" G.M.L. 3770	83, 87, 90
Tin, detrital	92
" lode	92
" oxide	22, 92, 158
Toomey's Hill	55, 76, 119, 137, 140, 144, 159
Topography	50, 162
"Tor" weathering	57
Tourmaline	88, 93, 106, 109, 154, 169
Tracks	45
Transvaal Mine, arsenical concentrates from	22, 158
" " arsenopyrite at	154
" " basic igneous rocks intrusive into Whitestone Series at	66, 70, 85
" " structure, vicinity of	138
" " Whitestone Series at	69, 71, 72, 136
Tuffs	67, 69, 74, 75, 76, 77, 83
Udden, J. A.	166
Ultrabasic intrusive rocks	84
Vegetation, relation to geology	33, 34
Vicker's Find	119, 128, 137

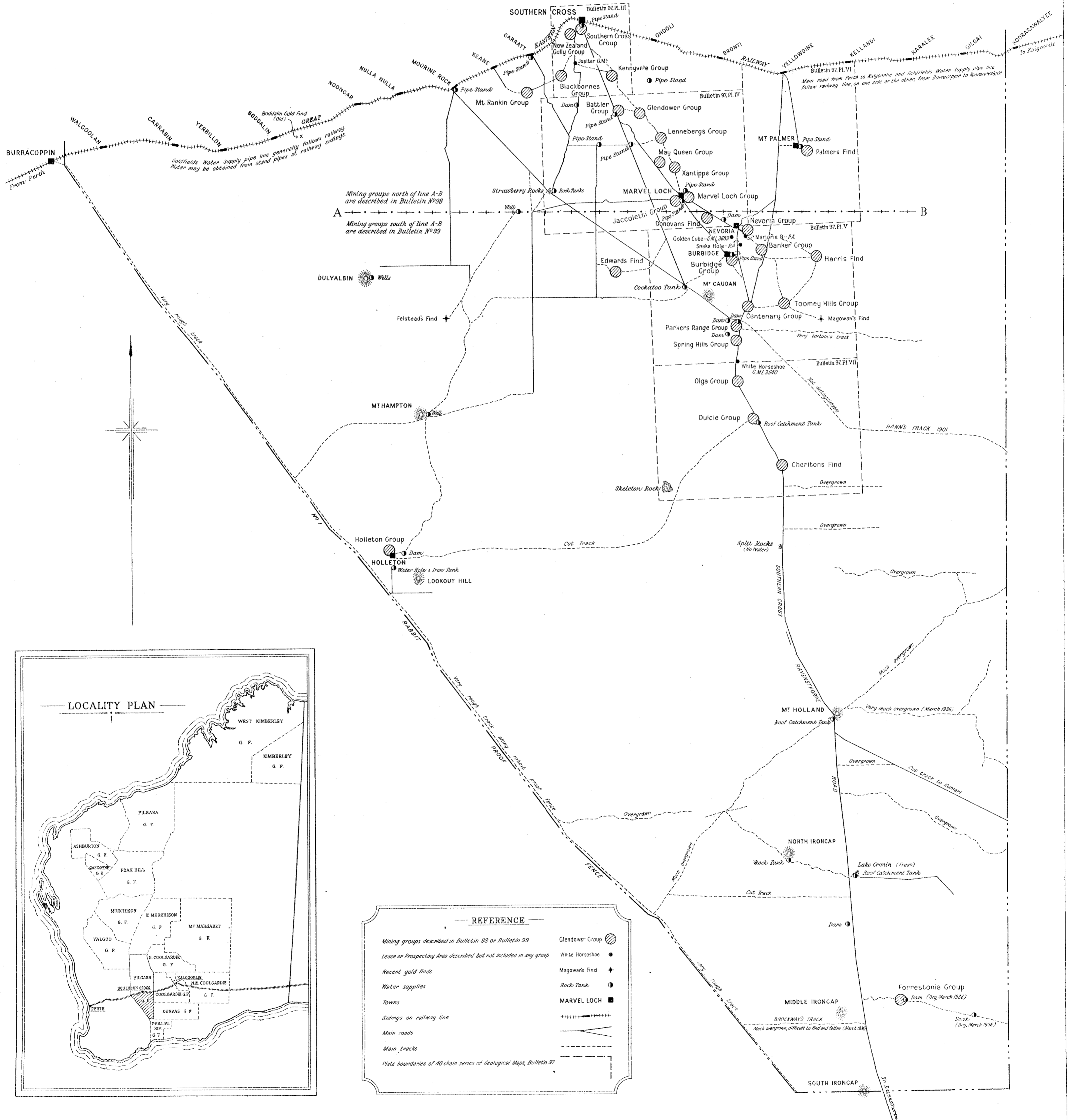
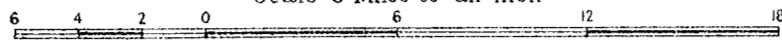
INDEX—*continued.*

Water Supply, dams	44, 46
" " domestic	44
" " Goldfields Water Supply Pipe Line	11, 44
" " mining	44
" " underground water	44, 52, 57
" " wells	46
Wavy extinction (<i>see also</i> Strain shadows)	99, 102, 103, 112
Wentworth, C. K.	164
" " scale	164
Westonia	143
Whinfield's reef	88
Whitestone Series	13, 14, 58, 63, 66, 67, 68, 74, 88, 89, 92, 118, 120, 124, 133, 135, 136, 139, 141, 142, 145, 149, 159, 163
" " basic rocks intrusive into	66, 70, 85
" " best outcrops of	69
" " jaspilite in	82
" " mines in	136
" " relative age of	13, 63, 64, 67, 74, 121
" " soils of	39
" " types of ore bodies in	151, 152
Wilson, R. A.	172
Winds	25, 52, 60
Xantippe	143, 144
Xenotime	93
Yellowdine Gold Development	139, 142, 149
" " Rock	57, 86, 90
" " Parker's Range Road	70, 134, 159, 160
" " " " prospecting recommendations, vicinity of	159, 160
" " Siding	60, 83, 90, 123, 128, 139
Yilgarn Goldfields, boundary of	9
" " System	15, 63, 66, 116, 117, 121, 124, 131, 140, 148, 149
" " " " junction with Gr/Gn	117
" " " " types of ore bodies in	152
" " " " structure of	118
Younger Greenstones	84
Zircon	93, 102, 108, 168, 173

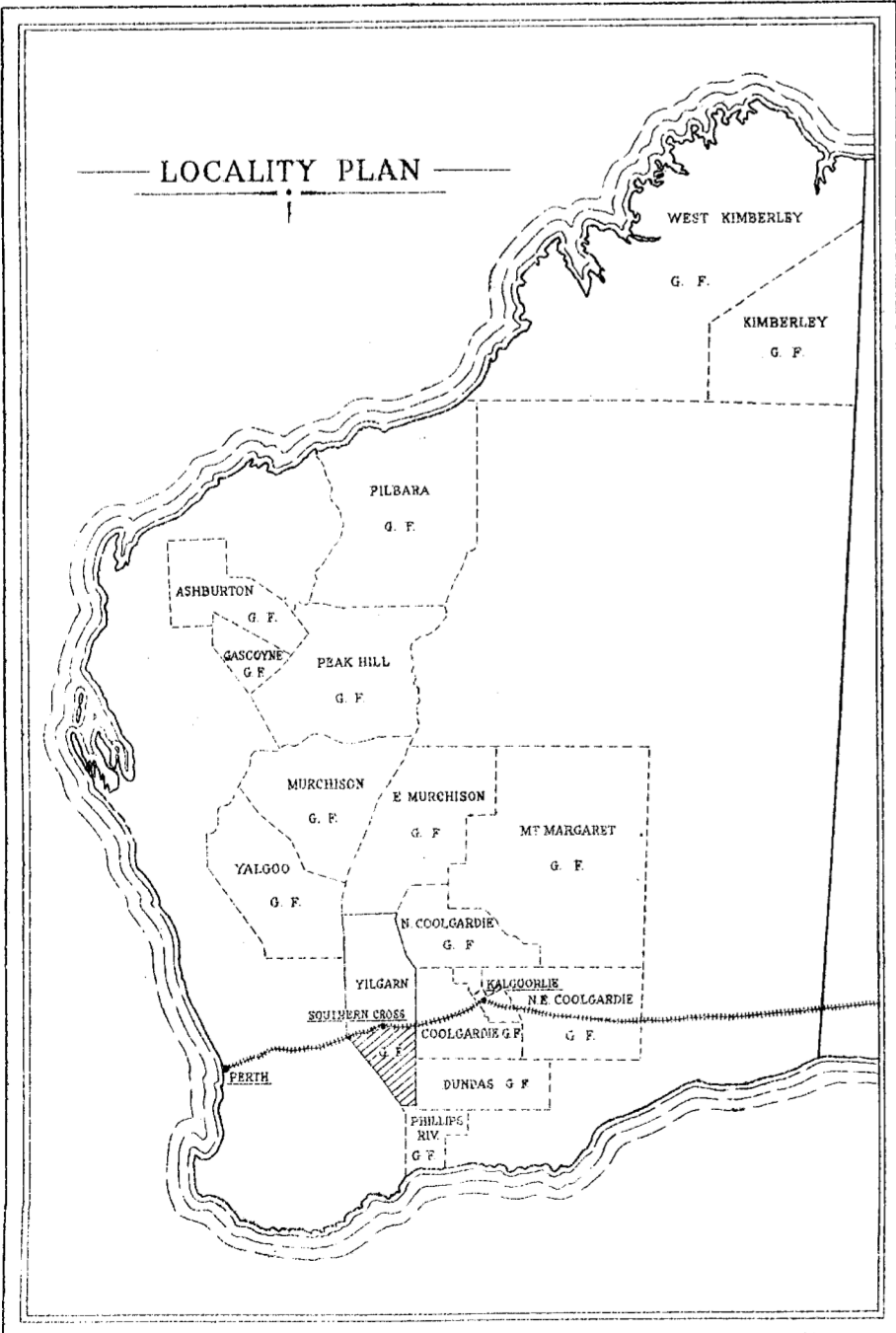
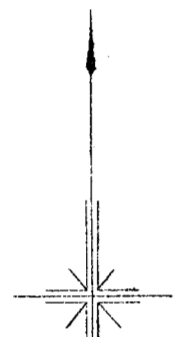
MAP OF PORTION OF THE YILGARN GOLDFIELD

SOUTH OF THE GREAT EASTERN RAILWAY
SHOWING MINING GROUPS, WATER SUPPLIES, MAIN ROADS AND TRACKS

Scale 6 Miles to an Inch



Mining groups north of line A-B are described in Bulletin No 98
Mining groups south of line A-B are described in Bulletin No 99



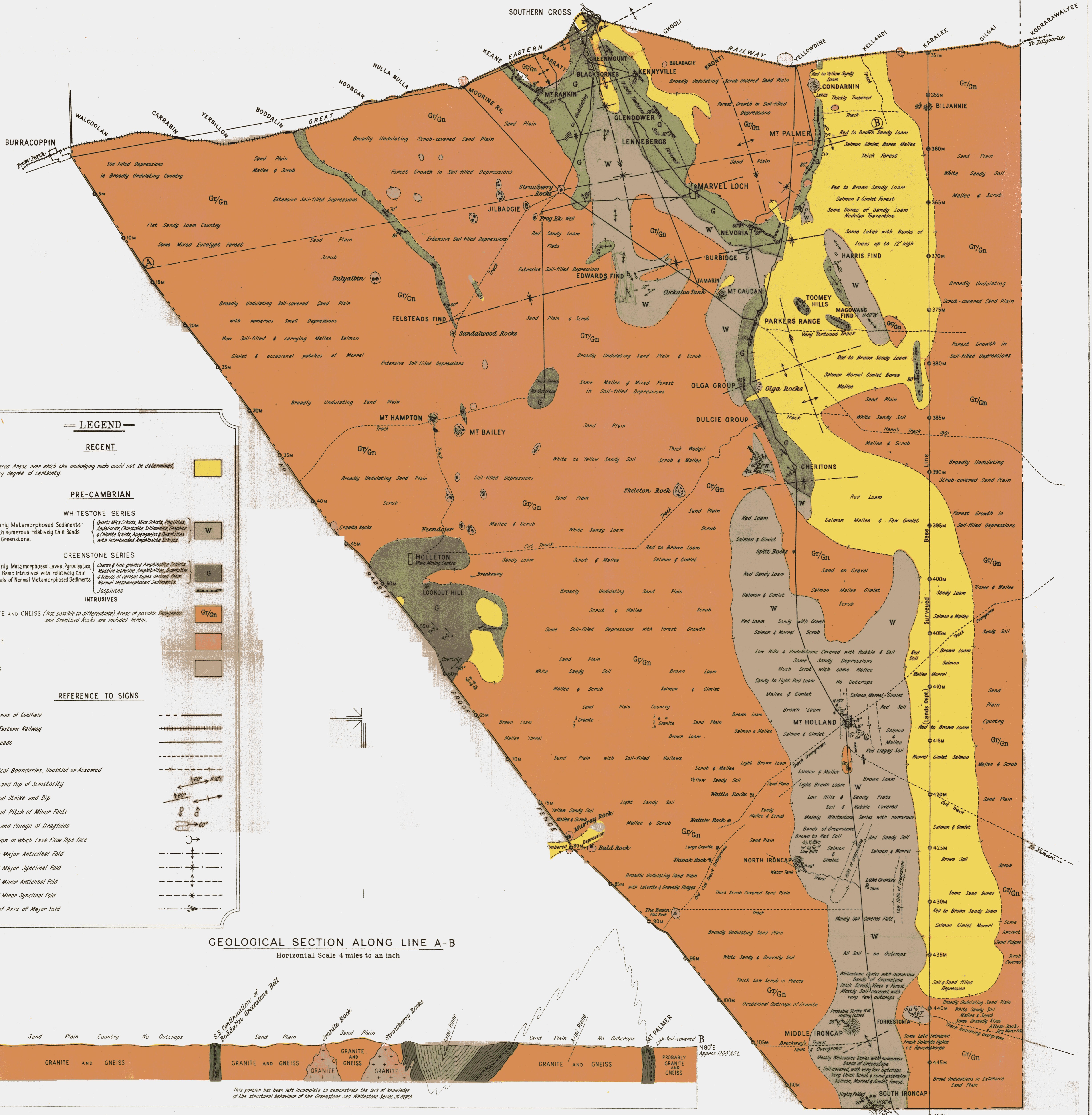
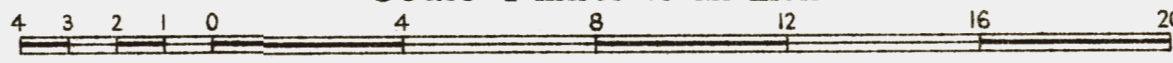
REFERENCE

Mining groups described in Bulletin 98 or Bulletin 99	Glendower Group
Lease or Prospecting Area described but not included in any group	White Horseshoe
Recent gold finds	Magowan's Find
Water supplies	Rock Tank
Towns	MARVEL LOCH
Sidings on railway line	+
Main roads	—
Main tracks	—
Plate boundaries of 40 chain series of Geological Maps, Bulletin 97	- - -

GEOLOGICAL MAP OF PORTION OF THE YILGARN GOLDFIELD SOUTH OF THE GREAT EASTERN RAILWAY

H. A. Ellis, Geologist, 1935-36

Scale 4 miles to an inch



LEGEND

RECENT

Soil-covered Areas over which the underlying rocks could not be determined, with any degree of certainty



PRE-CAMBRIAN

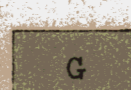
WHITESTONE SERIES

Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone.



GREENSTONE SERIES

Mainly Metamorphosed Lavas, Pyroclastics, and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments.



INTRUSIVES

GRANITE AND GNEISS (Not possible to differentiate) Areas of possible Plagioclase and Granitoid Rocks are included herein.



GRANITE



GNEISS

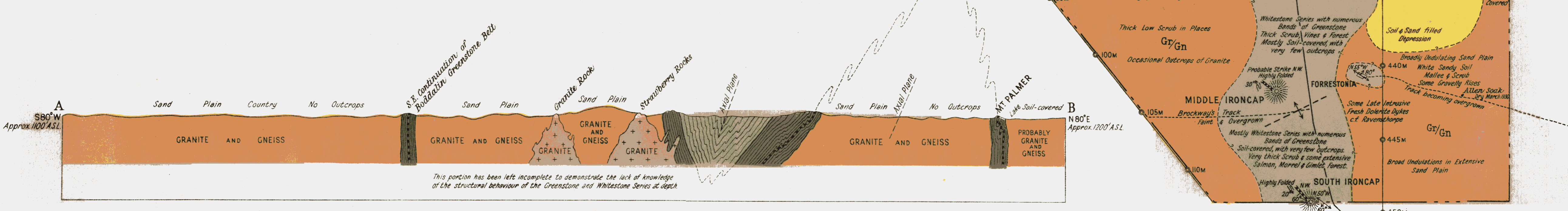


REFERENCE TO SIGNS

- Boundaries of Goldfield
- Great Eastern Railway
- Main Roads
- Tracks
- Geological Boundaries, Doubtful or Assumed
- Strike and Dip of Schistosity
- Regional Strike and Dip
- Regional Pitch of Minor Folds
- Strike and Plunge of Dragfolds
- Direction in which Lava Flow Tops face
- Axis of Major Anticlinal Fold
- Axis of Major Synclinal Fold
- Axis of Minor Anticlinal Fold
- Axis of Minor Synclinal Fold
- Pitch of Axis of Major Fold

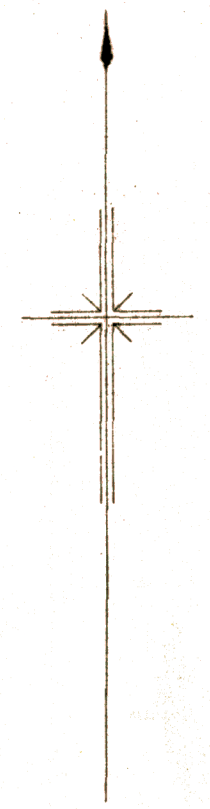
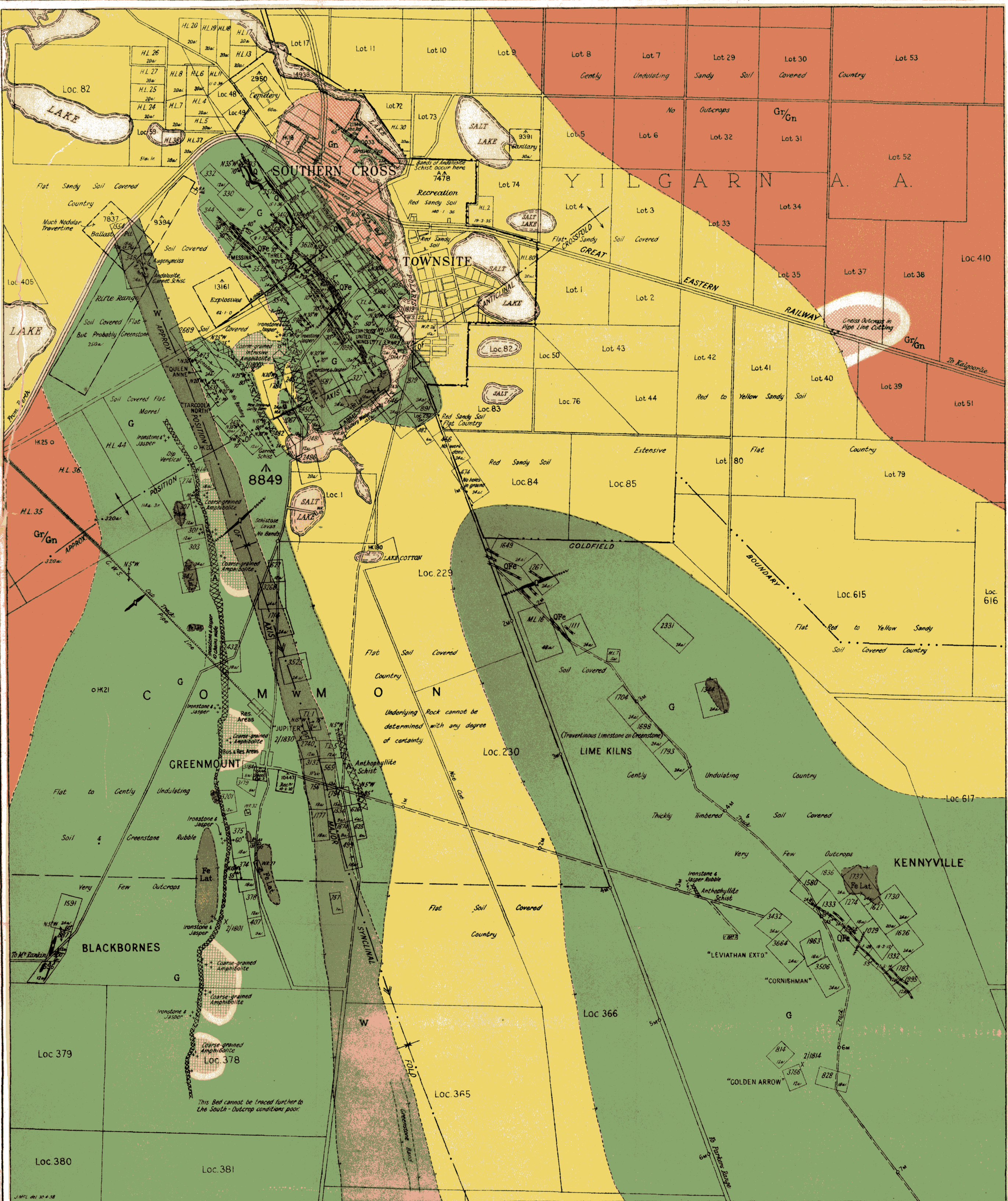
GEOLOGICAL SECTION ALONG LINE A-B

Horizontal Scale 4 miles to an inch



This map covers portion of the area contained in Lands Dept. Licenses Nos. 9260, 9261, 9262, 9263, 9264.

Compiled from survey data supplied by Lands Dept. with additional traverses by H. A. Ellis, R. A. Robson, & R. S. Macdonald, 1935-36.



GEOLOGICAL MAP OF COUNTRY IN VICINITY OF SOUTHERN CROSS

YILGARN GOLDFIELD

BY
H. A. Ellis Geologist

Scale 40 chains to an inch



— LEGEND —

RECENT

Soil-covered Areas over which the underlying rock could not be determined with any degree of certainty.

Ferruginous Laterite (Concretionary)

PRE-CAMBRIAN

WHITESTONE SERIES

Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone. W

GREENSTONE SERIES

Mainly Metamorphosed Lavas, Pyroclastics and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments. G

Jaspillites QPe

Anthophyllite Schist, (Ultrabasic Sill or Flow) XAX

INTRUSIVES

GRANITE AND GNEISS (Not possible to differentiate) Areas of possible Paragneiss and Granitised Rocks are included herein. Gr/Gn

GNEISS Gn

COARSE-GRAINED INTRUSIVE AMPHIBOLITE

BARREN QUARTZ REEFS Q

REFERENCE TO SIGNS

Gold Mining Leases 3526

Gold Mining Leases described in Bulletin No 98 "MESSINA"

Geological Boundaries Doubtful or Assumed ---

Strike and Dip of Schistosity 70° 43°E

Strike of Vertical Schistosity 70° 43°E

Strike of Vertical Bedding 70° 43°E

Strike and Plunge of Dragfolds 60°

Faults ~~~~~

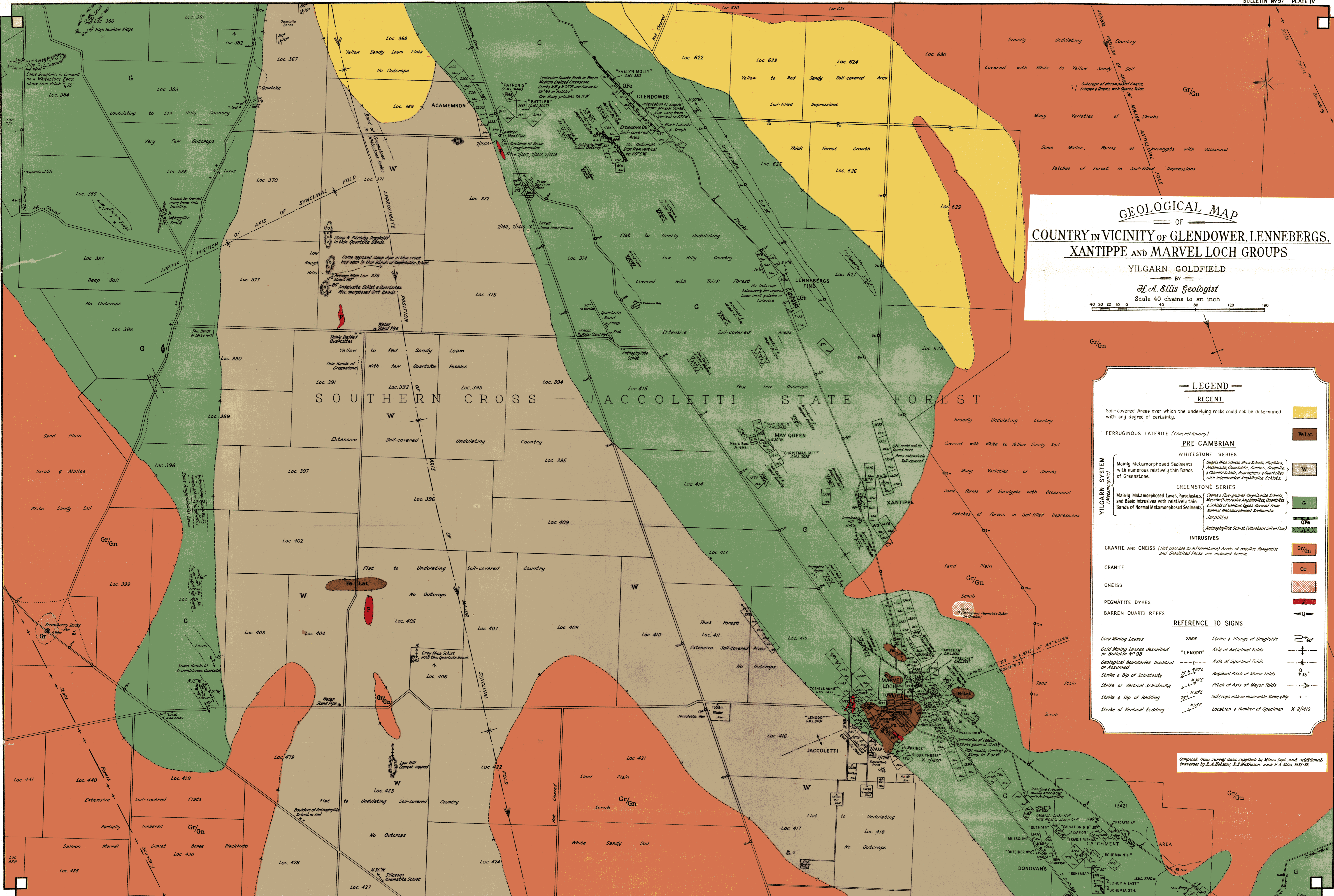
Axis of Anticlinal Folds ↑

Axis of Synclinal Folds ↓

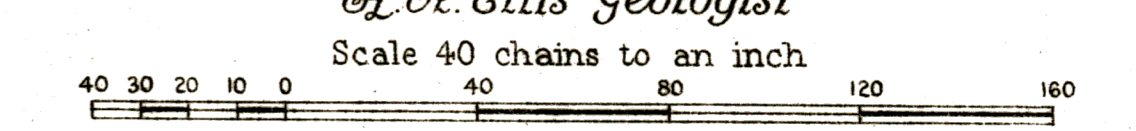
Pitch of Axis of Major Folds ---

Outcrops with no observable Strike and Dip + +

Location and Number of Specimen X 2/1814



GEOLOGICAL MAP
OF
**COUNTRY IN VICINITY OF GLENDOWER, LENNEBERGS,
XANTIPPE AND MARVEL LOCH GROUPS**
YILGARN GOLDFIELD
BY
H. A. Ellis Geologist
Scale 40 chains to an inch



LEGEND

RECENT

Soil-covered Areas over which the underlying rocks could not be determined with any degree of certainty. ■

FERRUGINOUS LATERITE (Concretionary) ■ FeLat

PRE-CAMBRIAN

WHITESTONE SERIES

YILGARN SYSTEM (Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone.) ■ W

Quartz Mica Schists, Mica Schists, Phylites, Amphibolite, Chertolite, Garnet, Gneiss, & Chlorite Schists, Augenmasses & Quartzites with interbedded Amphibolite Schists.

GREENSTONE SERIES

YILGARN SYSTEM (Mainly Metamorphosed Lavas, Pyroclastics, and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments.) ■ G

Course & Fine-grained Amphibolite Schists, Massive & Intrusive Amphibolites, Quartzites & Schists of various types derived from Normal Metamorphosed Sediments.

INTRUSIVES

Granite and Gneiss (Not possible to differentiate) Areas of possible Pegmatites and Crystallized Rocks are included therein. ■ Gr/Gn

Granite ■ Gr

Gneiss ■ Gn

Pegmatite Dykes ■ P

Barren Quartz Reefs ■ Q

REFERENCE TO SIGNS

Gold Mining Leases 2368 Strike & Plunge of Dragfolds $\curvearrowright 60^\circ$

Gold Mining Leases described in Bulletin No 98 "LENODO" Axis of Anticlinal Folds \updownarrow

Geological Boundaries Doubtful or Assumed - - - - - Axis of Synclinal Folds \updownarrow

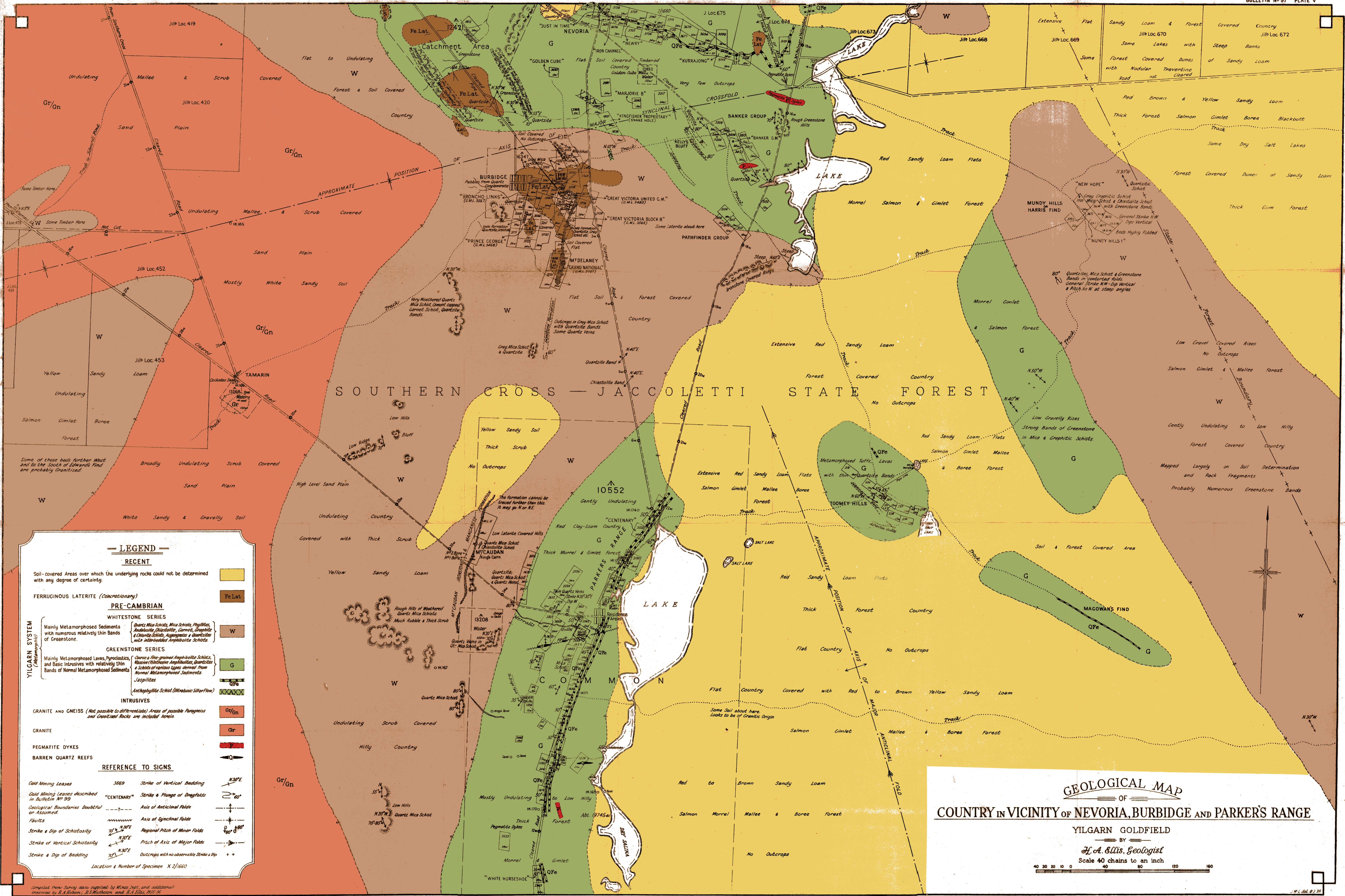
Strike & Dip of Schistosity $70^\circ N 30^\circ E$ Regional Pitch of Minor Folds $\downarrow 55^\circ$

Strike & Dip of Bedding $70^\circ N 30^\circ E$ Pitch of Axis of Major Folds $\downarrow 30^\circ$

Strike & Dip of Bedding $70^\circ N 30^\circ E$ Outcrops with no observable Strike & Dip \updownarrow

Strike of Vertical Bedding $N 30^\circ E$ Location & Number of Specimen X 2/412

Compiled from survey data supplied by Mines Dept. and additional coverings by R. A. Bohann, R. S. Matheson and H. A. Ellis, 1935-36



LEGEND

RECENT
Soil-covered Areas over which the underlying rocks could not be determined with any degree of certainty. [Yellow box]

FERRUGINOUS LATERITE (Concretionary) [Fe Lat box]

PRE-CAMBRIAN

WHITESTONE SERIES
Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone. [W box]

GREENSTONE SERIES
Mainly Metamorphosed Lavas, Pyroclastics and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments. [G box]

INTRUSIVES

GRANITE AND GNEISS (Not possible to differentiate) Areas of possible Panegyris and Gairdner Rocks are included herein. [Gr/Gn box]

GRANITE [Gr box]

PEGMATITE DYKES [P box]

BARREN QUARTZ REEFS [Q box]

REFERENCE TO SIGNS

Gold Mining Leases 3869 Strike of Vertical Bedding [N 30° E arrow]

Gold Mining Leases described in Bulletin No 99 "CENTENARY" Strike & Plunge of Dragfolds [N 30° E arrow]

Geological Boundaries Doubtful or Assumed [Dashed line]

Faults [Wavy line]

Strike & Dip of Schistosity [N 30° E arrow]

Strike of Vertical Schistosity [N 30° E arrow]

Strike & Dip of Bedding [N 30° E arrow]

Location & Number of Specimen X 2/1660 [++]

GEOLOGICAL MAP
OF
COUNTRY IN VICINITY OF NEVORIA, BURBIDGE AND PARKER'S RANGE

YILGARN GOLDFIELD
BY
H. A. Ellis, Geologist
Scale 40 chains to an inch

30 20 10 0 40 80 120 160

Compiled from Survey data supplied by Mines Dept. and additional traverses by R. A. Johnson, R. S. Macdonald, and F. A. Ellis, 1935-36

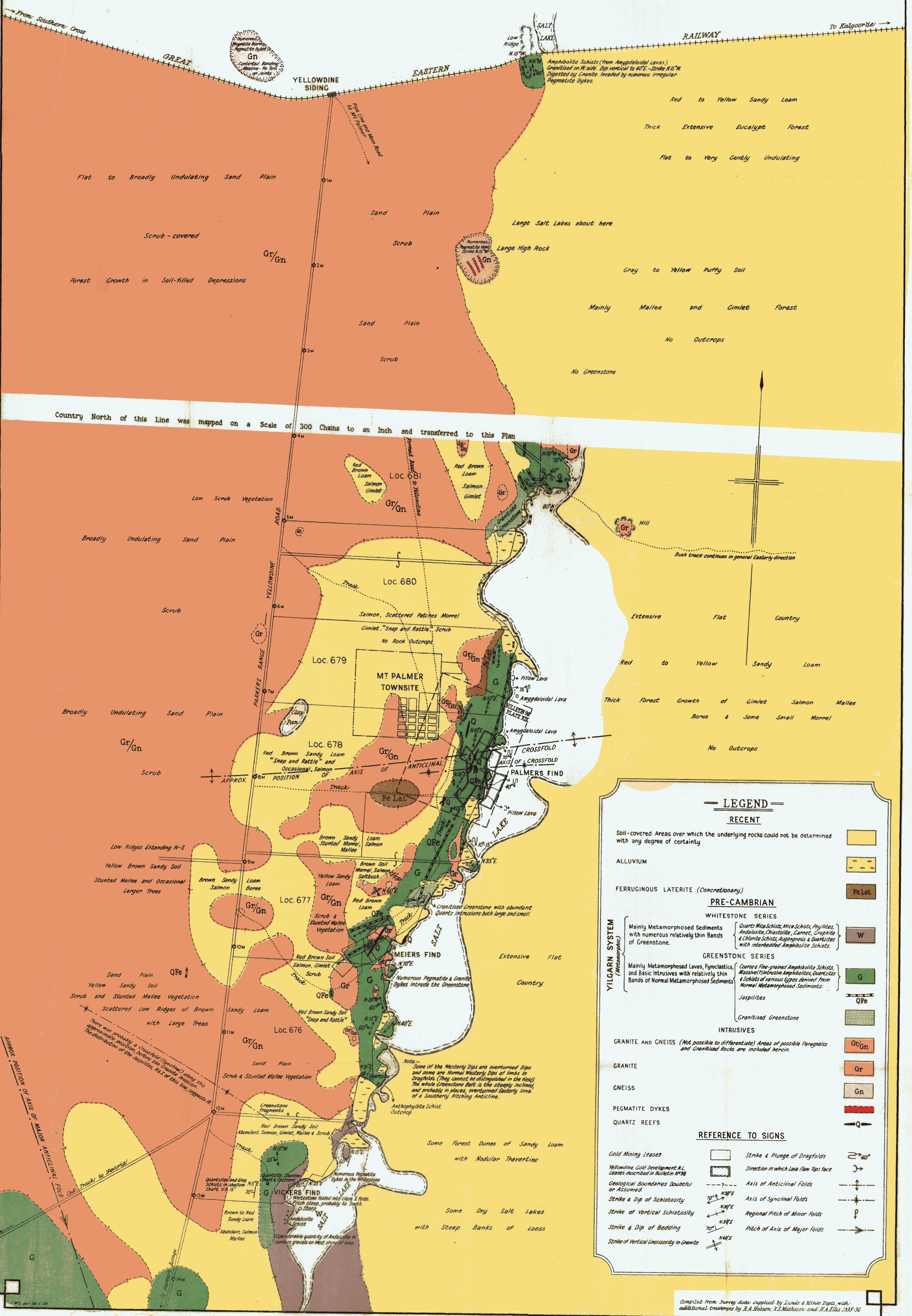
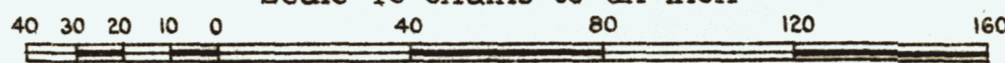
GEOLOGICAL MAP OF COUNTRY IN VICINITY OF MT PALMER

YILGARN GOLDFIELD

BY

R.A. Hobson, R.S. Matheson and H.A. Ellis

Scale 40 chains to an inch



Country North of this Line was mapped on a Scale of 300 Chains to an Inch and transferred to this Plan

LEGEND

RECENT

- Soil-covered Areas over which the underlying rocks could not be determined with any degree of certainty
- ALLUVIUM
- FERRUGINOUS LATERITE (Concretionary)

PRE-CAMBRIAN

WHITESTONE SERIES

- Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone.
- Quartz Mica Schists, Mica Schists, Phyllites, Andalusite, Chloritoid, Garnet, Graphite & Chlorite Schists, Augen-gneiss & Quartzites with interbedded Amphibolite Schists.

GREENSTONE SERIES

- Mainly Metamorphosed Lavas, Pyroclastics, and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments.
- Coarse & Fine-grained Amphibolite Schists, Massive(?) Intrusive Amphibolites, Quartzites & Schists of various types derived from Normal Metamorphosed Sediments.
- Jaspilites
- Granitised Greenstone

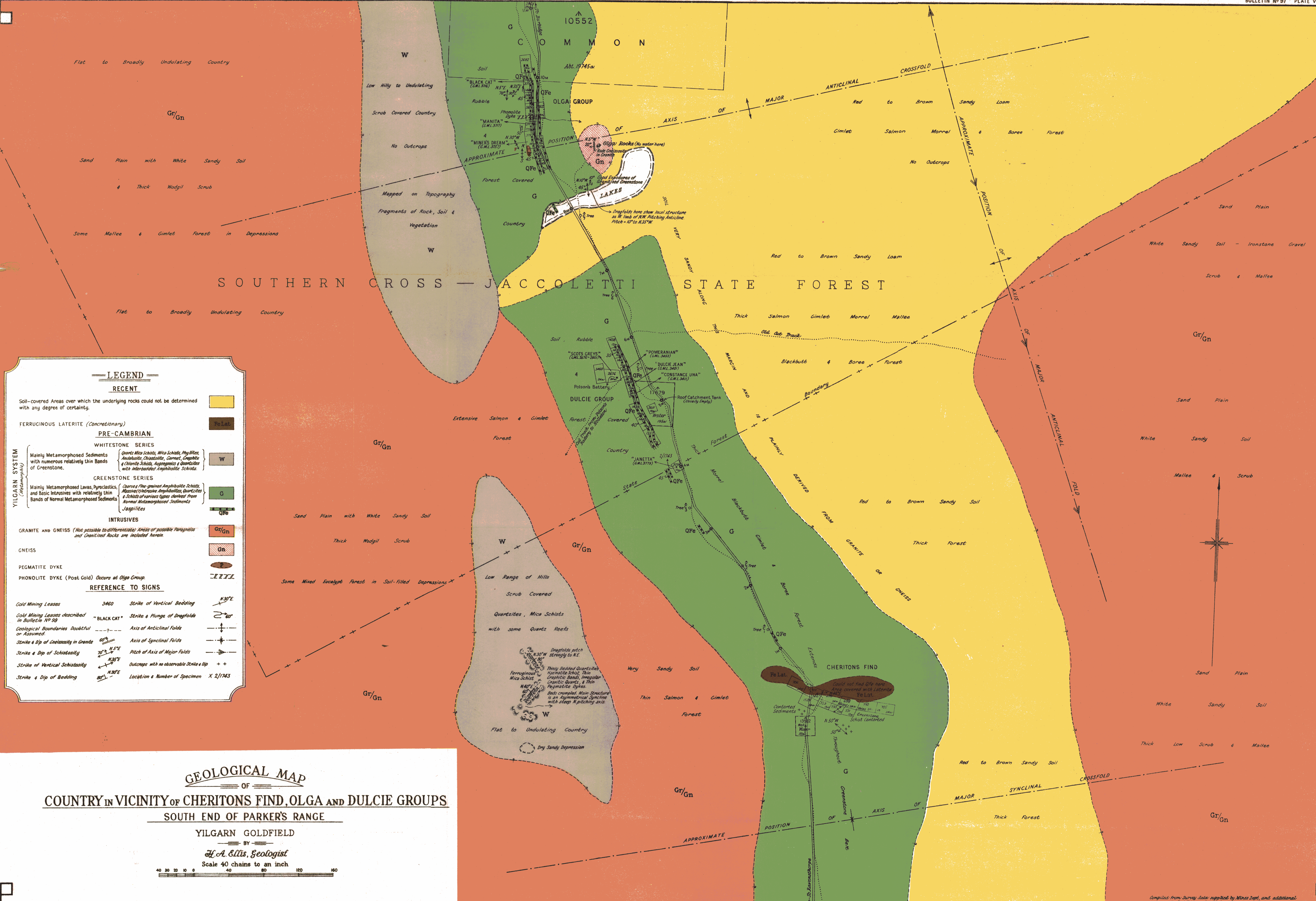
INTRUSIVES

- GRANITE AND GNEISS (Not possible to differentiate) Areas of possible Pegmatites and Granitised Rocks are included herein.
- GRANITE
- GNEISS
- PEGMATITE DYKES
- QUARTZ REEFS

REFERENCE TO SIGNS

- Gold Mining Leases
- Yellowline Gold Development N.L. Leases described in Bulletin No 98
- Geological Boundaries Doubtful or Assumed
- Strike & Dip of Schistosity
- Strike of Vertical Schistosity
- Strike & Dip of Bedding
- Strike of Vertical Gneissosity in Granite
- Strike & Plunge of Dragfolds
- Direction in which Lava Flow Tops face
- Axis of Anticlinal Folds
- Axis of Synclinal Folds
- Regional Pitch of Minor Folds
- Pitch of Axis of Major Folds

Compiled from Survey data supplied by Lands & Mines Dept., with additional traverses by R.A. Hobson, R.S. Matheson and H.A. Ellis 1935-36



LEGEND

RECENT

Soil-covered Areas over which the underlying rocks could not be determined with any degree of certainty.

FERRUGINOUS LATERITE (Concretionary)

PRE-CAMBRIAN

WHITESTONE SERIES

Mainly Metamorphosed Sediments with numerous relatively thin Bands of Greenstone.

GREENSTONE SERIES

Mainly Metamorphosed Lavas, Pyroclastics, and Basic Intrusives with relatively thin Bands of Normal Metamorphosed Sediments.

INTRUSIVES

GRANITE AND GNEISS (Not possible to differentiate) Areas of possible Pegmatites and Granitoid Rocks are included herein.

GNEISS

PEGMATITE DYKE

PHONOLITE DYKE (Post Gold) Occurs at Olga Group.

REFERENCE TO SIGNS

Gold Mining Leases 3460 Strike of Vertical Bedding N30°E

Gold Mining Leases described in Bulletin No 98 "BLACK CAT" Strike & Plunge of Dragfolds 60°

Geological Boundaries Doubtful or Assumed. Axis of Anticlinal Folds

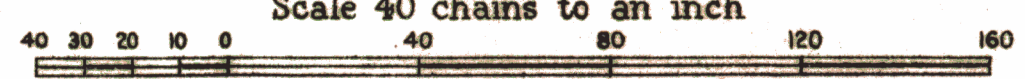
Strike & Dip of Gneissosity in Granite 60° Axis of Synclinal Folds

Strike & Dip of Schistosity 70° N 5° E Pitch of Axis of Major Folds

Strike of Vertical Schistosity N35° E Outcrops with no observable Strike & Dip

Strike & Dip of Bedding 80° N 30° E Location & Number of Specimen X 2/1743

GEOLOGICAL MAP
OF
COUNTRY IN VICINITY OF CHERITONS FIND, OLGA AND DULCIE GROUPS
SOUTH END OF PARKER'S RANGE
YILGARN GOLDFIELD
BY
H. A. Ellis, Geologist
Scale 40 chains to an inch



Compiled from Survey data supplied by Mines Dept. and additional traverses by R. A. Hobson, J. S. Washburn and J. A. Tills, 1935-36