JOURNAL OF
THE ROYAL SOCIETY
OF
WESTERN AUSTRALIA
INCORPORATED

VOLUME 41 (1958)
PART 3

PUBLISHED 10TH SEPTEMBER, 1958

THE

ROYAL SOCIETY

OF

WESTERN AUSTRALIA

INCORPORATED

COUNCIL 1958-1959

President	E. P. Hodgkin, D.Sc., F.R.E.S.
Past President	A. J. Millington, D.Sc. (Agric.).
Vice-Presidents	R. T. Prider, B.Sc., Ph.D., M.Aust.I.M.M., F.G.S. N. H. Brittan, B.Sc., Ph.D.
Joint Hon. Secretaries	D. P. Drover, B.Sc., Ph.D. L. E. Koch, B.Sc.
Hon. Treasurer	R. D. Royce, B.Sc. (Agric.)
Hon. Librarian	G. G. Smith, M.Sc.
Hon. Editor	J. E. Glover, B.Sc., Ph.D.
Hon. Assistant Editor	K. Sheard, D.Sc.

Alison M. Baird, M.Sc.
C. F. H. Jenkins, M.A.
R. J. Little.
L. W. Samuel, B.Sc., Ph.D.
A. C. Shedley, B.Sc., Dip. For.
A. R. Tomlinson.
A. F. Wilson, D.Sc., F.G.S.

10.—Advances in the Knowledge of the Structure and Petrology of the Precambrian Rocks of South-western Australia

Presidential Address, 1957

By Allan F. Wilson, D.Sc.*

Delivered 15th July, 1957

A new tectonic-geological map of one-quarter million square miles of south-western Australia is the result of the first attempt to integrate all known trends of granites and gneisses as well as of "greenstones" and of other metamorphic Precambrian rocks. Granite, gneiss, meta-sediments, "greenstones" and charnockitic rocks have been distinguished on a map of this region for the first time.

The well-known NNW. trend of the Goldfields areas is found to extend in a general way throughout much of the area under review. The strike of the granites conforms to the regional strike of the metamorphic rocks, but on a local scale structural criteria commonly indicate a magmatic emplacement. Granitization contacts are also common. Filter-press differentiation phenomena are known. Major deflections of trend are more common than thought hitherto, and some appear to be related to axes of major cross-folds of unknown origin which trend roughly in ENE. direction. The E. to ENE. trends of the south coast region are interrupted by the Darling Fault but may link with the comparable rocks of the N.-trending Leeuwin-Naturaliste region. A narrow belt of geosynclinal meta-sediments of ? early Precambrian age is thought to separate the E. to ENE.-trending gneisses of the south coast region and the N.-trending gneisses of the Leeuwin-Naturaliste region from the gneisses of the main mass of south-western Australia. It is postulated that along the west coast this meta-sedimentary belt was deposited in a geosyncline which was controlled by a very ancient structure. This crustal weakness, which has been re-activated several times in geological history, is probably related to the present-day "Darling Fault Zone." The meta-sediments are thought to lie beneath the Perth Basin but possibly show as remnants near Nannup and in the Chittering region, and may extend far to the north to the region of Mt. Dalgety near the Gascoyne river. Usually large negative Bouguer anomalies are associated with the thick sedimentary pile in the Perth Basin, and other notable negative anomalies on a traverse from Perth to Kalgoorlie can be related to geological structures.

Summaries are given of the major geochemical and petrographic features of the granites, gneisses, meta-sediments, meta-jaspilites, basic meta-igneous rocks, basic granulites and basic dykes. Comparison of the geochemical features of the granites and gneisses shows that many gneisses are similar in composition to greywacke, but the granites (mostly adamellite, as in the Wheat-Belt) are different, and original greywacke would need to be subject to some K-metasomatism and possibly some Na-metasomatism to produce these granites. The granites of the Darling Range appear to contain more soda and less ferric oxide than those of the Central Wheat-Belt.

Charnockitic rocks are found over a very large area, and they seem to be found in at least four environments in south-western Australia. Firstly, many of them may represent the basement-complex which became newly metamorphosed during the down-warping and partial mobilization of the thin Archaean crust beneath the troughs in which Archaean jaspilites, spilites, tuffs and erosion sediments were being deposited. Secondly, the keel of such a trough may also have been metamorphosed to produce rocks of granulite facies. Thirdly, rocks of charnockitic affinities may also have developed through appropriate thermal metamorphism of the basement-complex caused by injection of mobilized masses of the down-warped basement-complex. Fourthly, they may also have developed by thermal metamorphism (on a regional scale) of a block of the basement-complex which had been thrust down and held in hot zones by faulting on a grand scale. Retrograde metamorphism of many rocks in the "charnockitic area" has complicated the mineral parageneses. Two main periods of formation of the charnockitic rocks of the area are envisaged, viz., early Archaean and late Archaean.

The general significance of the latest estimates of the ages of the granites, pegmatites, and gold-ores of the area is discussed.

Some recommendations for future geological work are made.

Contents

Text Page
Introduction 57
General Precambrian stratigraphy and igneous activity 58
Advances in the geological mapping 59
  Western margins of the Shield 60
  South-coast region 60
  Central Goldfields and elsewhere 60
  General geology 60
  The geological map 60
Structure 60
  The granites 60
    The gross structure 61
    Some minor structural features .. 61
  The gneisses and meta-sediments 63
    The gross structure 63
    Some minor structural features .. 64
  Geophysical data 65
Petrology 68
  The granites 68
    Geochemistry of the major elements 68
    Geochemistry of the minor elements 69
    Petrography 70
  The granitic gneisses 70
    Geochemistry of the major elements 70

---

* Department of Geology, University of Western Australia, Nedlands, Western Australia

        Geochemistry of the minor elements 73
        Petrography 73
    The meta-sediments (so-called "white-stones") 73
    Meta-jaspilites (banded-iron-formations, or "Q-fe") 75
    The basic meta-igneous rocks, basic meta-sediments and basic gneisses and basic granulites 76
    Basic dykes 76
Radioactive-age-determinations 76
The charnockitic rocks 77
    Environments affecting mode of formation 77
    The age of the charnockitic rocks .. 79
Conclusions and recommendations 79
Acknowledgements 80
References 80

Illustrations

Figure Page
1. Filter-press differentiation in granite near Dale Bridge, Western Australia 62
2. Bouguer gravity anomaly and topography profiles from Rottnest Island through Perth to Kalgoorlie, Western Australia 65
3. The variety of chemical composition of some typical granites from Western Australia 67
4. The main chemical differences between the granites from the Darling Range and from the Central Wheat Belt, Western Australia 68
5. A comparison of the chemical composition of the granites of Western Australia and meta-sediments 69
6. Diagram to show the variation of the major oxides from some granites from Western Australia (plotted against SiO_2) 70
7. Some chemical features of the granitic gneisses and metamorphosed sedimentary rocks from Western Australia 71

Tables

Table Page
I. Suggested Precambrian succession in Kalgoorlie region 59
II. Chemical analyses, C.I.P.W. norms, and modes of *granites* from Western Australia 66
III. Chemical analyses, C.I.P.W. norms, and modes of *granitic gneisses* from Western Australia 72
IV. Chemical analyses, C.I.P.W. norms, and modes of some *meta-sediments* from Western Australia 74
V. Chemical analyses, C.I.P.W. norms, and modes of some *basic metamorphic and igneous rocks.* from Western Australia 75

Map

Geological map of the older Precambrian rocks of south-western Australia.

Introduction

On six occasions Presidents of this Society have chosen some aspect of the Precambrian rocks of Western Australia as the subject for a Presidential Address (Clarke 1923; Maitland 1927 and 1928; Forman 1937; Simpson 1939; Prider 1948*a*). The reading of these addresses in chronological order gives a clear picture of many aspects of Precambrian geology and the development of our ideas on some fundamental geological processes. A periodic review of our knowledge of their structure and petrology is essential, for the Precambrian rocks form the basement for all other geological systems in the vast state of Western Australia.

Andrews, David and others have long recognized that the Australasian Precambrian basement possibly extended at one time across Australia to the Tonga-Fiji region and northward to New Guinea. However, since the idea of a progressive easterly growth of post-Precambrian sediments from a Yilgarnian nucleus has been actively propounded by Australian geologists for some time, it would seem that most people have lost sight of an essential fact—namely, that there is a Precambrian basement for the whole Australian continent.

I have earlier expressed the opinion that the tectonic trend is more or less N.-S. or NNW.-SSE. for many of the earliest rocks of Central Australia, Eyre Peninsula in South Australia, and the Broken Hill area of New South Wales. There seems to be an essential structural unity of the Archaean basement of these areas and south-western Australia (cf. Wilson 1953*b*, p. 50), although the basement is transgressed in certain areas by later orogenies. E. S. Hills has recently come to a somewhat comparable conclusion (but with a different emphasis, and by a different approach). He says "Other conclusions that seem inescapable are firstly that the Australian block is everywhere underlain by a pre-Cambrian basement. . . . in the second place, the concept of the addition of successive folded belts to a proto-Australian nucleus disappears. Rather does it seem that the primitive continental mass has fractured both marginally and internally" (Hills 1956, p. 14).

In Africa the structures in the Precambrian basement are of fundamental importance and have had a profound controlling influence on subsequent geological history of that continent (Brock 1956, p. 162). If geologists would come to appreciate the importance of the structures in the Precambrian basement, light might be shed on many problems of "soft-rock" geology in Australia. The tendency today is for oil geologists, for instance, to map the sediments up to the Precambrian contact. Rarely do they note even the major structures in the "hard rocks."

It is with considerable zeal that I approach our subject tonight. In dealing with our present ideas on the structure of the Precambrian rocks of a large portion of the Australian Shield I hope my approach will be of value not only to the geologist who is "at home" in Precambrian rocks, but to those who hitherto have looked upon Shield merely as a frustrating, albeit necessary, source of material for sediments!

The area under review tonight is roughly one-quarter million square miles, lying SW. of a line drawn NW. from Zanthus (about 130 miles E. of Kalgoorlie) to the Murchison River about 150 miles NE. of Geraldton. This takes in not only what is formally called the South-west Division, but portion of the Central Goldfields.

A tectonic map to show the Precambrian rocks for the whole of Western Australia on a scale of 4 miles = 1 inch is in preparation, but it is only this south-westerly portion which is sufficiently advanced to publish at this stage.

In discussing "advances" in the knowledge of the structure and petrology of this region an arbitrary starting point should be taken. R. T. Prider, in 1945, gave his Presidential Address to the Society entitled "Igneous activity, metamorphism, and ore deposition in Western Australia" (published 1948). In this he gave an excellent account of his and other current views of the structure and petrology of the whole of the Western Australian portion of the Shield. Moreover, in 1955, Prider published a brief review on the stratigraphy of the Precambrian rocks of Western Australia, and sought to outline the significant stratigraphic contributions made by all papers on the subject since giving his Presidential Address in 1945. However, since no tectonic map has hitherto been published with either of these reviews, I propose to consider as "advances" contributions to our knowledge which have appeared since 1945.

General Precambrian Stratigraphy and Igneous Activity

Necessary modifications of Prider's 1955 paper are few.

A widely accepted generalized succession of events in the Precambrian of Western Australia is as follows:—

Late Proterozoic or Early Palaeozoic } Basic dykes (dolerite, norite, etc.) and periods of lead and copper mineralization.

igneous contact

Late Proterozoic—Nullagine "System"* (including sediments of the Stirling Range—Mt. Barren Range)

unconformity

Archaean—"Younger Granite" (dominant period of gold-mineralization, + Ta and Li pegmatites)

igneous contact

Archaean—"Older Granite" (gneisses and migmatites—period of granitization)

igneous contact

"Younger Greenstone"

Kalgoorlie "System"

(1) "Whitestones" (mostly erosion sediments).

(2) "Older Greenstones"—the oldest rocks known in Western Australia (mostly basaltic lavas, often spilitic and pillowed, and commonly associated with jaspilite and basic tuffs).

In the Pilbara region (1,000 miles N. of Perth, and outside our area) the oldest rocks are called the Warrawoona "System." These are similar to the Kalgoorlie "System." A younger, possibly Proterozoic succession, of (dominantly) erosion sediments overlies the Warrawoona "System" with unconformity. These are known as the Mosquito Creek "System." Overlying both Warrawoona and Mosquito Creek "Systems" is the widespread blanket of continental-facies erosion sediments and lavas called the Nullagine "system." These rocks are thought to be late Proterozoic or even early Cambrian in age.

In the Kalgoorlie region (Kalgoorlie, Coolgardie and nearby areas) the relationships of the Precambrian rocks to each other are well shown. The main features are set out in Table I.

The main changes in the succession are:—

(i) The Cardup Shales and Yandanooka Group are omitted from Table I. Hitherto, they have commonly been correlated with the Nullagine, and placed in the Upper Proterozoic. Recent work (Logan and Chase 1956, and McWhae *et al.* 1958) shows the possibility that the Cardup Shale, Yandanooka Group and Moora Group may be either of Lower Palaeozoic or Upper Proterozoic age. The Cardup Shale and Moora Group are cut by dolerites, but as yet no dolerites are known to cut the Yandanooka Group. The age of the dolerites along the western margin of the Shield is not known with certainty. However, an age of about 500 million years is possible (see Prider 1955, p. 76, who quotes some "galena" ages on dolerites).

(ii) The *"Younger Granite"*, to which I think the main period of gold mineralization is related, is placed in the Archaean, not Proterozoic. Associated pegmatites at Londonderry and Grosmont (near Coolgardie), Ravensthorpe, (and also Wodgina in the Pilbara Gold Field) are approximately 2800 million years old (see p. 77 for discussion of age-determinations).

Moreover, I consider that what is usually known as the "younger granite" is closely related in time to much of the so-called "older granite" (which is best called a gneiss in most places). Much of the migmatization and metamorphism which we see in the gneisses is due to metamorphism preceding and attending emplacement of the major "younger granite." Although there are probably several medium-grained "younger granites," the major masses of "younger granite" in south-western Australia would appear to be composed of a coarse porphyritic granite. Nor do I entirely agree with Prider and many other Western Australian geologists concerning the tectonic environment of the emplacement of the "younger granite." Prider has said that " .... the "younger" granite was not affected during its emplacement by orogenic movements and so, generally, has no gneissic structure ...." (Clarke, Prider and Teichert 1955, p. 217).

---

* See footnote under Table I.

TABLE I.

Suggested Precambrian Succession in Kalgoorlie Region.

(based on Forman 1953, p. 71, Table 2)

		Probable original rock or process	Rock types (most common types in italics)
Late Proterozoic or Early Palaeozoic	Basic Dykes	Quartz dolerite, norite	*Quartz dolerite*, *uralitized quartz dolerite*, norite
	——(igneous contact)——		
Proterozoic	*Nullagine "System"**	Not present in Kalgoorlie region, but possibly represented elsewhere by Stirling Range Beds	
	——(unconformity)——		
Archaeozoic	*"Younger Granite"*	Granite-emplacement and gold-mineralization	*medium-even-grained granite*, porphyritic granite; pegmatites with Li, Ta, W, Be; gold ores
	——(igneous contact)——		
	"Older Granite"	Period of granitization	*gneiss*, schist
	——(igneous contact)——		
	"Younger Greenstones"	Dominantly sill-injections of dolerite, gabbro and pyroxenite	*uralitized quartz dolerite*, *uralitized quartz gabbro*, *plagioclase-actinolite schist*, hornblendite, chloritized dolerite; some gold ores (Prider, 1948*a*)
	——(igneous contact)——		
	Kalgoorlie "System" *Kurrawang "Series"*	Erosion sediments	slightly metamorphosed *sandstones* and *conglomerates* (with boulders of jaspilite, granite, amphibole schist, etc.)
	(uncomformity assumed)		
	Yindarlgoorda "Series"	Basaltic and andesitic tuffs, agglomerates and interbedded erosion sediments	slightly metamorphosed (becoming schistose) *tuffs* and *erosion sediments*
	Black Flag "Series"	Erosion sediments, basic tuffs, some andesitic lavas	*Slates*, *sandstones*, graphitic slates, shales
	"Older Greenstones"	Basaltic lavas (with pillows), agglomerates, tuffs, narrow shaly intercalations and subordinate jaspilite, periodotite, serpentine	*Meta-basalt*, *plagioclase-actinolite schists*, *serpentine*, *actinolite schist*, *chlorite schist*, slate, jaspilite, talc schist
	(bottom not seen)		

* Names for the major subdivisions of the Precambrian rocks of Western Australia have been widely used long before the publication of the Australian Code of Stratigraphic Nomenclature. Throughout this paper these old terms are used, and shown in inverted commas (*e.g.*, " System "). It is beyond the scope of this paper to bring these terms into strict conformity with the Code. In the near future I hope to collaborate with several colleagues to carry out a thorough revision of the nomenclature of the Western Australian Precambrian rocks.

Although obvious gneissic structure is normally absent. I have been able to map the attitude of platy-flow layers, xenoliths and flow lines in most of the granite areas which are shown on my map. A consideration of the regional and local attitudes of these features leads me to the conclusion that most of the so-called "younger granites" (especially the coarse porphyritic types) were sufficiently affected by normal orogenic forces (or else by deep-seated crustal stresses on a regional scale) to be classed as synorogenic granites. However, some of the smaller bodies of fairly massive granite (in which flow-structures are not obvious) are probably post-kinematic granites. (Compare Prider 1948*b*, p. 109). At Boya, Stathams, Gosnells, Canning Dam, and near-by areas the granite is unusually homogeneous, and flow-layers are not easily recognised. Since these are places close to Perth the tendency has been to consider them typical of the "younger granites." Further afield from Perth (e.g. near Chidlows, Mundaring, the National Park, York, Dale Bridge) there is ample evidence that the granite was affected during its emplacement by orogenic movements (see map). The structures in the granites will be discussed in more detail in the section on "Structure."

The "older granite" is commonly gneissic. It should be remembered that large tracts of gneiss may have resulted from the metamorphism of masses of granites, meta-sediments or gneisses (of various ages). These rocks may have constituted the basement within which narrow Precambrian geosynclines were developed and destroyed. Hence, I believe that within the gneissic complex there is more than one "older granite." Moreover, it is probable that there is more than one major period of "younger granite" emplacement. It is obvious that the terms "younger" and "older" can be of little use except perhaps as local field terms. Unfortunately, the term "older granite" has come to be applied to the bulk of the gneissic complex, and the term "younger granite" to any unmetamorphosed granitic intrusions which appear to cut the gneisses.

Advances in the Geological Mapping

Since World War II the Geological Survey has been active in several parts of the State, but, owing to shortages of staff, the type of regional mapping most useful for a review such as this has been mainly confined to the Murchison, Coolgardie and Phillips River Goldfields. Many smaller areas with specific economic significance have been mapped by the Survey and various mining companies, and other areas have been studied (of necessity, mainly from an academic point of view) by staff and students of the University of Western Australia. For our purposes, a systematic summary of each of these contributions to the mapping or general geology is unnecessary. However, reference is made herewith to most of the recent published and unpublished works which were found useful as background for the preparation of this review and map. References to earlier works may be found in other publications (e.g., Prider 1948*a* and 1955).

Western margins of the Shield

Galena (Prider, pers. comm.), Geraldton (Playford 1953), Irwin River (Johnson *et al.* 1954), Yandanooka (Baker 1952), Bindi Bindi (Johnson 1950c), Moora (Logan and Chase 1956), Gillingarra (Ivanac 1946), Chittering Valley (Geary 1952), Bullsbrook (Jones 1952), Northam (Lord and Gray 1951), Lawnswood (McWhae 1948), York (Johnstone 1952, Willmott 1955), Darlington (Frost 1952), Dwellingup (Parry and Smith 1952), Roelands (Prider, pers. comm.), Collie (Lord 1952).

South-coast region

General review (Clarke *et al.* 1954), Balingup (Chung 1957), Greenbushes (Hobson and Matheson 1949; Ellis 1953*b*), Donnelly river (Ellis 1953*a*; Lord 1950), Jerramungup (Johnson 1950*b*; Wilson 1958*a*), Naendip (Sofoulis 1955*a*), Ravensthorpe (Ellis 1951; Sofoulis 1954 and 1955*b*; Woodall 1955), Young River (Johnson and Gleeson 1951).

Central Goldfields and elsewhere

Murchison (Johnson 1950*a*), Yilgarn (Matheson and Miles 1947; Clappison and Zani 1953; Wilson 1953*a*; Miles 1953), Coolgardie (McMath *et al.* 1953), Kalgoorlie (Campbell 1953; Finucane and Jensen 1953; Utting 1953; Stillwell 1953), Norseman (O'Driscoll 1953; Ellis 1953c), Fraser Range (Wilson 1952 and 1957).

General geology

General review (Geological Survey of W. Australia, map of W.A., 1950; McKinstry 1945; David and Browne 1950; Prider 1948*a* and 1955; Miles 1953), Structure (Prider 1952; Hills 1953 and 1956; Forman 1953; Wilson 1953*b* and 1957), Charnockitic rocks (Wilson 1952, 1955, 1957, 1958b), Mineralogy (Simpson 1948, 1951 and 1952).

The geological map

All published data and structural information from unpublished field sheets and theses housed at the University were plotted on a map of scale 1″ = 10 miles. Published data were found to be surprisingly rare for the region SW. of the Yilgarn Goldfield, and S. of the Yalgoo Goldfield. Even in the Goldfields regions the structural information is mostly of reconnaissance type published (at best) on a scale of 1″ = 4 miles, and of necessity is usually fairly restricted to the gold-bearing areas. Thus the general extent of the so-called "greenstone" belts in which gold usually occurs is fairly well known, even though considerable areas have had to be "mapped" purely on residual soil, vegetation and rare outcrop. However, there has been little or no attempt to map the structures in the granites and gneisses, nor to differentiate the granites and gneisses. Consequently, on my map it has been necessary to show most of the Goldfields areas merely as belts of "greenstones" and undifferentiated granite-gneiss complex. For some of the areas more specific information has been extracted from the published reports and added to the map. It is disappointing to find so little information of tectonic signficance for the granite/gneiss complex of the Goldfields. By way of explanation it should be pointed out, however, that most of the Goldfields were mapped in the early days of settlement in the State by geologists of a Geological Survey severely limited in staff and funds to carry out detailed work in country much of which is semi-desert. Moreover, the significance of platy-flow structures, and linear structures in igneous and metamorphic rocks was not understood, and consequently rarely recorded. In the last few years some of these features have been recorded by the geologists of both the University and the State Geological Survey (e.g. Prider 1944; Sofoulis 1955*b*), and it can be expected that future work will produce a rapid accumulation of tectonic data. The pattern of the faults W. of the Darling Fault as shown on the map is largely that deduced by the geologists of West Australian Petroleum Pty. Ltd. (McWhae *et al.* 1958).

After compilation of all known structural data I made reference to Simpson's "Minerals of Western Australia" (1948, 1951, 1952). Under such headings as kyanite, graphite, magnesite, etc. fairly accurate locations of gneisses, metasediments and other rock-types were recorded as the host rock for the mineral concerned. Moreover, owing to the systematic catalogue and cross-index system employed by the late Professor E. de C. Clarke, and now by Professor R. T. Prider, the collection of about 38,000 rock and mineral specimens in the Geological Museum of the University of Western Australia was very profitably studied for lithological information on the SW. portion of the State. The Curator, Mr. M. Lindsay, was very helpful in assisting to search the collection for data.

A series of reconnaissance traverses made by myself has been largely responsible for delineating for the first time the general outline and structure of the major granite masses and the gneisses in the area W. and SW. of the Yilgarn Goldfield. Over 90% of the structural data for the SW. are due to this survey. In addition to the structural data many new occurrences of jaspilite (common host rocks for gold in the goldfields) and charnockitic rocks were discovered.

All data were originally plotted on the 1″ = 4 miles Military Map Series, but for this paper the map was first prepared on the scale 1″ = 10 miles, and final drafting done on the scale of 1″ = 20 miles. Original maps and specimens are available for inspection at the University of Western Australia.

Structure

The granites[*]

The most obvious feature of the map is the huge expanse of granite. However, this is neither as massive nor as homogeneous nor as continuous as was thought by many of the earlier workers. Most outcrops of granite reveal a measurable *platy-flow structure*. This is produced by orientation of large tabular single

---

[*] The term "granite" is here used as a general field name to describe the fairly homogeneous alkali-granites, adamellites (quartz monzonites) and granodiorites (following Hatch, Wells and Wells 1949). This does not mean, of course, that a more precise name has not been given in the field notebooks, or University catalogue.

crystals or Carlsbad twin-groups of microcline, and biotite or hornblende normally are roughly alined parallel to the feldspar crystals. This is pronounced in many places, particularly near some contacts with the gneisses. However, this is by no means always so, for the feature is known in many places far from wall rocks or known (or presumed) roof rocks. In some places a strong flow-structure is found to be so variable in attitude even in a single outcrop, that turbulent flow is presumed to have taken place.

Linear flow structure, as shown by slightly elongate tablets of microcline or needles of hornblende and ellipsoidal xenoliths, is rarely found. Where noticed, the linear flow structure would appear to have sub-horizontal plunge approximately in the direction of the average strike of the platy-flow layers in the area. Fairly consistent readings of this attitude were made on flatly-dipping platy-flow layers in the Bruce Rock area.

The gross structure.—The strike of the granites in general conforms to the regional strike of the metamorphic rocks of the south-western portion of Australia. This has long been known to be roughly NW.-NNW., and is shown by the attitude of the "greenstone" belts of the Goldfields areas as at Kalgoorlie, Southern Cross and the general trend of gneisses and meta-sediments. On a local scale, however, the granite is commonly discordant and the attitude of phenocrysts and xenoliths implies that the granite has moved as a crystal mush into its present position. In places, too, there are granitization contacts.

In the Yilgarn Goldfield granitic rocks are known to form the core of a regional anticlinal structure which plunges gently south, as shown by the regional swing of the gold-bearing metamorphic rocks SSE. from Southern Cross through Nevoria and then NNE. to Yellowdine. Ellis infers that the largely-concealed granitic core consists of mostly granitic gneiss rather than normal granite, as was supposed by most earlier workers (cf., e.g., Ellis 1939, p.116, and Maitland and Montgomery 1924, p.15). However, from my limited knowledge of the granite outcrops in the area from Kondinin through Hyden to the Yilgarn Goldfield, it would appear that by recording the attitude of the granites a gross regional trend may be readily discovered. The important thing to realise is that this method can be used in areas of poor and isolated outcrop conditions. It is unfortunate, therefore, that no structural data are published of the isolated granite outcrops in the Yilgarn Goldfield between Southern Cross and Holleton, especially in view of the interesting structure which is becoming apparent from the reconnaissance to the E. of Hyden.

Swings in regional trends display an interesting pattern. In the Quairading area the swirls in structure (as shown by the trends in the granite and by the distribution of the charnockitic rocks) are reminiscent of the regional swing of the "greenstone" belt in the Southern Cross-Nevoria-Yellowdine area. Indeed, if a regional synclinal cross-fold be envisaged trending 20° S. of W. through the vicinity of Nevoria, it is perhaps significant that a continuation of the trend of the cross-fold would pass through the similar synclinal cross-fold axis in the Quairading area. Extrapolation in the other direction could link with somewhat comparable tectonic disturbances in the Coolgardie region and possibly the Kalgoorlie region. The significance of these regional structures in the search for gold deposits is worthy of investigation.

Other similarly-trending regional synclinal cross-fold axes may extend from the Dowerin or Koorda region to the Jackson region. As structural information is collected it may be found that the whole south-western part of Western Australia is broken up (in plan) into a series of roughly elliptical domes of metamorphic rocks which have been forced into such an attitude by diapiric up-rising of (palingenetic) granite masses. Subsequent erosion has removed, in many cases, all but the keels of the metamorphic rocks which may represent original geosynclines or material which has slumped into synclinorial attitude between slowly-rising granitic massifs. In the South-west Division relics of small synclinal masses of metamorphic rocks are not uncommon in the granite (e.g. near Danberrin). The significance of the association of granite and some of the jaspilite-bearing belts of metamorphic rocks is further discussed on page 77. It should also be noted that as yet no regular symmetrical domes such as are said to be common in the Pilbara area (1,000 miles N. of Perth) have been recognised in the south-west of Western Australia.

The dip of the granite is mostly steep (actual figures have been left off the map, but the dip is commonly close to 70° or 75° E. or W.). However, granites with sub-horizontal dip occur in the vicinity of Aldersyde (E. of Brookton); granites with very flat southerly dip occur in the area W. of Bridgetown; granites with very flat easterly dip occur between Merredin and Bruce Rock. In some places the attitude of the granite structure suggests turbulent rather than streamlined flow. In such areas either strike or dip (or both) may be too variable to show on the present map. Careful records of such areas, however, have been made on the original 4-mile Military Maps and in due course may prove of use.

In the South-west Division the granite masses are more or less defined, but in the Goldfields areas much of the country has been shown on the map as undifferentiated granite or gneiss. While it is possible, it is by no means certain that granite is more dominant in the South-west Division than in the Goldfields areas.

Large tracts of Western Australia are devoid of large masses of coarse granite. As far as is known, no more than rare narrow micro-granitic dyke-rocks occur in the Naturaliste-Leeuwin area, Northampton area, Fraser Range area, and Lake Grace area. Indeed, large expanses of rocks of the granulite facies containing only very subordinant granite skirt south-western Australia from Ajana, via Albany to Zanthus.

Some minor structural features.—In the Dale Bridge area detailed mapping of minor structures in the coarse porphyritic hornblende adamellite of the area has revealed some interesting filter-press differentiation phenomena. Fig. 1 is a map (generalized, but the contact is accurate) showing the relation of small "pods" of granite to the granitic gneisses. On a regional scale these granite bodies appear to be concordant with

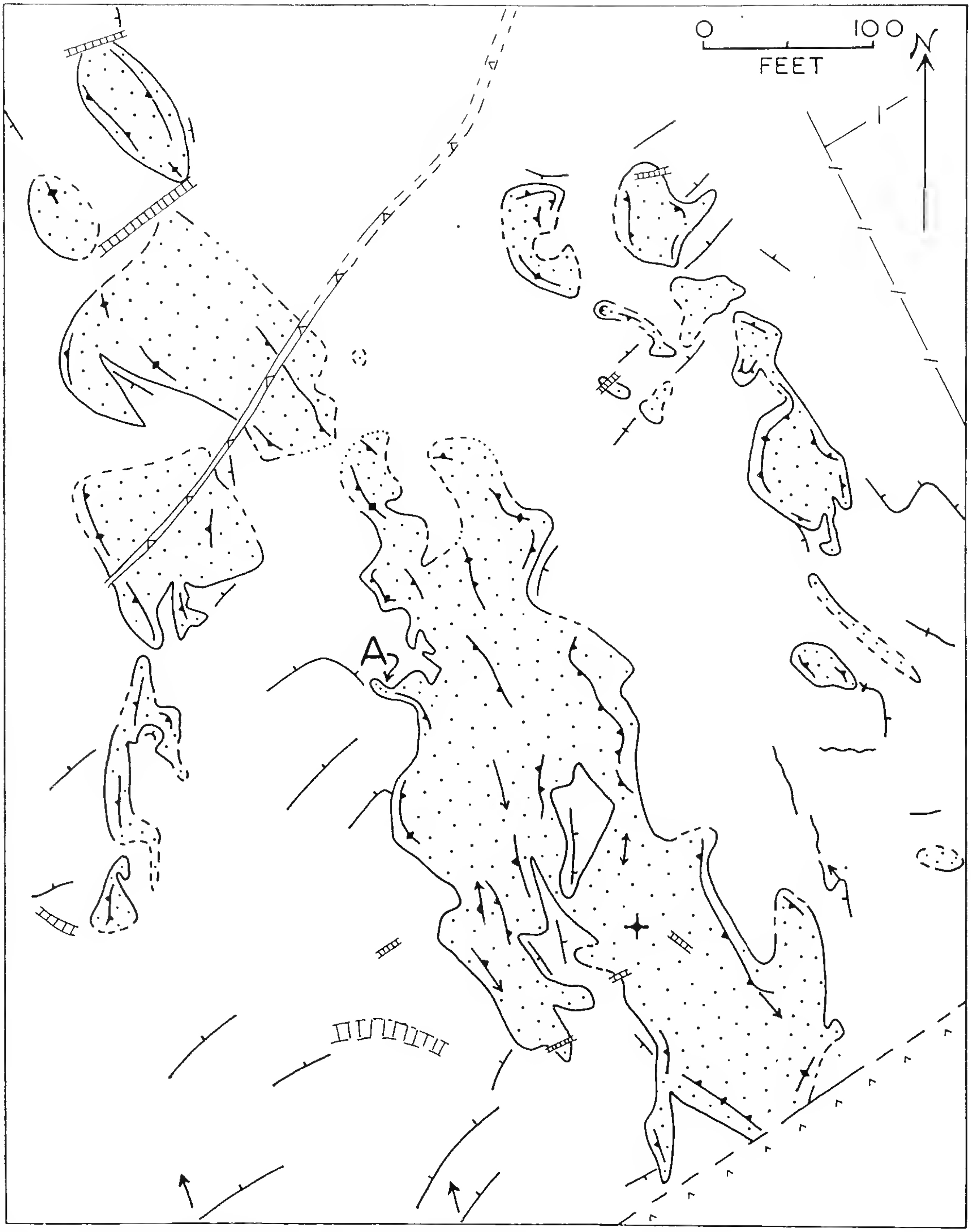

Fig. 1.—Filter-press differentiation in granite near Dale Bridge, W.A. The sketch map shows relationships of coarse porphyritic granite (spots) and gneiss (blank) near Dale Bridge about 6 miles WNW. of Beverley (Beverley 1 mile Military Map, 838, 327; corner fence post in NE. portion of map is about 1200 yd. on bearing 222° (magnetic) from Dale Bridge Siding). The platy-flow layers (normally steeply dipping, except in SE.) tend to parallel intrusive contacts with the gneiss. Flow lines in the granite have flat plunge. Lineation in the gneisses is parallel to the axial lines and in general has flat plunge. At A there is a good example of filter-press differentiation in a structurally favourable position (see text). Microgranites (shaded) and dolerites (shaftless arrows) occur as dykes. Structure symbols are as used on the main map.

the gneisses, but locally almost everywhere are transgressive and indicate forceful injection of crystal mush. In certain structural positions (e.g. at A) abnormal concentrations of phenocrysts of K-feldspar occur. Visual estimation of the concentration suggests that the normal granite contains about 10% phenocrysts (euhedral, and mostly twinned on the Carlsbad law), and the feldspar-rich differentiate about 80%. The concentration is thought to be due to a filter-press mechanism whereby the homogeneous granitic crystal mush was forcibly injected into gneisses which were sufficiently competent to break, yet sufficiently plastic to show drag against the magma. In structural traps phenocrysts appear to have been caught, and the fluid matrix squeezed out into pores and fissures of the gneisses. Granitization has taken place in the immediate vicinity of the filter-pressed pods, but the concentrations of crystals are not thought to be due to growth *in situ* by concentrated fluids.

The great diversity of composition and texture of the microgranites could be accounted for if the microgranites represented the material filter-pressed from the normal granite at various stages during the forceful injection.

The gneisses and meta-sediments

The gross structure.—Structure is much more easily recorded from an outcrop of gneiss than from an outcrop of granite. The strike and direction of dip of the planar structure (foliation) are recorded. The foliation is presumed to be parallel (or nearly so) to the original sedimentary bedding or volcanic flows from which many gneisses have been formed by metamorphism. This is deduced from the relation of gneisses to occasional quartzites, some of which show good current-bedding, as on Nardi near Toodyay (Prider 1944, p.87).

In many places where the dip is shallow (e.g., in the Toodyay region (Prider 1944), the Lake Grace region, Doubtful Island Bay, etc.) the gneisses have been isoclinally folded. Thus at Doubtful Island Bay the gneisses and granulites strike ENE. and dip at low or moderate angles to the SSE., and are isoclinally folded and overturned due to intense deforming forces from (presumably) the SSE. Again, in the large area from Dumbleyung to Newdegate the strike is remarkably constant at about ESE. with a low dip (commonly 30° - 35°) NNE. Study of drag-structures and lineations indicates that the gneisses and granulites have been almost isoclinally folded and there are probably several deep-seated reverse faults which have resulted from thrusting from the NE. or NNE. In general, it is found that steeper foliation planes are overturned limbs of anticlines.

In many of these rocks a lineation is developed due to elongation of hornblende, or orthopyroxene, sillimanite, etc. parallel to the *c*-crystallographic axis and there is a tendency for quartz to form a rough girdle of optic axes normal to the lineation. This is usually sub-parallel to the strike of the foliation and parallel to the axial line of both minor and major folds. On a regional scale the fold axes are considered to have little plunge. The measurement of the attitude of the lineation (*b*-lineation) is very valuable in recognizing changes in plunge of folds, and the presence of "cross-fold" structures (see Prider 1944).

The "down-structure" method of viewing not only maps but rock outcrops is very useful in the interpretation of linear structures, schlieren and minor drags. Quartzo-feldspathic schlieren which are sub-parallel when casually viewed from one direction may prove to be completely folded when viewed down the lineation (see Wilson 1957, p. 4 and Figs. 1 and 2).

In the Phillips River Goldfield Sofoulis (1955*b*, p.67) has recorded that the lineation swings sharply from SSE. near Mt. Short, N. of Ravensthorpe, through S. to the E. of Kundip and takes up the WSW.-ENE. attitude of the rocks of the south coast region.

Near Pemberton in the extreme SW. of the state the lineation appears to take another right-angle bend to link the E.-W. structures of the south coast region with the N.-S. structures of the western margin of the Shield. No detailed mapping has been carried out—indeed, only the broadest of reconnaissance has been done in this heavily timbered and poor-outcrop country. If the interpolations shown on the tectonic sketch are valid it means that the narrow belt of high-grade metamorphic rocks (mostly of granulite or high amphibolite facies) swings rapidly in the neighbourhood of Pt. D'Entrecasteaux and passes beneath younger sediments to join the belt of N.-trending granulites of similar type in the Leeuwin-Naturaliste belt. The dip in the south coast region is dominantly to the S. and often fairly shallow, and drags and lineation commonly indicate more or less isoclinal folding. Lineation where noticed is sub-horizontal. The dip in the Leeuwin-Naturaliste belt is considerably flatter—commonly 20° - 30° E., with a lineation or drag-folds plunging only a few degrees to the N. or just W. of N. If these two areas are joined by a right-angle bend across the no-outcrop area of the graben W. of the Darling Fault the following important structural considerations emerge:—

(i) There would appear to have been potent thrusting from the E. to develop the structures in the Leeuwin-Naturaliste belt. Thrusting from the E. (or ENE.) is a common feature of many parts of the Shield for about 200 miles E. of Perth, but particularly in the charnockitic terrains (as shown in the tectonic sketch). The Leeuwin-Naturaliste belt, therefore, has more obvious structural affinities with the main south-west region than with the south coast region.

(ii) The narrow belt of Al-rich meta-sediments and associated migmatites and normal gneisses which makes a right-angle bend E. of Ravensthorpe and continues westward N. of the charnockitic belt of the south coast would thus make another right-angle bend in the neighbourhood of Pemberton. Thus the meta-sediments may continue northward between the Leeuwin-Naturaliste belt and the main Shield area, but only to be mostly concealed as the basement rocks beneath the sediments of the Perth basin. Some similar pelitic schists occur just E. of the Darling Fault in the Nannup-Donnybrook area, and further N. in the Chittering Valley the Chittering "Series" could be their extension. Kyanite, staurolite, garnet and anthophyllite are common in the schists and gneisses of the whole belt from Ravensthorpe through Nannup to Moora. A further continuation of the meta-sedimentary belt may be the Mullingarra Inlier. In the vicinity of Yandanooka rocks somewhat similar to those of the Chittering area are found, but geological information from the main Shield area to the E. is so scanty that such correlations on grounds of lithology and trend lines are unwarranted.

Most geologists in Western Australia (e.g., Prider, McWhae and others have looked upon the Chittering meta-sediments as being of the same age as the Jimperding rocks (near Toodyay). Lithological differences have been considered to be due to a sedimentary facies change whereby the more-sandy Jimperding meta-sediments have given way along the strike to more-pelitic Chittering meta-sediments.

My reasons for preferring to link the Chittering rocks with the Al-rich meta-sediments of the Pemberton-Ravensthorpe area are—

(i) A need to continue northwards the Al-rich meta-sediments of the Nannup region.

(ii) Apparent absence of banded-iron-formations in the Chittering area, whereas they are common in the meta-sedimentary belt which trends SE. through Wundowie in the Toodyay-Northam belt of meta-sediments and gneisses. The banded-iron-formations of the Northam area, moreover, appear to continue NNW. through Bolgart and possibly into the New Norcia area.

A fault has been postulated to separate the rocks of the Wundowie-Toodyay areas from the Chittering meta-sediments. Several anomalies of tectonic strike and lithology can be separated by a fault along the Avon River gorge. Such a postulated fault could be called the "Avon Fault." Moreover, a major break (? strike fault) probably separates the high-grade and medium-grade metamorphic rocks of the area E. and W. (respectively) of a line from New Norcia to W. of Bolgart. However, it should be noted that banded-iron-formations also occur in the Ravensthorpe area, although these are rare or absent from the south coast region.

(iii) Large tracts of low to medium-grade metamorphosed pelitic and other sediments of types commonly found in the Chittering and Nannup-Pemberton areas are found far to the north in the Mt. Dalgety region near the Gascoyne River. These rocks form the eastern margin of the northerly continuation of the Perth Basin into the Carnarvon Basin. Although they have been pegmatized by Precambrian granites, the grade of metamorphism is rarely very high. Kyanite and staurolite schists are known from many parts. It is interesting to note, however, that Prider (pers. comm.) has noted a type of banded-iron-formation on Mt. Dalgety.

(iv) The trend of fold-axes and strike of the meta-sediments and gneisses on the W. margin of the shield is N.-S. and regionally consistent, whereas the general trend of the meta-sediments and gneisses of the Jimperding "Series" and its extensions through York is more nearly NW.-SE. or NNW.-SSE.

I think the Jimperding "Series" is comparable in age to the Kalgoorlie "System," whereas the Chittering "Series" and the meta-sediments of the Gascoyne and south coast region (those of the Pemberton-Ravensthorpe area, but not the (younger) Mt. Barren and Stirling Range Beds) are likely to belong to the Mosquito Creek "System." They may have been deposited in a long narrow geosyncline, the remnants of which are wrapped around the present SW. margin of the Shield. During metamorphism and granitization the rocks have become fused to the older basement somewhat after the manner envisaged by Sofoulis for the Ravensthorpe area in the Phillips River Goldfield. He says that "the general impression gained from recorded foliation trends of the gneissic terrains, in conjunction with structural axes, strike and distribution of Archaean lithologic units, is that the geological structure of the Phillips River Goldfield forms the south-eastern portion of an arcuately arranged geosynclinal belt, circumferentially disposed about, and welded to, a primitive but stable "Yilgarn"-trending nucleus located north-west of the Jarramungup-Ravensthorpe road" (1955*b*, p.67).

Some minor structural features.—The recognition of *boudinage structure* is important when mapping in highly granitized terrains such as the Avon valley near York and Beverley. Boudins of quartzite or basic granulite a few inches long are commonly found enclosed in granitic gneisses. The relationship between the gneiss and the quartzite or basic granulite boudins is one which suggests that strata differing greatly in competency have been deformed. The granitic gneiss (? originally a pelitic greywacke—see p. 72) would appear to have been the least competent of the original rocks and has actually flowed plastically around the ruptured ends of the (now) discontinuous band of the more competent quartzites (originally pure sandstones) and basic granulites (originally basic dykes or sills or flows, and perhaps basified or impure calcareous rocks). Such boudins have been recognised in all sizes from a few inches long to large relics ⅛th mile long, and appear to "float" in regular "stratigraphic" positions in the gneisses. Such relics of grossly dismembered competent bands may be easily confused with xenoliths in a magmatic rock. Careful mapping commonly shows (as in the Dale Ridge area) that any movement of the host gneiss has been relatively small and localized to zones of considerable relief of pressure. Moreover, portions of the gneissic complex appear to become completely mobilized in places, in which case relics of competent material become strewn chaotically through the granitic mass. A detailed description of the Dale Bridge area, where many of these phenomena may be seen, is in hand.

Geophysical data

Bouguer anomaly and topography profiles from Rottnest Island through Perth to Kalgoorlie are shown in Fig. 2. Thyer and Everingham (1956) interpreted the exceptionally large negative anomaly (up to about 130 milligals) on the coastal plain near Perth, as being due to very thick pile of sediments (up to 35,000 ft. near Watheroo), on a down-faulted block of the basement.

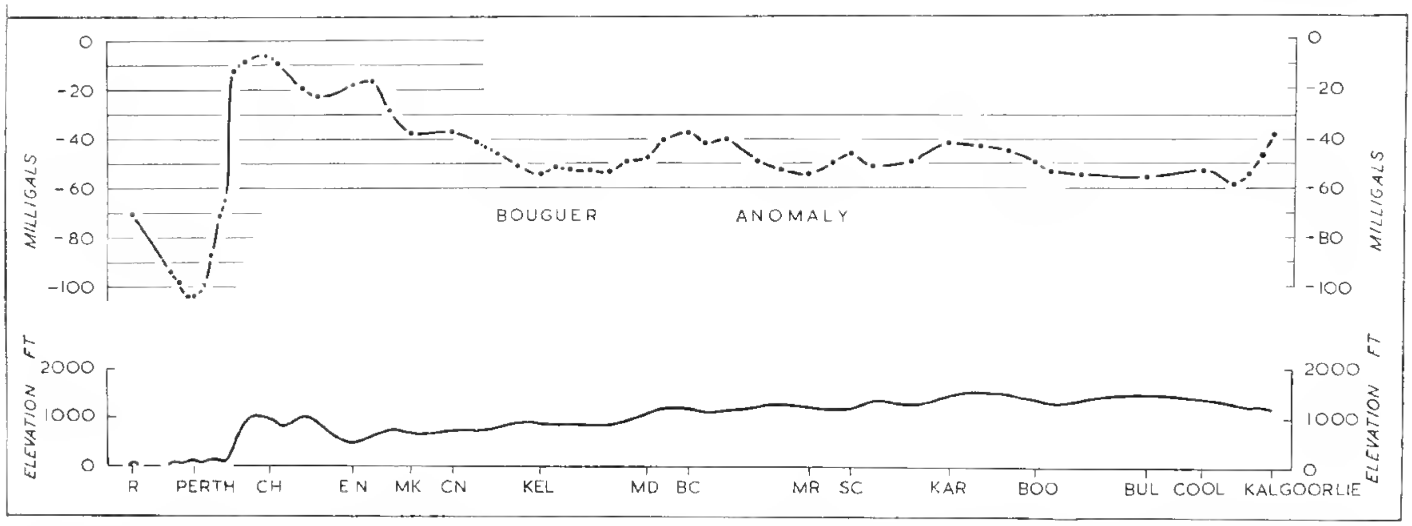

Fig. 2.—Bouguer gravity anomaly and topography profiles from Rottnest Island through Perth to Kalgoorlie (after Thyer and Everingham 1956, plate 3). See text for explanation of the large but variable negative gravity anomalies. R = Rottnest Island, CH = Chidlow, EN — East Northam, MK = Meckering, CN = Cunderdin, KEL = Kellerberrin, MD = Merredin, BC = Burracoppin, MR = Moorine Rock, SC = Southern Cross, KAR = Karalee, BOO = Boorabbin, BUL = Bullabulling, COOL = Coolgardie.

The rapid decrease in the anomaly to the E. is obviously related to the major structure known as the Darling Fault. The Bouguer anomaly curve continues to rise to about —10 and remains mostly above —20 till somewhat east of Northam. From there to Kalgoorlie the curve falls again and maintains a large Bouguer anomaly of roughly —50 (±10) milligals.

At the time of publication of the original curves (Thyer and Everingham, 1956) the structure and composition of the crust along the traverse line were unknown except for the "greenstone" belts of the Yilgarn and Coolgardie-Kalgoorlie region and the "sea of granite" which engulfed the Goldfields.

My interpretation of the curve in the light of our increased knowledge of the geology is as follows.

(i) There is a graben under Perth with the eastern side of the graben a major reversed fault zone, dipping fairly shallowly to the E. There are several mylonite zones near the Darling Scarp where overthrusting from the E. seems indicated at some time during its history. The structure in the Shield itself for some 200 miles eastward from Perth suggests general thrusting from the E. Thus the Darling Fault is considered to be an early Precambrian fundamental structure along which movement has taken place in (possibly) several directions at various times. At the present time the Darling Fault in the vicinity of Perth would appear to be a normal fault dipping very steeply to the W. Normal faulting may be expected to modify original reverse faulting if the "ramp hypothesis" to explain the formation of many graben is accepted as reasonable. Moreover, the width of the coastal plain and magnitude of the gravity anomalies are significantly comparable with the average width and gravity anomaly of the Rift Valleys of Central Africa (see Holmes 1954, p.440, Fig. 232).

I agree with Vening Meinesz (1948), Thyer and Everingham (1956) and others that the very large negative anomaly on the coastal plain is due to a thickening of the crust by addition of a thick pile of Palaeozoic and later sediments to a sunken sialic crustal block. Vening Meinesz also believes, as I do, that the original structure may have been a major overthrust from the E. However, in view of my comments on p. 63, I would tentatively suggest that some of the anomaly may be due to the possibility that the uppermost portion of the basement is composed dominantly of Precambrian sediments (of moderate metamorphism and thus low S.G.) and is not merely the normal granite-gneiss complex. As has been pointed out above, these meta-sediments are thought to have been deposited in a long narrow geosyncline, some of the remnants of which may still be seen in places along the W., SW. and S. margins of the Shield. Indeed, the formation of such a geosyncline itself may have been stimulated by the presence of a very early crustal weakness somewhat westward of what is now known as the Darling Fault. The Cardup Shale and the Moora Group, however, were probably deposited in another depression which subsequently was formed along the same crustal weakness.

(ii) The marked rise in gravity values between the Darling Fault and a point a little E. of Northam has been interpreted by Thyer and

TABLE II.

Chemical analyses, C.I.P.W. norms, and modes of Granites *from Western Australia*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO_2	74.56	75.40	64.76	67.29	68.65	62.08	66.90	68.11	71.40	73.80	71.32	70.40	75.83	72.00	68.56	73.36	73.49	74.80
TiO_2	0.05	0.05	0.97	0.87	0.41	0.54	0.63	0.74	0.38	0.23	0.11	0.34	0.08	0.38	0.24	0.04	0.14	0.14
Al_2O_3	14.58	12.68	13.99	12.06	14.75	15.94	14.76	15.77	14.73	13.42	15.14	14.18	14.11	12.46	16.64	13.88	14.24	13.93
Fe_2O_3	tr	0.76	2.07	1.72	1.78	0.76	0.32	0.11	1.01	0.71	0.67	0.50	0.49	0.62	0.89	0.84	0.88	0.78
FeO	0.78	0.44	3.52	4.60	1.62	3.56	5.01	2.99	2.38	1.00	0.54	1.67	0.12	3.13	1.77	0.93	0.92	0.97
MnO	0.22	0.13	0.27	0.35	0.14	0.08	0.12	0.16	tr	0.17	0.08	0.37	tr		0.03	0.15	tr	0.02
MgO	0.28	0.16	1.41	1.09	1.62	2.88	0.93	1.75	0.14	0.54	0.43	1.34	0.25	0.27	0.73	0.51	0.43	0.22
CaO ...	1.65	1.01	3.86	3.43	2.78	4.32	2.46	3.79	1.92	0.79	1.47	3.00	0.55	1.41	2.51	1.69	1.84	1.92
BaO			0.12												0.06	0.09	0.07	*nil*
Na_2O	3.92	3.14	3.42	3.15	3.52	3.56	2.42	4.58	2.92	3.54	5.25	5.18	3.12	3,47	4.14	3.22	3.86	3.89
K_2O	3.82	4.68	3.46	4.10	3.56	5.12	5.04	0.76	4.46	4.96	3.14	1.88	5.32	5.89	3.24	5.07	3.42	3.30
H_2O+	0.28	0.58	0.59	0.53	0.54	0.58	0.93	0.86	0.62	0.39	0.40	0.56	0.41	0.26	0.97	0.18	0.55	0.14
H_2O- ...	0.02	0.03	0.03	0.05	0.07	*nil*	0.08	0.11	0.08	0.01	0.16	0.06	0.13	0.15	0.03	0.11	0.08	0.24
P_2O_5	tr	0.04	0.47	0.76	0.13	0.51	0.21	0.28	0.05	0.10	0.57	0.14	0.20		0.12	0.07	0.01	0.05
CO_2	*nil*	0.88	0.16	0.37	0.15	*nil*	*nil*	0.21	*nil*	0.01	0.20	*nil*	*nil*	0.03	*nil*	*nil*	0.07	
FeS_2	0.06	0.19	0.49	0.21	0.06			0.17		0.23	*nil*	0.22	tr		0.02	0.05	0.01	
	100.22	100.17 (1)	99.89 (2)	100.58 (3)	100.03 (4)	99.93	99.81	100.39	100.09	99.92 (5)	99.61 (6)	99.84	100.61	100.07	99.96 (7)	100.19	100.01	100.40

Add (1) F = tr, ZrO_2 = tr, B_2O_3 = tr ; (2) V_2O_3 = 0.30, Cr_2O_3 = *nil*, ZrO_2 = tr ; (3) ZrO_2 = tr, B_2O_3 = tr ; (4) V_2O_3 = 0.25, Cr_2O_3 = *nil* ; (5) F = 0.02 ; (6) F = 0.13 ; (7) V_2O_3 = *nil*, Cr_2O_3 = *nil*, ZrO_2 = 0.01.

C.I.P.W. Norm

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
quartz	32.38	36.76	21.88	24.68	26.53	8.50	23.88	27.08	31.62	31.47	26.91	24.62	36.28	25.09	24.85	30.43	33.18	34.82
o'clase	22.56	27.62	20.39	24.17	21.07	30.23	29.47	4.50	26.69	29.29	18.50	11.11	31.40	34.73	19.12	29.90	20.17	19.45
albite	33.15	26.59	28.95	26.64	29.76	30.11	20.44	38.76	24.63	29.95	44.42	43.85	26.38	29.37	35.04	27.22	32.68	32.94
anorth	8.18	4.76	12.60	6.68	12.01	12.38	11.40	15.80	9.45	3.24	2.42	9.88	1.56	1.03	11.91	8.12	8.76	9.18
corund	1.00	0.70			0.68		1.22	1.62	1.53	1.03	2.22		2.65		1.96	0.12	0.98	0.60
di wo			1.25	2.44		2.50						1.74		2.40				
di en			0.63	0.77		1.40						0.92		0.33				
di fs			0.60	1.76		1.00						0.77		2.30				
hyp en ...	0.70	0.40	2.89	1.94	4.05	5.77	2.30	4.36	0.30	1.35	1.07	2.41	0.62	0.34	1.82	1.27	1.07	0.54
hyp of	1.77	0.33	2.79	4.46	0.90	4.14	7.92	4.47	2.90	1.19	0.40	2.00	*nil*	2.31	2.16	1.21	0.73	0.94
mag		1.11	3.47	2.50	2.95	1.11	0.46	0.16	1.39	1.02	0.97	0.72	0.16	0.90	1.30	1.23	1.27	1.13
ilm ...	0.09	0.09	1.84	1.65	0.76	1.03	1.22	1.41	0.76	0.44	0.21	0.65	0.15	0.73	0.46	0.08	0.27	0.27
pyrite	0.06	0.19	0.49	0.21	0.06			0.17		0.23	*nil*	0.22	tr		0.02	0.05	0.01	
apat	tr	0.10	1.11	1.82	0.30	1.21	0.34	0.67	tr	0.24	1.34	0.34	0.47		0.27	0.17	0.02	0.13
calc			0.36		0.34			0.48		0.02	0.45			0.07			0.16	
										fluor = 0.02	fluor = 0.16		haem = 0.38		zirc = 0.02			

Mode

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	q olig K-fel zois bio horn ep ilm zir ap	q K-fel alb musc calc zir tourm	olig q K-fel bio horn ilm ep ap zois zir (8)	olig K-fel q bio horn ilm mag zois ap pyr (9)		olig K-fel diop bio q hyp ilm mag ap horn	K-fel q olig bio horn mag ilm calc ap	olig q bio horn ilm leucox ap pyr	q K-fel olig bio ap mag zir	alb q K-fel bio chlor mag ilm musc limon leucox (10)	alb q K-fel horn ep bio ap mag calc sph (11)	olig q K-fel bio horn sph ep zois ilm zir (12)	q K-fel alb bio musc kaol	K-fel alb q bio chlor mag ep		K-fel olig q ep bio zois horn ap	q olig K-fel	K-fel olig q bio mag ep

Add (8) sph ; (9) zir, chlor, ep, tourm ; (10) rut, sph, fluor ; (11) fluor : (12) ap.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
S.G.	2.64	2.66	2.77	2.74	2.67	2.755	2.70	2.74		2.64	2.65	2.67	2.61	2.62	2.71	2.66	2.71	2,66

1 Adamellite, *Beeragoona* (Simpson 1948, p. 24).
2 Muscovite adamellite, *Mt. Mulgine* (Simpson 1948, p. 24).
3 Coarse porphyritic biotite-hornblende granodiorite, *Jitarning* (Simpson 1948, p. 24).
4 Coarse porphyritic biotite-hornblende adamellite, Reserve 9935 near *Jibberding* (Simpson, unpub. ms., p. 20).
5 Coarse porphyritic biotite adamellite, Reserve 10187 *Dilling*, near Corrigin (Simpson, unpub. ms., p. 20).
6 Coarse porphyritic pyroxene adamellite. *Jerramungup* (Wilson 1958*a*).
7 Coarse porphyritic biotite adamellite, *Albany* (Clarke, *et. al.* 1954, p. 43).
8 Coarse even-grained biotite-hornblende granodiorite, *Ravensthorpe* (Woodward, *et. al.* 1909, p. 21).
9 Coarse porphyritic biotite adamellite, *Esperance* (Clarke, *et. al.* 1954, p. 43).
10 Coarse even-grained biotite alkali granite, *Mt. Ridley* (Simpson, unpub. ms., p. 16).
11 Coarse even-grained hornblende soda-granite, *Mt. Norcote* (Maitland 1925, p. 112—n.b., F. quoted, in error, as S).
12 Biotite-hornblende granodiorite, *Coolgardie* (Simpson 1916, p. 16).
13 Muscovite-biotite alkali-granite, *Southern Cross* (Saint-Smith and Farquharson 1913, p. 57).
14 Biotite alkali-granite, *Bannister* (Simpson 1916, p. 18).
15 Biotite granodiorite, *Mundaring* (Simpson, unpub. ms., p. 18).
16 Biotite adamellite, *Mahogany Creek* (Simpson 1916, p. 18).
17 Biotite adamellite, *Boya* (Simpson, unpub. ms., p. 16).
18 Medium-even-grained biotite adamellite, *Canning Dam* (Prider 1945*a*, p. 142).

Everingham as due to a crustal-thinning which has brought nearer to the surface the basic substratum. This was thought to be related to movement and subsequent erosion in the vicinity of the fault. This interpretation is attractive, and may partly explain the abundance of dolerite dykes which are concentrated in the area. However, the depth of erosion implied by the thinning of the crust is not borne out by petrography. The grade of metamorphism only reaches that characteristic of the granulite facies east of Northam.

(iii) Eastward of Northam the gravity anomalies can be more easily interpreted. The first major slump in gravity corresponds to the granite batholith which extends from west of Meckering to the east of Merredin. Had gravity measurements been made between Meckering and Cunderdin I would have expected a slight rise in the curve to indicate the narrow belt of gneisses in that region. A slight rise appears near Kellerberrin, and may reasonably be interpreted as reflecting the presence or proximity of gneisses extending NNW. beneath soil-cover from a lobe of gneisses W. of Bruce Rock.

The area is one of poor outcrop, and beneath the soil-cover (e.g., near Tammin) there are probably minor patches of metamorphic rocks. However, the general smoothness of the curve between Cunderdin and Merredin indicates that the area is probably composed mostly of homogeneous granite.

(iv) E. of Merredin the marked rise in the curve corresponds to the gneisses and basic metamorphic rocks of the Burracoppin and Westonia areas.

(v) The next peak corresponds to the basic metamorphic rocks of Southern Cross region, but the anomaly of only —50 milligals to the E. suggests that there the rocks are mixed gneiss and granite. To the W. of Southern Cross, however, the greater anomaly may suggest a preponderance of homogeneous granite rather than gneiss.

(vi) In the vicinity of Karalee a major increase in gravity cannot be accounted for on our present knowledge of the basement rocks because a veneer of sand or laterite obscures hundreds of square miles of this area. The Bouguer anomaly is such that a major belt of basic metamorphic rocks could be expected. It is recommended that an aeromagnetic survey be

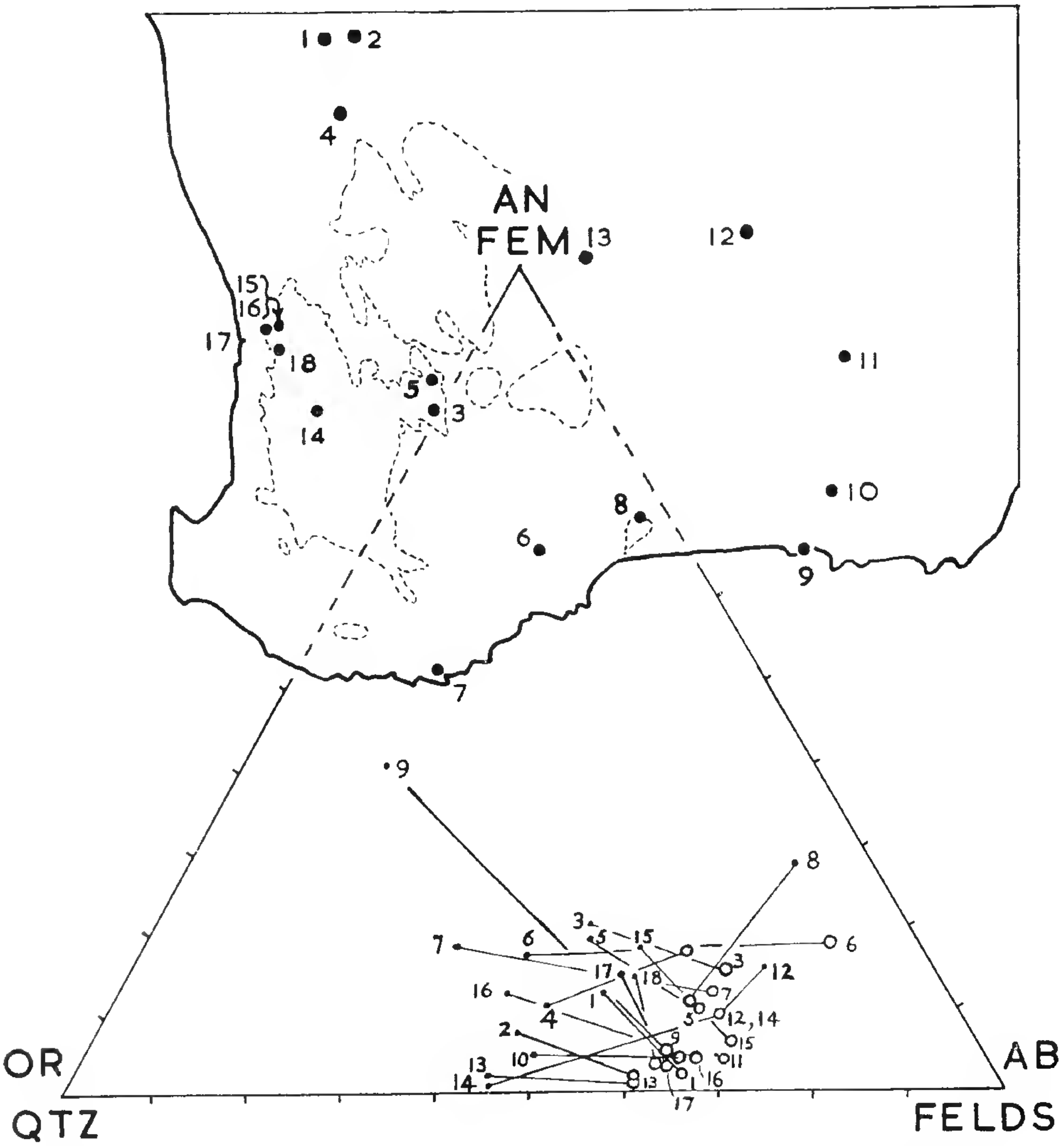

Fig. 3.—The variety of chemical composition of some typical granites from Western Australia as revealed by the proportions (from C.I.P.W. norm) of orthoclase-anorthite-albite (shown by dots), and quartz-femic minerals-feldspar (shown by circles). Approximate locations are indicated on the map (see also legend, Table II).

undertaken to try to discover whether a continuation of one or more of the iron-bearing and gold-bearing Koolyanobbing and Bremer Range belts of "greenstones" may be discovered in the area.

(vii) To the E. of the Karalee area the monotonous low gravity readings suggest granite, and the slight increase in gravity near Coolgardie is to be expected as the fringe of Eastern Goldfields is entered.

(viii) The belt of Kurrawang sediments between Coolgardie and Kalgoorlie is well shown, as is also the marked increase in gravity as the Kalgoorlie area, with its abundance of basic rocks at the surface and to a considerable depth, is approached.

Further correlations between gravity and geology may be deduced if careful comparison is made of Plate 2 of Thyer and Everingham (1956) and my map.

Petrology.

The granites

Geochemistry of the major elements.—Most of the available analyses of the granites of south-western Australia are set out in Table II (micro-granites have been omitted).

The considerable variety of composition is shown in Fig. 3, in which appear the proportions (from C.I.P.W. norm) of orthoclase-anorthite-albite (shown by a dot) and quartz-femic minerals-feldspar (shown by a circle). An attempt is made in Fig. 4 to show the degree of similarity between the granites from related batholiths. No. 3 and 5 represent the coarse porphyritic biotite-hornblende granodiorites and adamellites from the Corrigin area. In hand-specimen No. 4, the granite from Jibberding (NE. of Miling), is a similar adamellite. These three rocks may be taken as representative of several hundred square miles of south-western Australia. They show orientation of well-formed phenocrysts of K-feldspar, but cataclastic phenomena are rare or absent. Metamict allanite (mostly as granules 3mm × 2mm) is a common accessory. Somewhat more acidic varieties of similar granites are known from the Bencubbin and Koorda areas. Many of these show purple fluorite in hand-specimen. Preliminary chemical work suggests that coarse porphyritic granites of these areas are more potassic than the granites with comparable silica content from the Darling Range near Perth.

In Fig. 4 ellipses are drawn around the composition points to emphasize their geographic and chemical similarity. On the same diagram (Fig. 4) are superimposed points for four granites of the Darling Range near Perth, and one from Bannister SE. of Perth. According to the available evidence these should be of comparable age to the granites of the Corrigin region. However, the granites of the Darling Range appear to be less femic and possibly more sodic than the granites further east near Corrigin (see also Fig. 6 and associated discussion). Fig. 5 shows the difference in femic character of the granite of the two areas by plotting or, ab, and femic + anorthite + corundum. The purpose of plotting these values was to see if some of the granites showed a relationship suggesting albitization or K-metasomatism from originally more mafic and calcic rock-types. However, no such simple relationship is apparent for the granites—nor for the gneisses (see Fig. 7).

Scrutiny of Fig. 5 shows other features. The bulk of the granites have K-feldspar and Na-feldspar in approximately the same proportions (with Na-feldspar normally slightly in excess) but the granites from Ravensthorpe (8), Coolgardie (12), and Mt. Norcote (11) are considerably more sodic than the normal adamellites and granodiorites of south-western Australia. The length and direction of slope of the "join" for these rocks in Fig. 3 indicate their essential chemical features. The high K-feldspar content of the granites from Esperance (No. 9) and Albany (No. 7) may be a reflection of the coarse porphyritic character of these rocks and the difficulty of accurate sampling.

The gross chemical features of these granites are shown more clearly in Fig. 5. It is clear that none of the granites shows a composition similar to either shale or greywacke (as plotted). However, the granites could be conceived of as having been produced by K-metasomatism and reconstitution of average greywacke (e.g. the granites from the Corrigin area, and those from Albany, Esperance, and Jerramungup). Most of the other granites could be thought of as having been produced from average greywacke by albitization followed in most cases by partial replacement by K-feldspar. These phenomena can be recognized in thin-section in many of these rocks, but the granites have all been so thoroughly re-constituted that details of the process are not known.

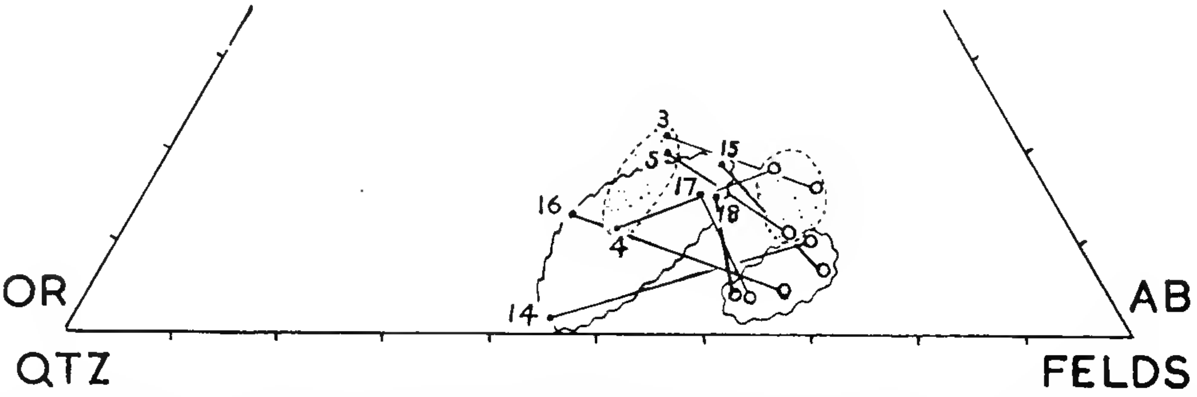

Fig. 4.—The main chemical differences between the granites from the Darling Range (clear ellipsoids) and from the Central Wheat Belt (e.g., near Corrigin). The figure is a truncated Larsen diagram comparable with Fig. 3 (q.v. for locations and legend).

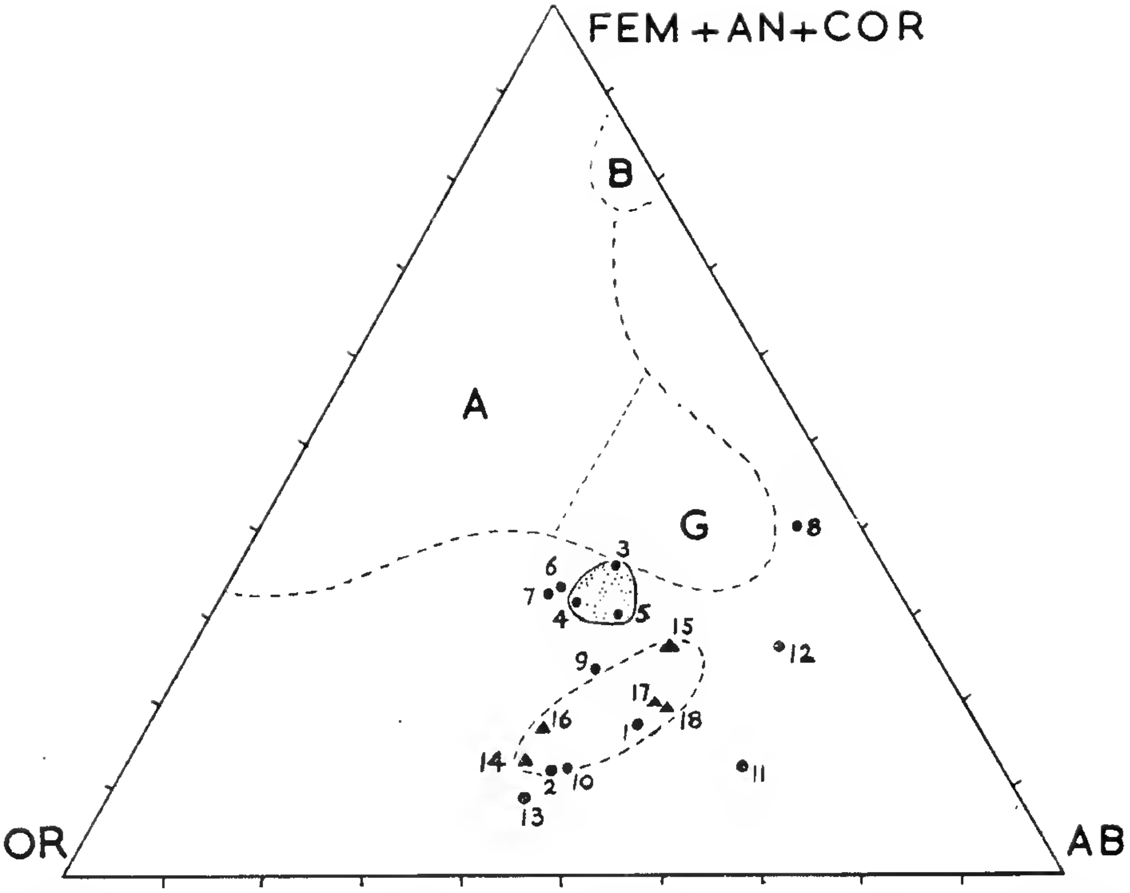

Fig. 5.—A comparison of the chemical composition of some typical granites from Western Australia and metasediments, as revealed by the proportion of orthoclase, albite, and combined femic minerals—anorthite—corundum (from C.I.P.W. norm), A = field of argillites, B = field of basic igneous rocks, G = field of greywackes. Note that the granites from the Central Wheat Belt (in stippled field) differ somewhat from those of the Darling Range (solid triangles in the open field). Other W.A. granites shown as spots. Legend and locations are as for Fig. 3.

One of the simplest ways to illustrate variations in the constituent oxides of a group of rocks is by the well-known "Harker diagram." In Fig. 6 the main oxides of the granites from south-western Australia have been plotted against silica. Superimposed on the diagram are curves (about which there is almost negligible scatter of ten analyses) showing variations in composition of the Precambrian granites of a large portion of Central Australia. These analyses of the Central Australian granites (Wilson 1954) represent the most extensive body of chemical data available for comparison from elsewhere in the Australian Precambrian Shield. The broad scatter of points for the south-western Australian granites is not surprising when it is realized that the granites are from widely separated places and are often different in appearance, texture, and geological environment. Moreover, it is possible that the plotted granites may be of different geological ages. The granites of the Darling Range (from Mundaring, Mahogany Creek, Boya and Canning Dam, but neglecting the more distant one from Bannister as being somewhat anomalous) show well-defined variation trends which are distinctly different from those of the Central Australian suite. The variation trends of the two analyses from the granites of the Corrigin region (from Dilling and Jitarning) which are typical of a large portion of south-western Australia differ somewhat from those of the Darling Range and from those of Central Australia.

The following generalizations appear from a study of Fig. 6:—

(i) Most granites from south-western Australia contain
  (a) less iron (both ferrous and ferric)
  (b) less potassium
  (c) more sodium
  (d) more combined water
 than those of Central Australia.
(ii) Granites from the Darling Range near Perth contain slightly
  (a) less ferric oxide
  (b) less potassium
  (c) more sodium
 than those of the Central Wheat-Belt area (Corrigin area to Jibberding).

The reasons for these variations are unknown.

Geochemistry of the minor elements.—Mno—This is invariably less than 0.4% and mostly near 0.1%.

BaO—This was determined in the four Darling Range granites. The range is 0.09% to nil, with average 0.06%. The only other determination is from the Jitarning granite (0.12%).

P_2O_5—The range is 0.76% to almost nil but most of the determinations are considerably less than 0.2%. Taken in conjunction with the profound leaching of the region during the period of laterite formation in the Tertiary, this low P_2O_5 content may be significant in connection with the known deficiency of the soils in P_2O_5.

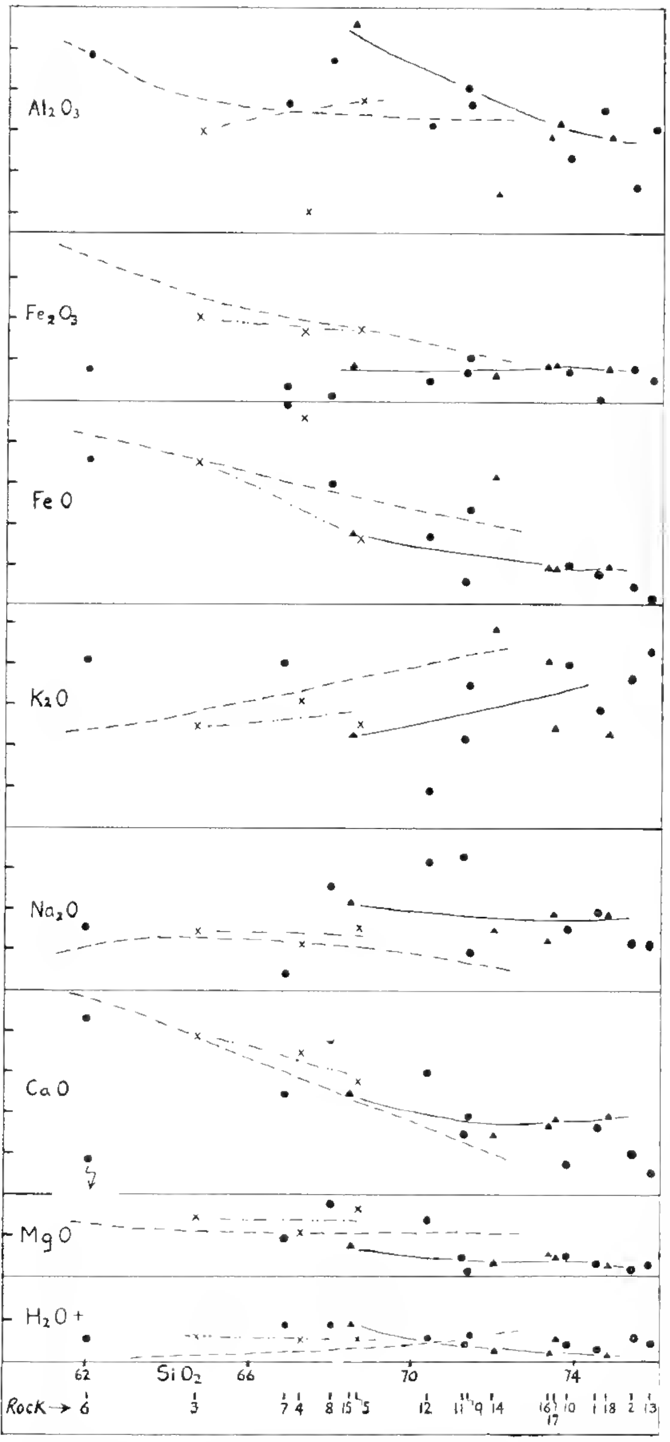

Fig. 6.—Diagram to show the variation of the major oxides from some granites from Western Australia, (plotted against SiO_2). Heavy line shows granites from Darling Range (solid triangles), dotted line shows granites from the Central Wheat Belt (crosses), and the dashed line granites from Central Australia. Other W.A. granites shown as spots. Numbers at bottom refer to the analyses in Tables II.

F—This has been determined in only a few rocks. Grains of fluorite are known from many granites in the Koorda—Beneubbin region, and in several granites from the Mt. Ridley area, and areas west of the Fraser Range. The highest recording is from Mt. Norcote (0.13%). Since the apatite throughout the region under survey seems to be always fluorapatite there would almost certainly be a trace of F in any of these granites. Other minor elements have rarely been sought. No systematic spectroscopic work on trace elements has been done on the granites of Western Australia (as far as I know).

Petrography.—Although more comprehensive studies of the granites of Western Australia are under way, there are some aspects of the mineral constituents which can be mentioned here. Most of the mineralogical data appearing in the modes in Table II are taken from publications of others. For the most part these merely comprise a list of minerals in order of abundance, and only in some cases is there mention of some optical data or mineral composition.

One of the most significant features of the granites is the variation in type of mafic minerals. The dominant granite in south-western Australia contains a normal *biotite* (in some cases partly chloritized) as the sole mafic mineral. *Hornblende* (usually with biotite) is important or dominant in many areas, particularly where the rock is somewhat more basic or has assimilated basic country-rock. The hornblendic facies thus tend to be in the smaller bodies of granite (e.g., near Dale Bridge and Clackline) or near margins of major masses. *Clinopyroxene-bearing granites* are common in restricted areas. These are best known from areas adjoining rocks of the granulite facies or rocks of high-amphibolite facies. The clinopyroxene, however, is mostly corroded by hornblende or biotite. Areas where clinopyroxenic granites are known are: Kunjin, Corrigin, Ongerup, Wadderin, Jerramungup (Wilson 1958*a*). *Orthopyroxene-bearing granites* are rare, unless one includes the large areas of charnockitic rocks where massive, dark, "greasy," fairly homogeneous granitic hypersthene-bearing rocks are common. The latter are metamorphic rocks and are discussed under "charnockitic rocks." The Jerramungup granite, however, is a handsome coarse porphyritic adamellite containing large dark pink phenocrysts of microcline and dark clots of the four mafic minerals biotite, hornblende, clinopyroxene and orthopyroxene (see Clarke *et al.* 1954, and Wilson 1958*a*). Clinopyroxenic gneisses and hypersthene-bearing hornfelses are close to this granite at Calyerup. A palingenetic origin of both pyroxenes is probable. It is probable that more of this type of rock exists in the little-known area from Jerramungup WSW. towards Pt. D'Entrecasteaux. The Ongerup granite, 27 miles W. of Jerramungup is clinopyroxenic, and similar (though finer-grained) to the Jerramungup granite.

The granitic gneisses

Geochemistry of the major elements.—Most of the available chemical analyses of acidic gneisses and granulites of south-western Australia are set out in Table III.

The variation of composition of these rocks is shown in Fig. 7 which records the normative (C.I.P.W.) values of orthoclase, albite, and femic + anorthite + corundum of each rock. On the same diagram are shown "average shale," "average greywacke," several obvious meta-sediments (graphitic slates, and mica schists containing andalusite or kyanite or staurolite) and several typical basic igneous rocks (a comparatively unaltered volcanic rock from the Kalgoorlie area ("Amphibolite," Mt. Hunt), an

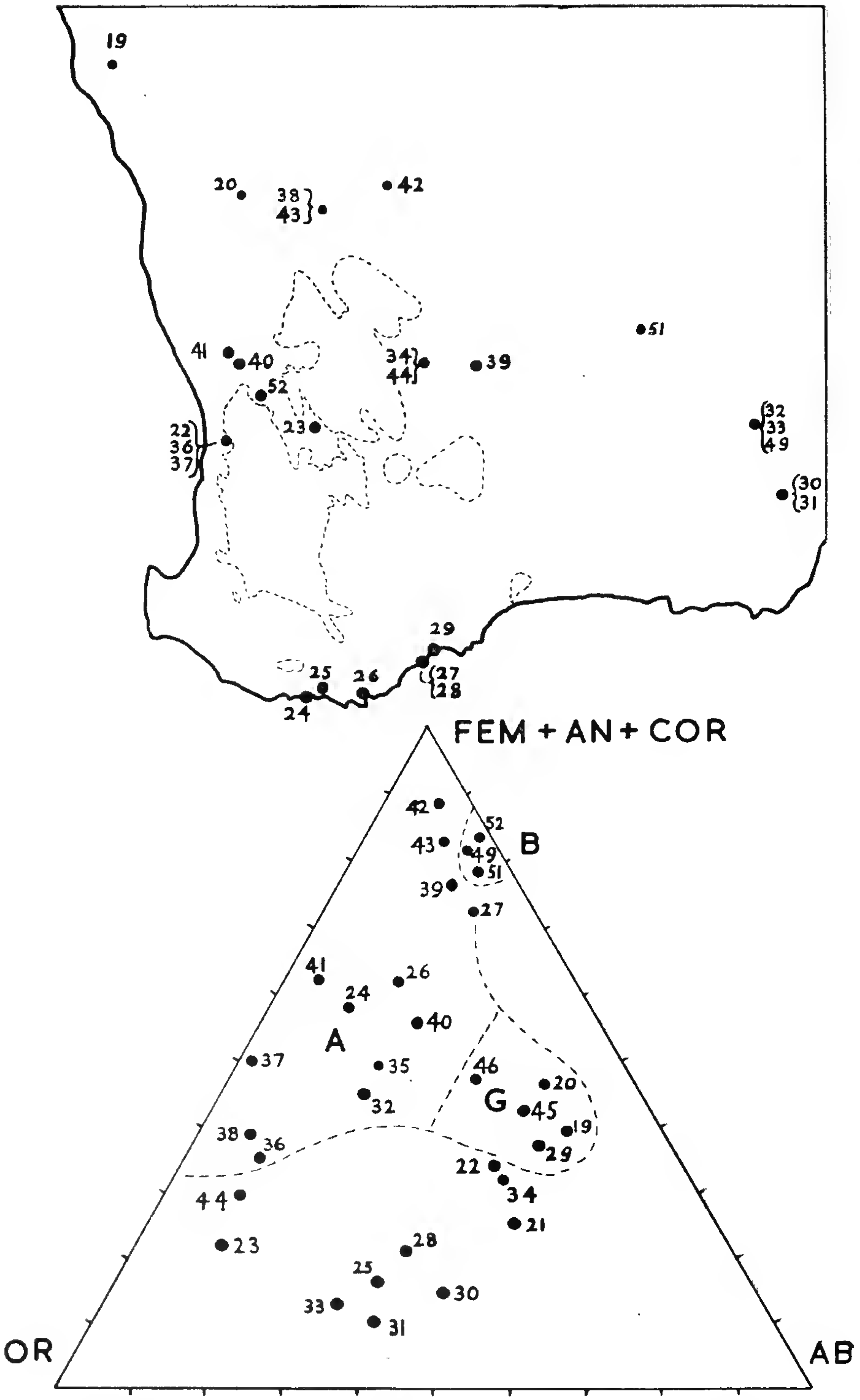

Fig. 7.—Some chemical features of the granitic gneisses, and metamorphosed sedimentary rocks from Western Australia. The symbols OR, AB, and FEM + AN + COR refer to minerals of the C.I.P.W. norm. A = field of argillites, B = field of basic igneous rocks, G = field of greywackes. Approximate locations are indicated on the map (see also legend, Tables III, IV, and V).

TABLE III.

Chemical analyses, C.I.P.W. norms, and modes of granitic gneisses *from Western Australia*

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	45
SiO_2	75.03	61.22	74.73	66.52	71.81	66.94	74.87	61.04	63.22	74.18	68.40	73.23	75.00	56.75	77.82	68.61	64.2
TiO_2	0.27	0.74	0.44	0.66	0.29	1.01	0.27	1.18	1.06	0.19	0.44	0.48	0.24	1.08	0.09	0.50	0.5
Al_2O_3	11.66	16.88	11.52	13.22	13.59	14.22	12.32	18.45	14.63	14.73	16.53	12.78	12.57	18.03	11.88	14.24	14.1
Fe_2O_3	1.37	1.46	1.97	4.99	0.63	0.30	0.72	0.61	2.91	0.60	0.74	1.06	0.85	0.44	0.24	0.71	1.0
FeO	3.78	5.28	2.80	3.29	2.33	8.92	1.59	8.90	9.23	0.79	2.29	1.98	1.00	9.24	1.19	2.23	4.2
MnO	0.17	0.13	0.14	0.15	0.03	0.23	0.01	0.09	0.58	*nil*	tr	0.15	0.15	0.34	0.06	0.10	0.1
MgO	1.56	1.97	0.30	0.58	1.74	1.42	0.30	3.11	2.32	0.18	1.46	0.50	0.17	3.28	0.29	1.41	2.9
CaO	0.62	4.99	1.86	2.84	0.48	2.20	1.32	1.23	2.92	1.84	3.08	1.27	0.87	2.82	0.56	3.20	3.5
Na_2O	2.82	4.12	3.54	3.45	0.86	0.74	2.59	1.20	1.46	2.64	3.74	3.66	2.90	2.05	2.06	3.70	3.4
K_2O	1.04	1.66	2.78	2.95	7.36	3.29	5.18	2.64	0.85	4.52	2.15	4.92	5.82	5.68	5.45	3.04	2.0
H_2O+	1.58	1.24	0.35	0.50	0.85	0.72	0.57	1.34	0.75	0.34	0.32	0.46	0.23	0.19	0.13	0.30	2.1
H_2O-	0.09	*nil*	0.06	*nil*	0.06	0.03	0.09	0.17	*nil*	0.18	0.46	0.03	0.04	*nil*	*nil*	0.06	0.1
P_2O_5	0.09	0.29	tr	0.10	0.14	0.28	0.03	0.22	tr	tr	0.15	0.17	0.07	0.07	tr	0.19	0.1
CO_2	0.10	0.02	*nil*	0.03		*nil*	0.03	0.50	*nil*	*nil*	*nil*	0.02	*nil*		*nil*	0.37	1.6
FeS_2	tr	0.04	tr	0.07			*nil*	0.15				*nil*	*nil*			Fe_7S_8 = 1.24	
	100.18 (1)	100.04	100.49 (2)	99.92 (3)	100.17	100.30	99.89	100.83	99.93	100.19	99.78	100.71	99.91	99.97	99.77	100.01	100.0

Add (1) C = tr ; (2) ZrO_2 = tr, B_2O_3 = tr ; (3) BaO = 0.53, V_2O_3 = 0.04.

C.I.P.W. Norm

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	45
quartz	48.91	14.69	38.13	28.21	33.85	37.32	35.92	30.82	35.40	36.96	29.10	29.41	33.45	5.49	42.15	26.67	26.82
o'clase	6.11	9.78	16.46	17.39	43.40	19.46	30.56	15.56	5.00	26.69	12.23	29.00	34.34	33.92	32.25	17.79	11.68
albite	23.86	34.88	29.87	29.21	7.29	6.29	21.92	10.18	12.58	22.53	31.44	30.94	24.55	17.29	17.82	31.44	28.82
anorth	1.95	22.67	7.34	11.96	1.56	8.90	6.37	4.84	14.46	9.17	14.46	3.92	3.90	13.07	2.78	12.51	6.67
corund	5.19				3.64	6.12	0.11	11.85	5.92	2.04	2.86		0.07	3.57	1.53	0.27	3.88
di wo		0.12	0.77	1.05								0.52					
di en		0.05	0.16	0.63								0.19					
di fs		0.06	0.66	0.36								0.34					
hyp en	3.89	4.86	0.59	0.81	4.34	3.60	0.74	7.74	5.80	0.40	3.04	1.05	0.42	8.05	0.70	3.50	7.20
hyp of	5.67	7.44	2.44	0.45	3.34	14.78	1.89	14.06	13.73	0.53	3.60	1.91	1.02	15.31	2.05	2.90	6.20
mag	1.99	2.11	2.78	7.76	0.90	0.46	1.04	0.88	4.18	0.93	0.93	1.53	1.23	0.70	0.35	0.93	1.39
ilm	0.52	1.41	0.84	1.26	0.55	1.98	0.52	2.25	2.13	0.46	0.76	0.91	0.46	2.13	0.15	0.91	0.91
pyrite	tr	0.04		0.07			*nil*	0.15				*nil*				pyrrhot. = 1.24	
apat	0.20	0.67	tr	0.24	0.34	0.67	0.07	0.50			0.34	0.40	0.17	0.17	tr	0.44	0.34
calc	0.23	0.05										0.05	*nil*			0.80	3.60

Mode

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	45
	q	andes	q	plag	K-fel	q	K-fel	cord	plag	K-fel	olig	K-fel	K-fel	K-fel	q	q	
	feld	K-fel	plag	q	q	K-fel	olig	q	q	andes	q	alb	q	plag	K-fel	olig	
	seric	q	K-fel	K-fel	cord	andes	q	bio	garn	q	K-fel	q	olig	garn	plag	K-fel	
	garn	bio	bio	bio	bio	bio	bio	plag	bio	bio	hyp	bio	bio	q	garn	bio	
	chlor	horn	horn	sph	hyp	garn	ep	garn	K-fel	mag	bio	horn	mag	hyp	mag	chlor	
	ilm	ilm	sph	mag	garn	mag	chlor	mag	mag	zir	mag	sph	limon	bio	ilm	horn	
	musc	mag	zir	ap	mag	zir	ap	sill	zir		ap	mag	sph	mag	ap	sph	
	zir	musc	ap	horn	ap	ap	zir	spin				calc	ap	ilm	zir	anker	
	pyr	ap			zir		rut	zir				ap	?fluor	diop		ap	
		(4)					(5)					(6)	(7)	(8)		(9)	

Add (4) ep, sph, zois ; (5) allan ; (6) zir ; (7) ? garn ; (8) ap ; (9) zir, pyrrhot, pyr.

	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	45
S.G.	2.74	2.79	2.73		2.68		2.65	2.85				2.66	2.63				

19 Garnetiferous acid granulite, *Geroldine*, Northampton district (Simpson, unpub. ms., p. 14).
20 Granodioritic gneiss from well on Reserve 14082/5953, 1 mile S. of railway station at *Bowgada* (Simpson 1948, p. 217).
21 Granitic gneiss, *Wattle Flat* near Cullalla (Simpson, unpub. ms., p. 42).
22 Hybrid gneiss, Roads Board Quarry, *Armadale* (Prider 1943, p. 36).
23 Cordierite-bearing charnockitic gneiss, *Dangin* (Prider 1945*b*, p. 164).
24 Garnet-biotite-quartz-andesine-microcline gneiss, *Point Nuyts*, near Nornalup (Clarke *et al.* 1954, p. 28).
25 Gneissic granite, near *Denmark* (Simpson, unpub. ms., p. 18).
26 Garnet-cordierite-feldspar-quartz granulite, Whale Head Rock, *Albany* (Simpson 1951, p. 105).
27 Garnet-biotite-quartz-plagioclase gneiss, *Cape Riche* (Clarke *et al.* 1954, p. 28).
28 Acid gneiss, *Cape Riche* (Clarke, *et al.* 1954, p. 28).
29 Hypersthene-bearing acid gneiss, *Point Irby* (Clarke, *et al.* 1954, p. 28).
30 Granitic gneiss, *Russell Range* (Maitland 1925, p. 112).
31 Granitic gneiss, Pine Hill, *Russell Range* (Maitland 1925, p. 112).
32 Hypersthene-quartz-garnet-plagioclase-microperthite granulite, near Simon Hill, *Fraser Range* (Wilson 1954, Vol. 2, p. 340).
33 Garnetiferous acid granulite, near Simon Hill, *Fraser Range* (Wilson 1954, Vol. 2, p. 339).
34 Granitic gneiss, 223 ft. in Duff's bore, *Westonia* (Simpson, unpub. ms., p. 44).
45 "*Average greywacke*" (Pettijohn 1949, p. 250).

olivine dolerite and a quartz dolerite). Some of the acidic gneisses are chemically very similar to average greywacke (e.g. the hypersthene-bearing gneiss from Pt. Irby, the gneiss from Westonia, and the gneissic "granodiorite" from Bowgada). The garnet granulite from Geraldine is typical of the more siliceous granulites and is very similar to a greywacke somewhat more siliceous than the world average.

Other gneisses are more potassic than those presumably derived directly from greywacke-type sediments. In composition (cf Fig. 5 and 7 and see Table III) they closely resemble some of the granites of the Darling Range (e.g. the gneiss from Wattle Flat in the Chittering area, the gneiss from Denmark, the gneisses from the Russell Range). It is reasonable, therefore, to conclude that these gneisses may represent metamorphosed granites of an age greater than that of the main granites described in this paper.

Other gneisses have almost certainly resulted from considerable metasomatism of more basic rocks. In composition these may be expected to vary greatly depending on the degree to which graitization or Na-metasomatism has progressed. Examples of such rocks are the gneiss from Armadale, the garnet-pyroxene granulite from near Simon Hill in the Fraser Range, and the cordierite-bearing gneiss from Dangin.

Other gneisses (possibly migmatized sediments) are from Cape Riche (two analyses). The cordierite-bearing granulite from Albany and the garnetiferous gneiss from Pt. Nuyts show many similarities to "average shale," and are probably of meta-sedimentary origin (see Clarke *et al.* 1954, p. 33 and 34).

A very acid garnet granulite which is fairly common in parts of the Fraser Range, (e.g. near Simon Hill), is among the most potassic gneisses yet studied (see No. 33). It may represent the end-product of granitization of basic rocks of which the garnet-pyroxene granulite of Simon Hill (No. 32) is an intermediate stage. There is some field evidence for this view, but as the Fraser Range charnockitic rocks are about to be studied in detail, further suggestions as to origin of these acid granulites are premature.

Geochemistry of the minor elements.—Insufficient data are available to warrant any comment on the distribution of minor elements in the granitic gneisses.

Petrography.—The granitic gneisses vary so greatly in mineralogy and texture that only broadest generalizations can be made here. In many respects the mineralogy and texture will depend on the degree and type of metamorphism which the original rocks have undergone.

Biotite gneisses predominate, but hornblende is a common mafic mineral particularly in the more basic gneisses. In large areas (those in which rocks of granulite metamorphic facies may occur—see tectonic sketch on main map) orthorhombic pyroxene may be a dominant mafic mineral. In addition, clinopyroxene may be present in the orthopyroxenic rocks (particularly in the more calcic types), but it is an important mafic mineral in basic non-hypersthenic gneisses and some acid gneisses of the Yilgarn area (e.g., Nevoria (Wilson 1953*a*) Westonia area, Ongerup area, Wellington Mills area, Leeuwin-Naturaliste area, Ravensthorpe area, Toodyay area, and elsewhere). The associated minerals in pelitic rocks (e.g., sillimanite, kyanite, garnet) indicate that the diopside gneisses may belong to the middle and upper levels of the amphibolite metamorphic facies.

Thin-section study commonly shows that biotite has developed at the expense of orthopyroxene and amphibole (and sometimes clinopyroxene). In many cases it seems likely that the biotite has developed in shear zones (potential or actual) where water-vapour pressure was higher than elsewhere in the rock, and where potassium has been introduced from outside or actively re-distributed within the rock. This amounts to a "down-grading" of such a rock in many cases (see p. 77 for further discussion of pyroxenic rocks).

Graphite, as accessory flakes or "dust," is present in the granitic gneisses in many areas, e.g., Geraldton-Northampton-Ajana region (in acidic garnet granulites and mica schists, etc.), the belt extending from Wongamine through Northam, Greenhills, Quairading, Kulin to Lake Grace (in granitic gneisses), the Chittering region (in schists and gneisses), the belt extending from Nannup through Donnelly River, Pemberton, Manjimup, Kendenup to the Hopetoun region (in granitic gneisses, muscovite schists, biotite schists, kyanite schists, etc.). Graphitic schists are well-known among the low-grade rocks of many of the Goldfields areas, e.g., Coolgardie, Bullfinch, Binduli, Bulong, Kalgoorlie. It is thought that in the more-highly metamorphosed rocks of the south-western Australia the graphite represents carbon relics from the granitization and metamorphism of sediments.

The meta-sediments (so called "whitestones")

Where the gneisses or basic meta-igneous rocks ("greenstones") pass into significant areas of more obvious meta-sediments (so-called "whitestones") (such as quartzites, meta-jaspilites, mica schists, sillimanite (or kyanite or andalusite or corundum) bearing schists and gneisses), a different colour has been used on the map. Distinction between meta-sediments of different ages is not yet possible, although it is suspected that the belt of meta-sediments, which extends southward through the Chittering and reappears (? from beneath the Coastal Plain) near Nannup and continues eastward through Pemberton, Manjimup, Kendenup to the Ravensthorpe area, may be younger than similar belts of meta-sediments in the Central Goldfields areas (see p. 63). No attempt is made to describe these rocks in this paper. Analyses of a few selected rock-types, which will indicate some of the variations of the meta-sediments, appear in Table IV. Included in Table IV are analyses of "average shale" (Clarke 1924) and "average greywacke" (Pettijohn 1949) and analyses of the white and black slate of the Cardup Shale (lower Palaeozoic or late Precambrian) of the Armadale area, and an analysis of a meta-greywacke from the Kanmantoo Group (Lower Palaeozoic) of South Australia. Plots of these analyses help to delineate the pelitic and greywacke fields in Fig. 7. Calculation of the C.I.P.W. norms for pelitic sediments introduces obvious difficulties. Thus, in many pelites considerable CO_2 remains after the calculation, and emphasizes how much volatile matter may be given off with water during metamorphism of even normal shales. This is an important observation when the relationship is considered between sulphide and carbonate ore-formation on the one hand and magmatism and granitization on the other hand.

The graphite content of average shale and of several other meta-sediments of Table IV is interesting in connection with the graphite-bearing granitic gneisses mentioned above.

Quartzites of variable purity have been recorded in many places. The best development of quartzites is well described by Prider (1944) from the Toodyay area, and the study of similar highly-metamorphosed quartzites and associated

TABLE IV.

Chemical analyses, C.I.P.W. norms, and modes of some meta-sediments *from Western Australia*

	35	36	37	38	39	40	41	42	43	44	45	46
SiO_2	58.10	65.22	63.24	73.84	69.77	53.01	74.79	72.57	74.28	80.52	64.2	68.76
TiO_2	0.65	0.35	0.28	0.69	1.39	1.18	0.47	0.57	0.10	0.28	0.5	0.74
Al_2O_3	15.40	16.71	17.20	13.65	18.38	20.38	10.28	10.15	21.91	12.68	14.1	13.79
Fe_2O_3	4.02	1.93	n.d.	n.d.	2.16	3.39	2.69	0.49	tr	0.15	1.0	0.66
FeO	2.45	3.23	5.88	2.09	0.28	7.44	4.18	2.70	0.54	0.86	4.2	4.60
MnO		0.03	0.66	0.09	tr	0.09	0.10	0.05	0.05	0.08	0.1	0.07
MgO	2.44	2.87	2.94	0.90	0.48	4.53	3.44	9.38	0.33	0.30	2.9	2.65
CaO	3.11	0.05	*nil*	0.17	0.60	2.70	*nil*	*nil*	0.12	0.03	3.5	2.81
Na_2O	1.30	0.76	0.11	0.36	0.56	2.07	0.22	0.34	0.38	0.42	3.4	2.54
K_2O	3.24	5.98	5.11	4.06	0.46	3.43	2.24	0.28	0.30	3.66	2.0	2.29
H_2O+	} 5.00	2.12	3.14	1.96	2.35	1.30	1.60	3.19	0.51	0.87	2.1	0.53
H_2O-		0.16	0.25	0.32	0.52	0.07	0.08	0.02	0.10	0.08	0.1	0.04
P_2O_5	0.17	0.08	tr	0.04	0.18	0.11	tr	0.20	tr	0.01	0.1	0.21
CO_2	2.63	0.05	0.19	*nil*	0.34	0.45	*nil*	*nil*	0.02	0.02	1.6	
FeS_2		*nil*	tr	0.21	0.32	0.08	*nil*	*nil*	0.15	*nil*		S = 0·13
C	0.80	0.05	1.28	1.89	1.25				1.50			
	100.00 (1)	99.85 (2)	100.28	100.27	99.94 (3)	100.23	100.09	99.94	100.29	100.04 (4)	100.0	100.15 (5)

Add (1) SO_3 = 0·64, BaO = 0.05 ; (2) Cr_2O_3 = 0.01. V_2O_3 = 0.03, SO_3 = 0.11, BaO = 0.11 ; (3) SO_3 = 0.90 ; (4) BaO = 0.08 ; (5) BaO = 0.14, ZrO_2 = 0.19.

C.I.P.W. Norm

	35	36	37	38	39	40	41	42	43	44	45	46
quartz .	34.6	31.96	33.66	53.31	64.04	12.68	57.60	53.84	69.94	63.04	26.82	32.52
o'clase . .	18.9	35.29	30.12	23.95	2.72	20.23	13.26	1.67	1.78	21.62	11.68	13.34
albite	11.0	6.45	0.94	3.04	4.72	17.52	1.84	2.88	3.20	3.57	28.82	21.48
anorth . . .				0.58		9.90			0.17	0.08	6.67	13.34
corund	9.8	8.98	11.49	8.45	16.97	9.64	7.49	9.28	20.90	7.99	3.88	2.24
hyp { en	6.1	7.15	7.32	2.24	1.19	11.29	8.56	23.36	0.82	0.74	7.20	6.60
hyp { of	*nil*	3.63	10.99	2.88	*nil*	9.08	4.87	3.71	0.91	1.15	6.20	6.60
mag	5.8	2.86		haemat. =	2.16	4.91	3.89	0.72	tr	0.21	1.39	0.93
ilm	1.2	0.67	0.53	1.31	0.59	2.25	0.90	1.08	0.20	0.53	0.91	1.37
pyr . . .	0.2	*nil*	tr	0.21	0.32	0.08	*nil*	*nil*	0.15	*nil*		0.24
ap	0.3	0.19	tr	0.09	0.44	0.26	tr	tr	tr	0.02	0.34	0.34
graph	0.8	0.05 (7)	1.28 (8)	1.89	1.25				1.50		Zirc. =	0.37
calc	5.2 (6)				0.77 (9)	1.02			0.05	0.05	3.60	

Add (6) excess CO_2 = 0.3, excess S = 0.2, H_2O = 5.0 ; (7) add siderite = 0.13, excess S = 0.04 ; (8) add siderite = 0.50 ; (9) add rutile = 1.08, excess S = 0.36.

Mode

	35	36	37	38	39	40	41	42	43	44	45	46
				q chlor seric graph	q garn graph fel ores	bio q staur K-fel plag	q staur bio musc chlor horn (10)	q chlor kyan bio musc rut (11)	q andal seric alb chlor graph	q bio sill musc chlor K-fel (12)		q bio K-fel alb musc mag (13)

Add (10) fel, ores, zir ; (11) zir, limon ; (12) zir, rut. ilm, ap ; (13) zir, ap, tourm.

	35	36	37	38	39	40	41	42	43	44	45	46
S.G.						2.84	2.80		2.77	2.72		

35 *Average shale* (Clarke 1924, p. 34).
36 White slate, Cardup Beds. *Armadale* (Prider 1943, p. 39).
37 Graphitic slate, Cardup Beds, *Kelmscott* (Simpson 1951, p. 474).
38 Graphitic slate, *Yandanhoo Hills* (Simpson 1951, p. 475).
39 Graphitic garnetiferous phyllite, *Southern Cross* (Saint-Smith and Farquharson 1913, p. 53).
40 Staurolite schist, *Chittering valley* (Simpson 1933, p. 78).
41 Staurolite schist, *Culalla* (Simpson, unpub. ms., p. 42).
42 Kyanite schist, near *Mt. Kenneth* (Simpson 1952, p. 49).
43 Andalusite schist, *Yandanhoo Hills* (Simpson 1948, p. 81).
44 Sillimanite schist, *Westonia* (Simpson 1952, p. 563).
45 *Average greywacke* (Pettijohn 1949, p. 250).
46 Biotite-quartz schist, *Rosetta Head*, S. Aust. (Bowes 1954, p. 189).

gneisses, meta-jaspilites and granites has been the object of field-mapping classes by senior University students under R. T. Prider and A. F. Wilson for several years in the belt of country extending from the Lower Chittering through York to the Beverley district (roughly the Avon valley) (Jones 1952; McWhae 1948; Johnstone 1952; Willmott 1955).

Some of these highly-metamorphosed quartzites show current-bedding (e.g., on N. flank of Nardie, near Toodyay) but in most cases stratigraphic "top" cannot be determined in them. Other quartzites are exceptionally pure, and some may represent original cherts. The coarseness of grain-size of the normal quartzites of the York-Beverley area (commonly 2 cm in diameter) is a metamorphic phenomenon and is not related to original grain-size.

Outside the Avon valley, quartzites are uncommon and are always of local development. In view of this paucity of quartzites and the virtual absence of (recognizable) meta-limestones and paucity of meta-argillite in the whole of the area under consideration, it would appear that sediments of greywacke-type were the dominant non-igneous materials from which many of the gneisses (and probably many of the granites, by some palingenetic process) have been developed.

Meta-jaspilites (banded-iron-formations, or "Q-Fe")

Silica-iron oxide sediments are common within the meta-sedimentary belts and are also found closely associated with basic pillow-lavas.

All known occurrences of these rocks are shown on the map. Many small patches of highly-metamorphosed jaspilite (e.g., orthopyroxene-magnetite-quartz rocks, or amphibole-garnet-magnetite-quartz rocks) have recently been located in the granitic gneisses as bands which have resisted granitization.

The meta-jaspilites normally show greatly complicated fold structures. Where the grade of metamorphism is not high (as in some of the Goldfields areas) it is possible to recognize primary slump structures in these ancient sediments. However, most of the folding seems to be of tectonic origin. The best petrologic descriptions of these rocks are those of Miles (1946).

The discovery of new occurrences of the banded-iron-formations is of potential economic significance, for in Western Australia gold and iron ore are commonly found to be associated with these rocks. The map shows many new occurrences of these rocks, but they are mostly small and many have suffered more metamorphism than is usual for known hosts of gold elsewhere in the state.

The possible concealment of iron-ore and/or gold-bearing rocks in the Karalee area is worthy of investigation (see p. 67).

TABLE V.

Chemical analyses, C.I.P.W. norms, and modes of some basic metamorphic and igneous rocks *from Western Australia*

	47	48	49	50	51	52	53	54	55	56	57
SiO_2	47.88	48.14	49.04	49.98	52.53	49.13	49.53	49.04	49.42	50.55	50.57
TiO_2	2.95	1.44	1.92	1.19	0.86	1.27	2.13	0.96	1.76	0.05	1.37
Al_2O_3	14.22	14.72	15.74	16.67	13.42	13.13	12.92	15.02	15.37	17.16	15.11
Fe_2O_3	1.73	1.93	2.50	0.68	0.42	3.65	2.60	1.82	1.84	1.04	3.65
FeO	12.36	12.92	12.13	11.16	8.97	8.95	11.40	11.61	12.23	3.40	8.80
MnO	0.15	0.24	0.36	0.26	0.63	0.15	0.35	0.24	0.26	0.19	0.26
MgO	6.35	6.78	6.52	7.64	9.17	7.64	6.24	5.73	5.32	9.97	5.55
CaO	10.23	10.53	9.27	9.22	9.63	11.84	10.37	10.42	10.13	14.77	10.64
Na_2O	2.47	2.26	1.56	1.87	1.99	1.72	2.08	2.06	1.94	1.62	2.29
K_2O	0.51	0.35	0.57	0.78	0.72	0.16	0.36	0.49	0.89	0.11	0.57
H_2O+	0.23	0.68	0.14	0.18	1.42	1.72	2.21	2.28	0.40	0.36	0.25
$H_2O—$	0.07	*nil*	*nil*	0.34	0.16	0.04	0.09	0.12	*nil*	0.12	1.42
P_2O_5	0.40	0.19	0.52	0.09	0.20	0.14	0.16	0.09	0.28		0.07
CO_2	*nil*	tr	*nil*	*nil*	*nil*		*nil*	*nil*	*nil*	*nil*	*nil*
	99.71 (1)	100.18	100.27	100.06	100.38 (2)	99.99 (3)	100.72 (4)	99.88	99.84	99.51 (5)	100.55

(1) Add BaO = tr., Cr_2O_3 = tr., S = 0.08. Cl = 0.08: (2) add FeS_2 = 0.30, Cr_2O_3 = 0.02, V_2O_3 = 0.04 but note summation is probably 100.48 ; (3) add FeS_2 = 0.45 ; (4) add FeS_2 = 0.28 ; (5, add FeS_2 = 0.17.

C.I.P.W. Norm

		47	48	49	50	51	52	53	54	55	56	57
quartz				3.60		1.68	3.54	3.22	0.78	1.26		3.99
o'clase		2.78	1.67	3.34	5.00	4.45	1.11	2.11	2.78	5.56	0.67	3.39
albite		20.96	18.86	13.10	16.24	16.77	14.15	17.62	17.29	16.24	13.69	19.35
anorth		26.13	29.19	34.19	34.47	25.58	27.52	24.85	30.30	30.58	39.23	29.27
di	wo	9.28	9.28	3.36	4.29		12.76	10.72	8.58	7.42	14.22	9.0[illegible]
	en	4.50	4.20	1.60	2.10	17.03	7.50	5.21	3.70	3.20	10.47	5.12
	fs	4.62	5.02	1.72	2.11		4.62	5.33	4.88	4.22	2.39	4.22
hyp	en	8.80	8.20	14.70	14.30	30.28	11.60	10.33	10.60	10.10	11.42	8.70
	of	9.11	9.64	15.84	13.86		6.86	10.58	13.73	14.26	2.60	7.15
oliv	fo	1.82	3.15		1.89						2.06	
	fa	2.04	4.18		1.94						0.52	
mag		2.55	2.78	3.71	0.93	0.70	5.34	3.77	2.55	2.55	1.51	5.30
ilm		5.62	2.74	3.65	2.28	1.67	2.43	4.05	1.82	3.34	0.09	2.59
pyr		tr				0.30	0.45	0.28			0.17	
ap		1.01	0.34	1.34	0.34	0.48	0.34	0.37	0.34	0.67		0.17

Mode

	47	48	49	50	51	52	53	54	55	56	57
	andes horn hyp aug ilm ap zir	plag aug hyp horn mag ap	plag hyp aug mag K-fel ap q zir	plag hyp aug mag K-fel ap	amphib chlor zois alb musc ilm	aug plag ilm mag q horn ural bio ap	horn plag ilm mag q leucox ap ep	plag aug q ilm ap horn bio ural	plag aug ilm q o'clase horn bio ap	plag hyp aug mag	plag aug ilm ap glass
S.G.					2.98	3.05	3.07			2.95	

47 Pyroxene-hornblende-andesine granulite (a basic charnockite), *Bunker Bay*, near Cape Naturaliste (Aurousseau 1926, p. 624).
48 Hornblende-pyroxene-plagioclase granulite (a basic charnockite), *Point Irby* (Clarke *et al.* 1954, p. 38).
49 Pyroxene-plagioclase granulite (a basic charnockite), near Simon Hill, *Fraser Range* (Wilson 1954, Vol. 2, p. 341).
50 Pyroxene-plagioclase granulite (a basic charnockite), 10 *miles east of Fraser Range Homestead* (Wilson 1954, Vol. 2, p. 341).
51 Meta-volcanic rock, *Mt. Hunt*, Kalgoorlie (Simpson 1916, p. 26).
52 Slightly uralitized quartz dolerite, *Toodyay* (Prider 1944, p. 127).
53 Uralitized dolerite, *Bickley Brook Reservoir*, Darling Range (Simpson, unpub. ms., p. 36).
54 Uralitized quartz dolerite, *Mt. Hassell*, Stirling Range (Clarke *et al.* 1954, p. 51).
55 Quartz dolerite, *West Cape Howe* (Clarke *et al.* 1954, p. 51).
56 Norite, *Norseman* (Simpson 1916, p. 30).
57 Tholeiite, *mouth of Donnelly River* (Edwards 1938, p. 6).

The basic meta-igneous rocks, basic meta-sediments and basic gneisses and basic granulites

In Western Australia the term *"greenstone"* has been loosely applied to the varied group of basic and ultra-basic meta-igneous and basic meta-sediments which enclose the dominant goldfields of the state. Some of these rocks have suffered only a low grade of metamorphism (e.g., in the Kalgoorlie area) and original structures of the rocks (such as pillows and vesicles in lava, graded bedding and cross-bedding in tuffs and basic sediments) have been recognized. These features are used to indicate stratigraphic sequence during mapping. Very little reliable chemical information is available concerning the basic meta-volcanic rocks and basic meta-sediments. Many analyses of "greenstones" are of rocks from goldmines. The rocks are so impregnated by solutions associated with ore-deposition that they are of little value for our purposes. No. 51 (Table V) is a meta-basalt from the Mt. Hunt region near Kalgoorlie. In the period under review some useful petrological work has been done on these rocks (e.g., Woodall 1955; Wilson 1953*a*).

Basic gneisses and amphibole-bearing rocks of various types are commonly found where belts of basic rocks have suffered varying degrees of granitization.

Basic granulites are common. The inset on the main map indicates the huge area in Western Australia where rocks of granulite metamorphic facies may be found. Basic rocks, whether of igneous, metamorphic or sedimentary origin, may be reconstituted to give pyroxene granulites. A common type is a hypersthene-augite-labradorite granulite such as was early called a basic charnockite in India (Holland 1900). Dark brown hornblende is a common associated mafic mineral within the granulite facies.

The significance of these charnockitic rocks is outlined below under "charnockitic rocks," and published details are given by Prider (1945*b*), Lord and Gray (1951), and Wilson (1952, 1954, 1955, 1957, 1958*b*).

In Table V analyses are given of four typical charnockitic pyroxene granulites. No. 47 occurs at Bunker Bay (2 miles east of Cape Naturaliste) and is typical of basic granulites in the Leeuwin-Naturaliste belt. It may represent a completely reconstituted basic dyke in the acidic granulites of the area. No. 48 is a basic band typical of many to be found in the acid gneisses of the south coast region between Pt. D'Entrecasteaux and Esperance. It is remarkably similar in composition and mode to the Bunker Bay rock (cf. Clarke *et al.* 1954, p. 41). The presence of greenish-brown hornblende in both of these pyroxenic rocks is interesting. Nos. 49 and 50 are typical of the Fraser Range where occur the largest masses of basic granulite known in Western Australia. Neither of these rocks contains amphibole. Detailed work on the Fraser Range is in progress. Some references to the area have been given by Maitland (1925) and Wilson (1952, 1954, 1955, 1957, 1958*b*). On the current geological map of Western Australia the Fraser Range is shown as a large area of "greenstone." The outline of the area has been modified and transferred to my map and given the symbol for rocks of granulite facies. In composition several types of (charnockitic) basic granulites may be considered to be the highly-metamorphosed equivalents of the rocks commonly known as greenstones elsewhere in Western Australia.

Table V also contains analyses of various basic igneous rocks with which the basic granulites may be compared. There are many other basic granulites whose composition suggests a meta-sedimentary or metasomatic origin. It is not proposed to discuss these here.

Basic dykes

Many geologists have commented on the petrological, structural and age differences between the various basic dykes of south-western Australia. No systematic study, however, has been made of these rocks. Some of the more significant references are as follow:—Prider (1948*a*, 1943), Clarke *et al.* (1954), Hills (1946), Woodall (1955), Sofoulis (1955*b*) and Frost (1952).

No major contribution to the study of the dykes has been made in the last few years and they have been left off the map. Although there are probably dolerites of several ages in the area, it is thought that many (if not most) are of Upper Proterozic or Lower Palaeozoic age (Prider 1943, 1948*a*, and 1955).

In eastern portions of the Fraser Range, olivine dolerites and gabbros are common. These have suffered thermal metamorphism (apparently on a regional scale). I have a study of these rocks in hand.

The basic dykes are almost all quartz dolerite. Analyses of examples of dykes occurring near Perth (52 and 53), in the Stirling Ranges where they cut the (?) Upper Proterozoic sediments (54), and on the south coast (55) are shown in Table V. In addition analyses of the Norseman Norite which is of unknown age (56) and of a (?) Tertiary tholeiitic basalt (57) are also shown. Olivine dolerites are almost unkown from the area under consideration.

Radioactive-Age-Determinations

For many years I have been collecting allanite and other minerals with a view to their use for radioactive-age-determination. Weakly radioactive metamict allanite is a common accessory in most of the coarse porphyritic granites (and pegmatitic schlieren therein), and in some of the granitic gneisses in south-western Australia. Some of the more important localities where I have found radioactive minerals of this type are as follow (details of these and other localities may be obtained from the catalogue of the Department of Geology, University of Western Australia):—Brookton, Dale Bridge, Doubtful Island Bay, Fraser Range, Hyden Rock, near Koorda, Merredin, Mundaring Weir, Porongorups, Waddouring Hill, and York. Allanite from Doubtful Island Bay (from pegmatitic schlieren in charnockitic rocks) and from the Fraser Range (from coarse pegmatite cutting charnockitic rocks) gave "ages" (uncorrected for lead isotopes) of 1390 × 10^6 years and 1210 × 10^6 years, respectively (Prider 1955, p. 76). This suggests that the metamorphism which produced the charnockitic rocks of the Albany-Esperance-Fraser Range belt may be much younger than the primary metamorphism which affected the Goldfields areas and produced the major granite of south-western Australia. K-A age determination of mica associated with the allanite from Doubtful Island Bay is underway and should help confirm or refute this suggestion.

A comprehensive programme of age-determinations of the major granites of south-western Australia has begun. This work involves the use of the K-A and Rb-Sr techniques. In this work I am co-operating with Dr. Jeffery of the Physics Department of the University of Western Australia. Dr. Jeffery (1956) has shown the lithium-rich pegmatites of Ravensthorpe, Londonderry (S. of Coolgardie), and Grosmont (W. of Coolgardie) are about 2,800 million years old. He has recently told me that similar work on the Cunderdin granite (which is typical of the coarse porphyritic granites of south-western Australia) is showing that it is probably indistinguishable in age from that of the pegmatites mentioned above. "Galena ages" from the gold-bearing lodes of Norseman, Kalgoorlie, and Bullfinch give a somewhat comparable early Archaean age, viz. 2300 × 10^6 years (Prider 1955, p. 76), but the K-A, Rb-Sr "ages" are thought to be of more value.

In summary, it would appear that the bulk of south-western Australia is of early Archaean age, and that a late Archaean period of metamorphism has affected parts of the S. and SE., and also (in view of the possible meta-sediments beneath the Perth area) possibly the western margins of the Shield.

The Charnockitic Rocks

In many parts of the area under discussion there are pyroxene granulites comparable throughout their range of composition and appearance to the rocks commonly known as charnockitic rocks from India. The structural and petrological significance of these rocks is very great for it would seem that they usually represent not only metamorphosed rocks of a wide range of composition but rocks which have suffered more than one metamorphism.

Environments affecting mode of formation

Now that the distribution in Western Australia of charnockitic rocks (better known as granulites, or rocks of granulite metamorphic facies) is better known some suggestions concerning their mode of formation can be made. In Western Australia many of them appear to represent the basement-complex which has become newly metamorphosed at the time of the down-warping and partial mobilization of the thin Archaean crust beneath the troughs in which the jaspilites, spilites, tuffs and erosion sediments were being deposited. Handley (1956) presents a very plausible hypothesis to explain the peculiarities of distribution, environment and structure, and low degree of metamorphism of the rock systems containing the banded-iron-formations (or jaspilites).

New light is thrown on the origin of charnockitic rocks by developing some of the ideas contained in Handley's hypothesis. The Precambrian cycle of accumulation, magmatism and metamorphism is probably somewhat as Handley (1956 p. 43) states:—

"(1) During volcanic activity the greatest accumulations of lavas and tuffs took place in low lying areas of the surface. These areas were relatively low, because they were underlain by somewhat heavier rocks of the heterogeneous crust, and with nearly perfect isostatic controls relief was largely controlled by such differences of the crust.

(2) As the volcanic-sedimentary pile increased in weight the crust was depressed, setting up anomalies in the sub-crust and leading to sub-crustal flow. The migration of material in the sub-crust away from the depressed section probably led to augmented volcanic activity on the margins of the depression.

(3) Continued sinking and accumulation led eventually to the deeper layers of granite below the downwarp becoming plastic, and this greatly facilitated further sinking.

(4) The sediments and volcanics in the sinking trough were tilted throughout their deposition, so that slumping phenomena on a large scale were produced before consolidation.

(5) Finally the granitic crust became unable to support the weight of the accumulations, and these tended to sink further under gravity. This pulled the granitic crust towards the trough, causing tension in the crust parallel to the trough but applying compression to the descending trough.

(6) The sinking trough created far greater isostatic anomalies than those previously present, and the base of the granitic layer was sufficiently depressed for it to be mobilized and flow horizontally into areas of lower pressure. This mobilized granite reached the fractured crust lateral to the trough and intruded the granite. Smaller bodies of mobilized granite rose adjacent to the sinking trough, or actually intruded the accumulations.

(7) The trough stopped sinking when it reached a certain depth in the crust as it had become much narrower, and created less general sag. The weight of the column was supported by friction with adjacent granites and the upward hydrostatic pressure exerted by the basaltic substratum.

(8) As the trough had become a zone of compaction related to two fracture zones on either side, volcanic activity ceased and the cycle was completed. Isostatic recovery was attained by sub-crustal flow and probably slight rising of the depressed column."

In areas affected by this cycle charnockitic rocks may be expected in at least two significantly different environments.

The *first environment* is that in which the basement-complex has been almost sufficiently depressed to bring it to the mobilized state. The keel of the trough itself would be subject to comparable heat and pressure but connate waters in the volcanic-sedimentary pile would make less likely a wholesale conversion of these rocks to rocks of granulite metamorphic facies. Nevertheless, there are likely to be many zones in the keel of the trough where such rocks could occur.

Thus, rocks of granulite facies where found to be intimately associated with trough sediments (as may be seen near the meta-jaspilites near Northam, Dangin, Corrigin, Dumbleyung, and elswhere), may be merely the product of a single regional metamorphism. Many of the acidic granulites of these areas, however, may represent the re-metamorphosed old basement-complex, now fused to the metamorphosed trough-rocks.

However, it should be noted that some of the connate waters from the trough-rocks could be expected to aid the formation of hydrous mafic minerals in micro-shears and mega-shears in the surrounding granulites produced from both basement-complex and trough. This would help to produce rocks which more properly would fall within the upper levels of the amphibolite facies.

An important feature of the granulites forming within this environment is the regional lineation which is almost always present. In hand-specimen the lineation is not obvious unless in rocks where amphiboles or sillimanite are noteworthy constituents, although lineated hypersthene is known in some rocks. Thin-section study, however, commonly shows a marked optical orientation of such granular minerals as K-feldspar, plagioclase, scapolite, hypersthene and quartz. As far as I know, the lineation is always parallel to the *b*-axis of minor folds and schlieren of the rock. A marked parallelism of the banding of the rocks of the granulite metamorphic facies is common. Careful study shows that isoclinal folds on all scales are common in such rocks, and (where observed) the lineation is parallel to the axes of the folds.

Moreover, I consider that the characteristic fine- to medium-grained appearance of these granulites is due in large measure to intense granulation and recrystallization of the original rocks. A coarse homogeneous massive biotite granite, for example, could become a rigidly banded or streaked fine-grained hypersthene-quartz-feldspar granulite. In Western Australia these features can be seen in the Fraser Range (Wilson 1957) and near Lake Grace, Cape Naturaliste, Doubtful Island Bay, and elsewhere.

It is concluded that plastic deformation (under high temperature) of a fairly "dry" basement-complex has caused these phenomena to develop on a regional scale. However, these lineated granulites cannot appear at the surface unless exposed by deep erosion such as would take place subsequent to faulting and regional uplift. Those rocks near Cape Naturaliste and Doubtful Island Bay are probable examples of tectonism of this type.

A *second environment* for the formation of rocks of granulite metamorphic facies is that in which the basement-complex has been thermally metamorphosed by the intrusion of mobilized masses of the basement-complex. According to the hypothesis set out above, bodies of "granite" can be expected to develop beneath the trough, flow horizontally into areas of lower pressure and there intrude the upper levels of the crust. Under such conditions, there may be sufficient "superheat" in the crystal mush to produce coarse pyroxene hornfelses and allied rocks within a restricted aureole. Basic rocks may be expected to give identical mineral assemblages under thermal metamorphism of this type or under the more deep-seated regional dynamo-thermal metamorphism described above. In thermal metamorphism of this type, however, cordierite is a mineral which could form, whereas in dynamo-thermal metamorphism of this type, cordierite is probably unstable. Thus, the cordierite-hypersthene assemblage near the contact with the Calyerup Granodiorite (Wilson 1958*a*) and the cordierite-garnet granulites in the aureole of the orthopyroxenic Ernabella Adamellite (Wilson 1954) are possible examples of such thermal activity. However, the rarity of recognizable thermal phenomena of this type may be due in large measure to the activity of volatiles which would tend to be released from the palingenetic magma when it reached these regions of lower pressure. Biotite and amphibole would tend to be the main mafic minerals, especially as in a region of lower pressures the conditions required for granulite metamorphism could rarely prevail.

A *third environment* for the formation of rocks of charnockitic type is envisaged. Here appropriate metamorphism of the basement-complex would appear to be brought about by its regional depression through large-scale faulting rather than by the downward drag related to the formation of a primitive geosyncline. It is postulated that blocks of the basement-complex may be thrust down and held in hot zones by major reversed faults. The basement-complex may not give rise to a palingenetic magma by such a depression but it is thought to be capable of receiving an essentially thermal metamorphic imprint. The resultant rock would be a coarse hornfels or granulite. Linear elements could not be expected to develop through normal thermal metamorphism excepting as mimetic features. However, it is obvious that a regional depression of a block of the crust by forces of the magnitude here envisaged would probably produce varying degrees of plasticity of the rocks especially where there are zones of contrasted competency. Under such conditions a poor lineation of the type characteristic of the "first environment" could develop in favoured zones.

For some time I have suspected that the rocks of the region extending from Geraldton through Northampton to the Murchison River near Galena have suffered at least two regional metamorphisms (Wilson 1958*b*). The second regional metamorphism possibly took place when the area was depressed into a hotter zone of the earth. This could have taken place during an Archaean movement somewhere in the vicinity of what is now known as the Darling Fault zone. Alternatively, crustal depression sufficient to produce the metamorphism may have developed during the deposition of sediments in the trough situated mostly west of the present Darling Fault. Visible evidence of the trough sediments may be seen in the regions of Yandanooka, Chittering, Nannup and possibly the lower Gascoyne River (see page 63). Prider (1958) has recently given brief descriptions of the co-existence of pyrope-almandine and cordierite in the granulites of greywacke composition, and the co-existence of the garnet-cordierite granulites with the hypersthene-augite-plagioclase granulites of gabbroic composition from the Galena area. These mineral associations suggest to me that the latest regional metamorphism of the area has been mainly of a thermal type. Such a thermal metamorphism would produce rocks normally referable to the pyroxene hornfels facies. However, in so far as plastic deformation as well as purely thermal metamorphism has occurred locally, some linear elements may be expected in these rocks, and these linear elements may become superimposed on linear elements and other structures of earlier metamorphisms.

It is apparent, therefore, that the granulites of all three postulated environments have many features in common. Indeed, the basic granulites are virtually indistinguishable mineralogically from one another. This fact is a cogent reason why the name "basic charnockite" is of limited value for these rocks.

A *fourth environment* for charnockitic rocks is widespread in Western Australia. In the York-Northam region, for example, large boudins of pyroxene granulite commonly occur within gneisses which belong to a lower metamorphic facies, and common hornblende or biotite usually rim the pyroxene in the granulites. These features suggest that retrograde metamorphism of some type has taken place (Wilson 1955, p.14). In this connection, however, it should be pointed out that in discussing rocks as complicated as charnockitic rocks, one must not overlook the possibility that, during a major period of metamorphism, there may be considerable waxing and waning of pressure, temperature and other factors. This may be sufficient to ensure that the final texture and mineralogy of a rock will reflect a paragenesis which is much more complex than that normally due to a simple progressive rise in intensity of metamorphic processes. The significance to the "Charnockite problem" of repeated metamorphisms and fluctuations within a single major period of metamorphism is discussed by Rao (1940).

Magmatic charnockites are unknown in Western Australia. However, hypersthene-bearing granites which have been magmatically emplaced have been recorded (e.g., the Jerramungup Adamellite—Wilson 1958*a*), but the hypersthene grains are possibly merely xenocrysts from the charnockitic basement which is not far distant. "Magmatic" rocks comparable with the ferro-hypersthenic Ernabella Adamellite from Central Australia have not yet been found (Wilson 1955 and 1954).

The age of the charnockitic rocks

The formation of charnockitic rocks would appear to have taken place on at least two occasions in Western Australia.

(a) *Early Archaean.*—The granites which have injected charnockitic rocks in the Wheat-Belt of Western Australia (e.g., near Meekering, Corrigin, Bruce Rock, etc.) are about 2800×10^6 years old (K-A method, P. Jeffery, pers. comm.).

(b) *Late Archaean.*—Pegmatitic schlieren (which appear to have been sweated out of the basement during its conversion to charnockitic rocks) at Doubtful Island Bay (south coast of Western Australia), and coarse pegmatites which cut the charnockitic rocks of the Fraser Range are 1390×10^6 and 1210×10^6 years old, respectively (Note: estimations were based on Pb, Th, U ratios (uncorrected for isotopes) from allanite—see p. 76).

If these "ages" can be accepted as being of the right order of magnitude it would seem that a metamorphism was proceeding about 1400-1200 million years ago. This may have been the time of the re-metamorphism of the basement-complex enclosing the postulated geosyncline in the Pemberton-Ravensthorpe area. If this be true, I would expect the pegmatitic schlieren of the Northampton-Ajana area to be of comparable age, for I am suggesting that the re-metamorphism of that area was related to a geosyncline similar in age (see p. 63).

Conclusions and Recommendations

The geological map has brought together new information from several quarters. Granite, gneiss, meta-sediments, "greenstones" and charnockitic rocks have been distinguished on a single map for the first time and all available structural trends have been recorded. During the next few years the boundaries of some of these rock units will be changed and more structural data and radioactive-age-determinations will be amassed.

For the purpose of this address I have felt obliged to show some "interpretations" on the map. A careful study of the map or of the original plans at the University will show where the data on which the interpretations are based are most complete.

My efforts to produce this map and to present my present ideas on the structure and petrological history of south-western Australia will be amply rewarded if they stimulate constructive criticism and research. Indeed, I would like to make some observations on how I think the knowledge of our Precambrian terrain can be rapidly increased.

Firstly, the following suggestions are brought to the notice of geologists (or geologists-in-training) who make excursions into the Precambrian areas of Western Australia.

(i) Structural and petrological data should be systematically and carefully collected from all portions of the Precambrian areas. Strike and dip of foliation, lineation, and description of grain-size, homogeneity and any other structural features should be recorded, and a representative specimen (preferably oriented) collected. The collection of an oriented specimen takes about twice as long as that of an "ordinary" specimen. However, an oriented specimen may prove of considerably greater value to us in later years should micro-fabric studies be used in an attempt to piece together structural information in some areas, particularly if the rocks show little or no obvious "foliation" in the field.

(ii) The systematic collection of specimens is important, for with rapid advance of methods of radioactive-age-determination, mica, feldspar, zircons and monazite from granite and gneiss (as well as from pegmatite) can now be used to give the age of metamorphisms. A sample of about three pounds of fresh granite will normally yield (at present) sufficient material for our purposes.

Secondly, to research students I would like to point out a few of the more important projects in need of immediate attention.

(i) Mapping of the belt of meta-sediments from Jimperding area near Toodyay and the Wundowie area to discover the relationship between the meta-sediments of these areas and those of the Chittering area.

(ii) Investigation of the significance of the lineation found in many of the (? sheared) metamorphic rocks of the Chittering area.

(iii) Investigation of a possible fault to separate the (? younger) granitic rocks of the Darling Range and the high-grade gneisses which are common to the east of a line joining the New Norcia, Bolgart, Northam, York, Brookton, and Wagin areas.

(iv) Investigation of the cause of the marked difference in rock-type and metamorphic grade of the rocks E. and W. of a line running N. through Bridgetown.

(v) Investigation of the structural significance of mylonites in the vicinity of the Darling Fault (e.g., at Cookernup and Roelands).

(vi) Study of the high-grade metamorphic rocks of the Wellington Mills area to discover their age and relationship (if any) to the rocks of the Cape Naturaliste area.

(vii) Investigation of the cause of the double regional metamorphism which appears to have affected the rocks of the Northampton-Ajana area.

(viii) Magnetic and gravity surveys of areas covered by soil or laterite (such as E. of Karalee) in search of banded-iron-formations which may prove host rocks for gold or sources of iron ore.

(ix) Investigation of the basic dyke systems to determine their age-relationships and structural significance with respect to possible fundamental crustal weaknesses.

Acknowledgments

Professor R. T. Prider's wide knowledge of the geology of Western Australia and his willingness to discuss problems have been of great value.

The University of Western Australia has been liberal in its allocation of research funds to assist the widespread reconnaissance necessary to collect structural data for the map.

The officers of the Government Chemical Laboratories have made available some chemical analyses which were in an unpublished manuscript by the late Dr. E. S. Simpson.

The officers of the Geological section of the Mines Department of Western Australia (particularly Mr. Jones and Mr. Wilkinson) have made a notable contribution to this paper by their willingness to prepare the map for publication.

References

Aurousseau, M. (1926).—Analyses of three Australian rocks. *Proc. Linn. Soc. N.S.W.* 51: 614-626.

Baker, G. F. U. (1952).—Pre-Cambrian geology of Yandanooka, Western Australia. Thesis, Univ. W. Aust.

Bowes, D. R. (1954).—The metamorphic and igneous history of Rosetta Head, South Australia. *Trans. Roy. Soc. S. Aust.* 77: 182-214.

Brock, B. B. (1956).—Structural mosaics and related concepts. *Trans. Geol. Soc. S. Afr.* 59: 149-197.

Campbell, J. D. (1953).—The structure of the Kalgoorlie Goldfield. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 79-93.

Chung, S. K. (1957).—The geology of the Ferndale Area near Balingup, Western Australia. Thesis, Univ. W. Aust.

Clappison, R. J. S., and Zani, J. A. (1953).—The structure of the Southern Cross-Bullfinch Belt, Yilgarn Goldfield. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 128-137.

Clarke, E. de C. (1923).—The Pre-Cambrian System in Western Australia. *J. Roy. Soc. W. Aust.* 9: 13-37.

————, Phillipps, H. T., and Prider, R. T. (1954).—The Pre-Cambrian geology of part of the south coast of Western Australia. *J. Roy. Soc. W. Aust.* 38: 1-64.

————, Prider, R. T., and Teichert, C. (1955).—Elements of Geology for Western Australian Students (3rd Ed.). (Univ. W. Aust. Press: Nedlands, W. Aust.)

Clarke, F. W. (1924).—The data of geochemistry. *Bull U.S. Geol. Surv.* 770.

David, T. W. E., and Browne, W. R. (1950).—"The Geology of the Commonwealth of Australia." (Arnold & Co.: London.)

Edwards, A. B. (1938).—Tertiary tholeiite magma in Western Australia. *J. Roy. Soc. W. Aust.* 24: 1-12.

Ellis, H. A. (1939).—The geology of the Yilgarn Goldfield, south of the Great Eastern Railway. *Bull. Geol. Surv. W. Aust.* 97.

————(1951).—Kyanite at West Beach, 10 miles west of Hopetoun, and near East Mt. Barren, 5 miles west of Hopetoun. *Rep. Dep. Min. W. Aust.* for 1949: 57-58.

————(1953*a*).—Report on the Donnelly River graphite deposits, Western Australia. *Rep. Dep. Min. W. Aust.* for 1951: 48-49.

————(1953*b*).—The Greenbushes Tin-Tantalite District. Geology of Australian Ore Deposits. (5th Emp. Min. Met. Congr. 1953): 182-187.

————(1953c).—Norseman Gold Mines N.L. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 150-158.

Finucane, K. J., and Jensen, H. E. (1953).—Lode structures in the Kalgoorlie Goldfield. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 94-111.

Forman, F. G. (1937).—A contribution to our knowledge of the Pre-Cambrian Succession in some parts of Western Australia. *J. Roy. Soc. W. Aust.* 23: xvii-xxvii.

————(1953).—The Geological structure of the shield in southern Western Australia in relation to mineralization. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 65-78.

Frost, M. J. (1952).—The fracture systems of the Darlington area. Thesis, Univ. W. Aust.

Geary, J. K. (1952).—The geology of the Wattle Flat area, Chittering Valley, Western Australia. *J. Roy. Soc. W. Aust.* 36: 77-107.

Geological Survey of Western Australia (1950).—Geological sketch map of Western Australia. (Government Printer: Perth.)

Handley, J. R. F. (1956).—Banded iron stones and associated rocks. *East-Central Regional Committee for Geology*, First Meeting, Dar-es-Salaam: 39-46

Hatch, F. H., Wells, A. K., and Wells, M. K. (1949).—"The Petrology of the Igneous Rocks," 10th Ed. (Murby: London.)

Hills, E. S. (1946).—Some aspects of the tectonics of Australia. *J. Roy. Soc. N.S.W.* 79: 67-91.

————(1953).—Tectonic setting of Australian ore deposits. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 41-61.

————(1956).—A contribution to the morphotectonics of Australia. *J. Geol. Soc. Aust.* 3: 1-15.

Hobson, R. A., and Matheson, R. S. (1949).—Greenbushes Mineral Field. *Bull. Geol. Surv. W. Aust.* 102.

Holland, T. H. (1900).—The charnockitic series, a group of Archaean hypersthenic rocks in Peninsular India. *Mem. Geol. Surv. India.* 28, pt. 2.

Holmes, A. (1954).—"Principles of Physical Geology." (Nelson: London.)

Ivanac, J. F. (1946).—The geology and geomorphology of the Gillingarra area. Thesis, Univ. W. Aust.

Jeffery, P. M. (1956).—The radioactive-age of four Western Australian pegmatites by the potassium and rubidium methods. *Geochim. et Cosmoch. Acta* 10: 191-195.

Johnson, W. (1950*a*).—A geological reconnaissance survey of . . . . , parts of the Yalgoo, Murchison, Peak Hill and Gascoyne Goldfields. *Bull. Geol. Surv. W. Aust.* 106.

———(1950*b*).—Report on a geological examination of a new gold find on Calyerup Creek in the South-West Land Division of Western Australia. *Rep. Dep. Min. W. Aust.* for 1948: 97-99.

———(1950c).—Report on a deposit of anthophyllite asbestos two miles north of Bindi Bindi Siding on the Perth-Miling Railway. *Rep. Dep. Min. W. Aust.* for 1948: 104-106.

———, and Gleeson, J. (1951).—Report on the vermiculite deposits on M.C. 187H, Young River, Oldfield District, Eucla Land Division of Western Australia. *Rep. Dep. Min. W. Aust.* for 1949: 92-95.

———, de la Hunty, L. E., and Gleeson, J. S. (1954).—The geology of the Irwin River and Eradu districts and surrounding country. *Bull. Geol. Surv. W. Aust.* 108.

Johustone, M. H. (1952).—The geology of the Hamersley Siding area. *J. Roy. Soc. W. Aust.* 36: 45-75.

Jones, W. R. (1952).—The geology of the Bullsbrook area. Thesis, Univ. W. Aust.

Logan, B. W., and Chase, R. L. St. L. (1956).—The geology of the Moora area and stratigraphy of the Moora Group. Thesis, Univ. W. Aust.

Lord, J. H. (1950).—Report on kyanite deposits to the north of Yanmah, Nelson District, South-west Division. *Rep. Dep. Min. W. Aust.* for 1948: 91-92.

———(1952).—Collie mineral field. *Bull. Geol. Surv. W. Aust.* 105.

———, and Gray, N. M. (1951).—Report on examination of the iron deposit at Mt. Dick near Northam, Western Australia. *Rep. Dep. Min. W. Aust* for 1949: 83-85.

Maitland, A. Gibb (1925).—Notes on the country in the vicinity of and to the northward of Israelite Bay, Eucla Division (petrology by C. O. G. Larcombe). *Rep. Dep. Min. W. Aust.* for 1924: 107-112.

———(1927).—Western Australia's contribution to earth history. *J. Roy. Soc. W. Aust.* 12: 211-232.

———(1928).—The volcanic history of Western Australia. *J. Roy. Soc. W. Aust.* 13: 79-86.

———, and Montgomery, A. (1924).—The geology and mineral industry of Western Australia. *Bull. Geol. Surv. W. Aust.* 89.

Matheson, R. S., and Miles, K. R. (1947).—The mining groups of the Yilgarn Goldfield north of the Great Eastern Railway. *Bull. Geol. Surv. W. Aust.* 101.

McKinstry, H. E. (1945).—Pre-Cambrian problems in Western Australia. *Amer. J. Sci.* 243A (Daly Volume): 448-466.

McMath, J. C., Gray, N. M., and Ward, H. J. (1953).—The geology of the country about Coolgardie, Coolgardie Goldfield, W.A. *Bull. Geol. Surv. W. Aust.* 107.

McWhae, J. R. H. (1948).—The geology and physiography of the Lawnswood area. *J. Roy. Soc. W. Aust.* 32: 49-74.

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E. (1958).—The stratigraphy of Western Australia. *J. Geol. Soc. Aust.* 4: 1-161.

Miles, K. R. (1953).—Banded-iron-formation in Western Australia. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 159-171.

Miles, K. R. (1946).—Metamorphism of the jasper bars of Western Australia. *Quart. J. Geol. Soc. Lond.* 102: 115-155.

O'Driscoll, D. (1953).—Operations on the Norseman Field. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 138-149.

Parry, J. C., and Smith, D. N. (1952).—The geology and physiography of the Brookdale-Bergining area. Thesis, Univ. W. Aust.

Pettijohn, F. J. (1949).—"Sedimentary Rocks." (Harper and Brothers: New York.)

Playford, P. E. (1953).—Jurassic stratigraphy of the Geraldton area. Thesis, Univ. W. Aust.

Prider, R. T. (1943).—The contact between the granitic rocks and the Cardup Series at Armadale. *J. Roy. Soc. W. Aust.* 27: 27-55.

———(1944).—The geology and petrology of part of the Toodyay District, Western Australia. *J. Roy. Soc. W. Aust.* 28: 83-137.

———(1945*a*).—Granitic rocks from Canning Dam. *J. Roy. Soc. W. Aust.* 29: 137-149.

———(1945*b*).—Charnockitic and related cordierite-bearing rocks from Dangin, Western Australia. *Geol. Mag.* 82: 145-172.

———(1948*a*).—Igneous Activity, metamorphism and ore-formation in Western Australia. *J. Roy. Soc. W. Aust.* 31: 43-84.

———(1948*b*).—The geology of the Darling Scarp at Ridge Hill. *J. Roy, Soc. W. Aust.* 32: 105-129.

———(1952).—South-west Yilgarnia. Sir D. Mawson Anniv. Vol., Uni. Adelaide: 143-151.

———(1955).—The Pre-Cambrian succession in Western Australia. *Proc. Pan-Ind. Ocean Sci. Congr.*, Perth, Sect. C: 69-78.

———(1958).—The granulites and associated rocks of Galena, Western Australia. Stillwell Festband, *Aust. Inst. Min. Met* (in press).

Rao, B. Rama (1940).—The Archaean complex of Mysore. *Bull. Mysore Geol. Dep., India.* 17.

Russell, R. D., Farquhar, R. M., Cumming, G. L., and Wilson, J. T. (1954).—Dating galenas by means of their isotopic constitutions. *Trans. Amer. Geophys. Un.* 35: 301-309.

Saint-Smith, E. C., and Farquharson, R. A. (1913).—Geology and mineral resources of the Yilgarn Goldfield. Part 1—Southern Cross. *Bull. Geol. Surv. W. Aust.* 49.

Simpson, E. S. (1916).—Analyses of Western Australian rocks, meteorites and natural waters. *Bull. Geol. Surv. W. Aust.* 67.

———(1933).—The occurrence of andalusite, kyanite, sillimanite and staurolite in the Chittering valley. *J. Roy. Soc. W. Aust.* 18: 75-82.

———(1939).—Mineral provinces and metallogenetic epochs in Western Australia. *J. Roy. Soc. W. Aust.* 25: 207-237.

———(1948, 1951, 1952).—Minerals of Western Australia, Vols. 1, 2 and 3 (resp.). (Govt. Printer: Perth, W. Aust.)

———Annotations to Bull. Geol. Surv. W. Aust. 67. Unpub. MS. at Govt. Chem. Lab., Perth.

Stillwell, F. L. (1953).—Tellurides in Western Australia. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 119-127.

Sofoulis, J. (1954).—Report on Cattlin Creek spodumene pegmatite, Raveusthorpe, Phillips River Goldfield, Western Australia. *Rep. Dep. Min. W. Aust* for 1952: 83-86.

———(1955*a*).—Report on manganese prospect near Naendip, Kent Division, South-west Division, Western Australia. *Rep. Dep. Min. W. Aust.* for 1953: 62-64.

———(1955*b*).—Report on the broad geological structure of the Phillips River Goldfield, Western Australia. *Rep. Dep. Min. W. Aust.* for 1953: 64-68.

Thyer, R. F., and Everingham, I. B. (1956).—Gravity survey of the Perth Basin, Western Australia. *Bull. Bur. Miner. Resour. Aust.* 33.

Utting, E. P. (1953).—The Hannan's North Gold Mine. Geology of Australian Ore Deposits (5th Emp. Min. Met. Congr. 1953): 112-118.

Vening Melnesz, F. A. (1948).—Gravity expeditions at sea, 1923-1939, Vol. IV. (A. J. Mulder.) (Drukkerij Waltmann: Delft.)

Willmott, S. P. (1955).—The geology of the Quartz Hill area, York. Thesis, Univ. W. Aust.

Wilson, A. F. (1952).—The charnockite problem in Australia. Sir D. Mawson Anniv. Vol., Univ. Adelaide: 203-224.

————(1953*a*).—Diopsidization and hornblendization—important metasomatic phenomena in the basic schists near Southern Cross, Western Australia. *J. Roy. Soc. W. Aust.* 37: 97-103.

————(1953*b*).—The significance of lineation in Central Australia. *Aust. J. Sci.* **16**: 47-50.

————(1954).—Studies on Australian charnockitic rocks and related problems:—

Vol. II. The charnockitic granulites and associated gneisses of the Musgrave Ranges.

Vol. III. The charnockitic granites and associated granites of Central Australia. Thesis, Univ. W. Aust.

————(1955).—Charnockitic rocks in Australia—a review. *Proc. Pan-Ind. Ocean Sci. Congr.*, Perth, Sect. C: 10-17.

————(1957).—Some structural notes on charnockitic rocks. *Bull. Mysore Geol. Assoc.* 13.

————(1958*a*).—Pyroxenic granites and related rocks in the Jerramungup-Calyerup Creek Area, Western Australia. *J. Roy. Soc. W. Aust.* 41: 34-40.

————(1958*b*).—The charnockitic rocks of Australia. *Geol. Rdsch.* (in press).

Woodall, R. (1955).—Amphibolites and associated Precambrian rocks of part of the Phillips River Goldfield, Western Australia. *J. Roy. Soc. W. Aust.* 39: 1-17.

Woodward, H. P., Simpson, E. S., and Glauert, L. (1909).—Geological report upon the gold and copper deposits of the Phillips River Goldfield. *Bull. Geol. Surv. W. Aust.* 35.

11.—Teichertia in the Plantagenet Beds of Western Australia

By Brian F. Glenister* and J. E. Glover*

Manuscript accepted—20th May, 1958

The accurrence of *Teichertia prora* and *Aturia clarkei* in the Plantagenet Beds of Western Australia indicates a Middle Eocene (Lutetian) and possibly an Upper Eocene age for at least part of this unit.

Introduction

Nautiloids are rare in the extensive Tertiary strata of Western Australia, and until recently only a few well-preserved specimens were available for study. However, detailed stratigraphic surveys of all the major sedimentary areas of the State have resulted in the assemblage of useful collections of Tertiary nautiloids from the Giralia-Cardabia Range and the northern end of the Kennedy Range in the Carnarvon Basin, and from the coastal strip to the east of Albany. These pelagic molluscs have proved to be of value in the local correlation of Tertiary strata, although they are of limited worth for detailed studies in absolute chronology.

Early records of Tertiary nautiloids from Western Australia are included in papers by Jutson & Simpson (1916, p.50), Newton (1919), Chapman & Crespin (1934, p. 125), and Condit, Raggatt & Rudd (1936, p. 1059). Later mainly descriptive contributions were made by Miller & Crespin (1939), Teichert (1944), Teichert (*in* Teichert & Glenister, 1952, p. 737-738), Condon (1954, p. 117-120), Glaessner (1955, p. 354-357) and Glenister, Miller & Furnish (1956).

Our knowledge of Tertiary nautiloids is in an advanced state. This conclusion is warranted by the fact that intensive recent studies of extensive faunas from widely spaced geographic areas have resulted in the erection of very few new genera. The discovery of a new genus, *Teichertia* Glenister *et al.* (1956), from the Eocene Giralia and Jubilee Calcarenites of the Carnarvon Basin, was consequently of great interest. Until recently *Teichertia* was known from only 15 specimens collected in the Giralia Range. The present paper records the presence of this genus in the Plantagenet Beds on the Bremer River, some 850 miles S.S.E. of the previous locality.

The authors wish to acknowledge their gratitude to Mr. K. C. C. Tiller of the Perth Technical College who collected the new material on which this paper is based and supplied the necessary stratigraphic and geographic information. Anne Treloar Glenister drew the original of text-figure 2A.

Systematic Palaeontology

Genus **Teichertia** Glenister *et al.*, 1956

Type species.—Teichertia prora Glenister *et al.*, 1956, pp. 497-499, pl. 54, fig. 1-8, text-fig. 3B, 4B, 4C.

This genus was proposed to include a single species from the Eocene of Western Australia. It resembles *Deltoidonautilus,* but differs both in cross-section and sutural contours. In *Teichertia,* the venter is acutely angular rather than narrowly rounded, and the complete suture consists of seven lobes instead of the five developed by *Deltoidonautilus.* The most notable feature of the suture is the unusually high angular ventral saddle.

Teichertia prora Glenister *et al.*, 1956

Deltoidonautilus sp. and *Hercoglossa* sp. **Teichert**, 1952, *J. Paleont.* 26, pp. 737-738; **Condon**, 1954, *Rep. Bur. Miner. Resour. Aust.* No. 15, pp. 117-118.

Teichertia prora **Glenister** *et al.*, 1956, pp. 497-499, pl. 54, fig. 1-8, text-fig. 3B, 4B, 4C.

Description of type material.—This species was originally described from 15 specimens. Most are fragmentary, but together they display the significant morphological features of the species and represent the various ontogenetic stages from 15 mm to 300 mm shell diameter. The smallest available shells are thickly lenticular, but larger specimens develop narrowly compressed whorls, flattened flanks, an acutely angular venter, and a deep impressed zone. The umbilicus is narrow and is almost invariably closed by an umbilical callus. Fine growth lines form broad rounded lateral salients and moderately deep ventral sinuses.

Moderately large specimens develop 20 to 25 septa to the volution. Each suture forms a high subangular ventral saddle and on either side of it a broad rounded lateral lobe and a high rounded lateral saddle. The pair of shallow rounded lobes across the umbilicus are divided by a low umbilical saddle, and are succeeded by an asymmetric internal lateral saddle and a deep narrow dorsal lobe.

The siphuncle is subcentral and has a diameter equal to about a twentieth the height of the corresponding whorl. Septal necks are orthochoanitic and the siphuncle is slightly inflated between adjacent septal foramina.

Additional material.—A single additional specimen (University of Western Australia hypotype 39129) is known from the Bremer River. It is an imperfect internal mould which is preserved in fine-grained siliceous sandstone. Crushing of the specimen is not apparent. The maximum diameter of the conch is estimated to be 70 mm, and about one-third of the ultimate whorl is represented by body chamber. The umbilicus has a diameter of 3½ mm, and it lacks an umbilical plug. The whorl cross-section appears to be almost identical to that of the

---

*Department of Geology, University of Western Australia, Nedlands, Western Australia

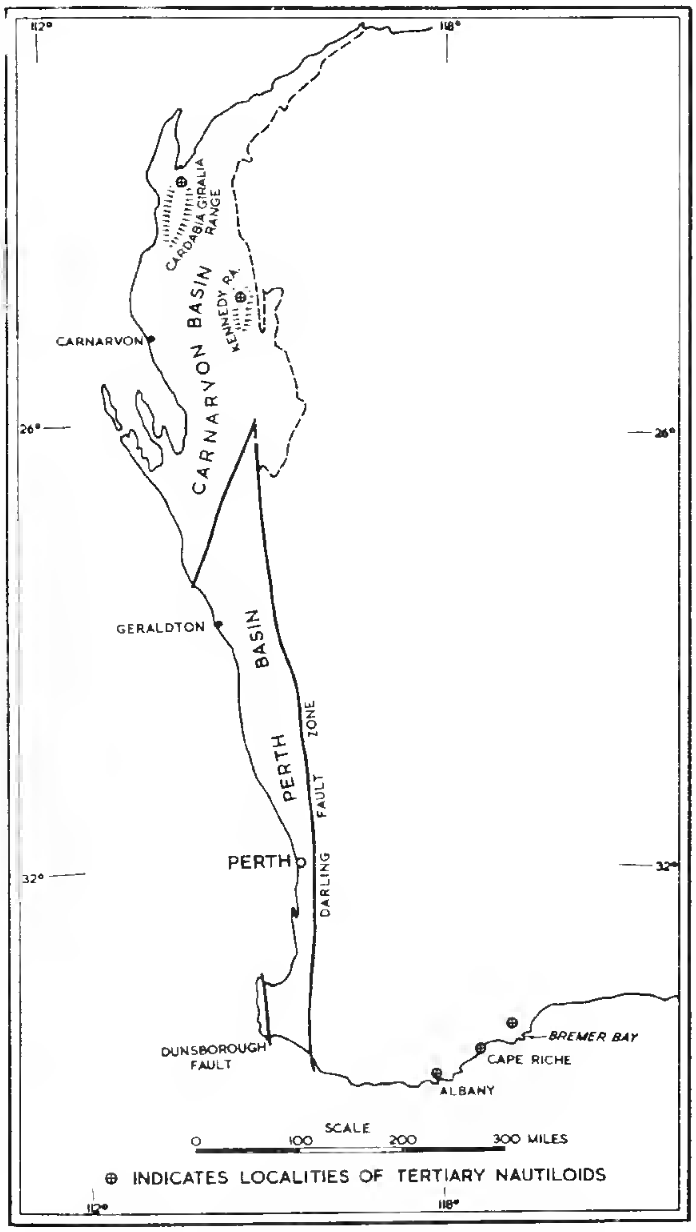

Fig. 1.—Locality map showing western part of Western Australia.

holotype, with an acutely angular venter, flattened flanks, and uniformly rounded umbilical shoulders. Six camerae are present in one-quarter of the ultimate whorl.

Only part of the suture is discernible, but the ventral saddle and part of the lateral lobe are identical with those of similar-sized type specimens.

Occurrence.—Most of the known specimens of this species are from the Giralia Calcarenite and the Jubilee Calcarenite of the Giralia Range, in the north of the Carnarvon Basin. One additional specimen (University of Western Australia hypotype 39129) was collected from an isolated exposure of the Plantagenet Beds in the cliffs which rise from the south bank of the Bremer River, 15½ miles north-west of John Cove in Bremer Bay and ¾ mile east of the Dog-Proof Fence. It was associated with a large but poorly preserved fauna of Foraminifera, sponge spicules, corals, bryozoans, brachiopods, worms, gastropods, pelecypods and scaphopods. All occurrences of the species are thought to be of Middle or possibly Upper Eocene age.

Repository.—Holotype 1700, figured paratypes 1701-1703, and unfigured paratypes 1704 and 1708 are lodged with the Commonwealth of Australia Bureau of Mineral Resources, and hypotype 39129 is housed in the Department of Geology, University of Western Australia.

Stratigraphic Implications

A recent general account of the stratigraphy of Western Australia is available in McWhae *et al.* (1958). The Plantagenet Beds are exposed sporadically for about 400 miles along the south coastal strip of Western Australia, from Nornalup Inlet to the Great Australian Bight. Sections up to 300 feet thick have been measured (Clarke & Phillipps, 1954), but nowhere have the strata been subjected to detailed mapping and extensive palaeontological studies. The unit had long been considered to be of Lower Miocene age (Chapman & Crespin, 1934, p. 127). However, Glaessner (1953, p. 143) suggested that the Plantagenet Beds of Western Australia, with *Aturia clarkei* Teichert and a rich fauna of sponges are probably about the same age as the late Eocene marine strata of south-eastern Australia. In a later paper Glaessner (1955, p. 357) indicated that, in South Australia, *Aturia clarkei attenuata* is restricted to the Tortachilla Limestone and its equivalents. This formation lies beneath the "transitional" member of the Blanche Point Marl, in which *Hantkenina alabamensis compressa* and other distinctive Upper Eocene Foraminifera are found. The other subspecies, *Aturia clarkei clarkei*, occurs above the "transitional" member in the "Banded Marl member" of the Blanche Point Marl of South Australia, about 40 feet above the Tortachilla Limestone. Glaessner attributed chronological importance to the relative stratigraphic positions of the two subspecies, although they were both considered to be of Upper Eocene age; the same age was indicated for strata with *Aturia clarkei* in the Plantagenet Beds. However, the range of *Aturia clarkei* probably extends down into the Middle Eocene, as this species has been recorded doubtfully from near the base of the Giralia Calcarenite (Glenister *et al.* 1956, p. 502).

It is doubtful whether there is any chronological significance in the relative stratigraphic positions of the two subspecies of *Aturia clarkei*, as both morphological types occur together in the thin Merlinleigh Sandstone of Western Australia. Glenister is at present assembling a collection to test the possibility that the two "subspecies" of *A. clarkei* are ontogenetic stages of the one species.

The known specimens of *Teichertia prora* from the Carnarvon Basin were collected from near the top of the Jubilee Calcarenite and the overlying basal beds of the Giralia Calcarenite. *Aturia* cf. *A. clarkei* is associated with the species near the base of the Giralia Calcarenite (Glenister *et al.*, 1956, p. 502). Dr. R. O. Brunnschweiler has studied the brachiopods, gastropods, pelecypods and echinoids of the two formations, and he considers both to be "Middle Eocene, mainly Lutetian" (writ. comm., 1/6/55). Dr H. S. Edgell's foraminiferal studies (writ. comm., 1/8/56) also indicate that both formations should be referred to the Lutetian. The possibility of a slightly younger age for at least part

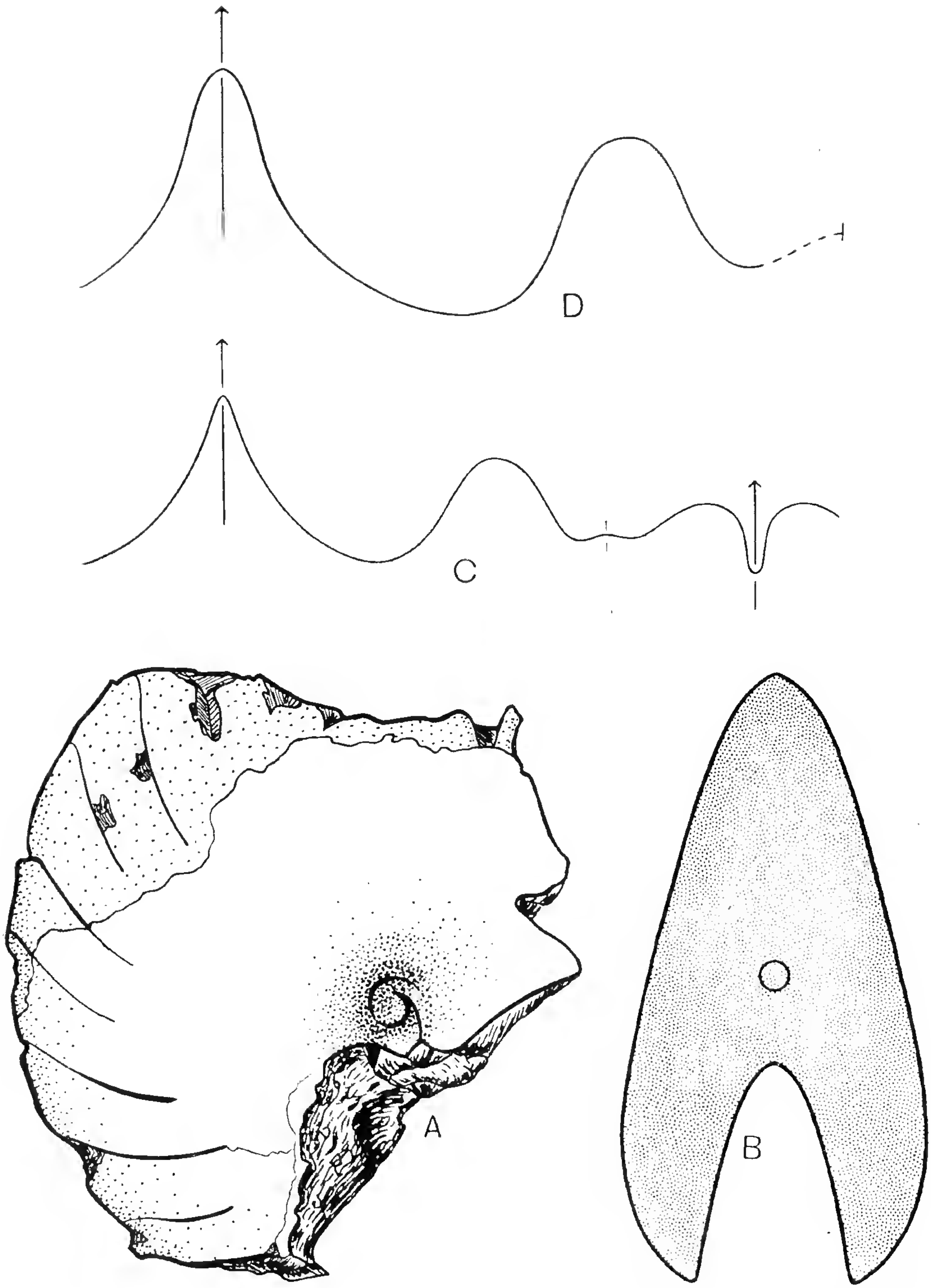

Fig. 2.—*Teichertia prora* from the Eocene of Western Australia. (A) hypotype 39129, from the Plantagenet Beds on the Bremer River, x 2; (B) cross-section of holotype 1700, from the Giralia Calcarenite of the Giralia Range, x 1¾; (C) suture of holotype at conch height of 55 mm; (D) suture of paratype 1703, from the Giralia Calcarenite of the Giralia Range at conch height of 165 mm. (B-D) after Glenister *et al.* (1956).

of the Giralia Calcarenite is suggested in foraminiferal studies by Crespin (*in* Crespin *et al.*, 1956, p. 6), who considers that "The species recognised indicate chiefly an upper Eocene age, but some of the limestones may be equivalent to 'a-b' stage of the Indo-Pacific 'letter' classification; that is, middle to upper Eocene." *Teichertia* is not known to occur above the basal beds of the Giralia Calcarenite, and so a Middle Eocene (Lutetian) age for the containing beds seems probable, although the possibility that they are Upper Eocene cannot be eliminated.

Aturia clarkei occurs in large numbers in the Merlinleigh Sandstone of the Kennedy Range. Dr. R. O. Brunnschweiler (writ. comm. 1/6/55) has studied an extensive collection of pelecypods gastropods, and echinoids from the formation, and believes that they are of Lutetian age. *Aturia clarkei* also suggests the correlation of the Merlinleigh Sandstone with the basal beds of the Giralia Calcarenite.

In conclusion, it is almost certain that at least parts of the Plantagenet Beds are of Eocene age. The cephalopods *Teichertia prora* and *Aturia clarkei* suggest correlation of the Plantagenet Beds with the Middle and possibly Upper Eocene Giralia Calcarenite and Jubilee Calcarenite of the Giralia Range and the Middle Eocene Merlinleigh Sandstone of the Kennedy Range. *Aturia clarkei* is known from the Upper Eocene of South Australia, although it could range down into the Middle Eocene in that area. Consequently, the age of the nautiloid-bearing strata of the Plantagenet Beds can be given as Middle Eocene (Lutetian) or possible Upper Eocene.

References

Chapman, F., and Crespin, I. (1934).—The palaeontology of the Plantagenet Beds of Western Australia. *J. Roy. Soc. W. Aust.* 20: 103-136.

Clarke, E. de C., and Phillipps, H. T. (1954).—The Plantagenet Beds of Western Australia. *J. Roy. Soc. W. Aust.* 39: 1-9.

Condit, D. D., Raggatt, H. G., and Rudd, E. A. (1936).—Geology of Northwest Basin, Western Australia. *Bull. Amer. Ass. Petrol. Geol.* 20: 1028-1070.

Condon, M. A. (1954).—Progress Report on the stratigraphy and structure of the Carnarvon Basin, Western Australia. *Rep. Bur. Miner. Resour. Aust.* No. 15.

Crespin, I., Kicinski, F. M., Patterson, S. J., and Belford, D. J. (1956).—Papers on Tertiary micropalaeontology. *Rep. Bur. Miner. Resour. Aust.* No. 25.

Glaessner, M. F. (1953).—Conditions of Tertiary sedimentation in southern Australia. *Trans. Roy. Soc. S. Aust.* 76: 141-146.

——————(1955).—Pelagic fossils (*Aturia*, penguins, whales) from the Tertiary of South Australia. *Rec. S. Aust. Mus.* 11: 353-372.

Glenister, B. F., Miller, A. K., and Furnish, W. M. (1956).—Upper Cretaceous and early Tertiary nautiloids from Western Australia. *J. Paleont.* 30: 492-503.

Jutson, J. T., and Simpson, E. S. (1916).—Notes on the geology and physiography of Albany. *J. Roy. Soc. W. Aust.* 2: 45-58.

McWhae, J. R. H., Playford, P. E., Lindner, A. W., Glenister, B. F., and Balme, B. E. (1958).—The stratigraphy of Western Australia. *J. Geol. Soc. Aust.* 4, 1-161.

Miller, A. K., and Crespin, I. (1939).—An *Aturia* from the Northwest Division of Western Australia. *J. Paleont.* 13: 79-81.

Newton, R. B. (1919).—On a sandstone cast of *Aturia Aturi* (Basterot) from the Miocene of Western Australia. *Proc. Malac. Soc. Lond.* 13: 160-167.

Teichert, C. (1944).—The genus *Aturia* in the Tertiary of Australia. *J. Paleont.* 18: 73-82.

Teichert, C., and Glenister, B. F. (1952).—Fossil nautiloid faunas from Australia. *J. Paleont.* 26: 730-752.

INSTRUCTIONS TO AUTHORS

Papers may be submitted to the Society in accordance with Rules and Regulations 38 to 41 inclusive (see below). They should be addressed to *The Honorary Secretary, Royal Society of Western Australia, Gledden Building, Perth.*

Authors are solely responsible for the factual accuracy and for any opinion expressed in their papers. They are particularly requested to verify references. Alterations to MSS. submitted to the printer will be allowed only under exceptional circumstances, and no changes will be permitted after galley-proof stage.

In the preparation of MSS. authors are required to follow the C.S.I.R.O., *Guide to Authors* (C.S.I.R.O., Melbourne, 1953), except that papers longer than 10,000 words (30 foolscap pages of pica type, with 6 inch lines 40 to the page) will not normally be accepted.

Authors may be required to meet half the cost of preparation of the blocks of diagrams and illustrations.

Authors shall receive a total of 30 reprints free of charge. Further reprints may be ordered at cost, provided that such orders are submitted with the MS.

RULES AND REGULATIONS

38. Every paper intended to be read before the Society or to be published in the Society's Journal must be sent to the Secretaries at least seven days before the date of the next ensuing Council meeting, to be laid before the Council. It will be the duty of the Council to decide whether such contribution shall be accepted, and if so, whether it shall be read in full, in abstract, or taken as read. All papers accepted for publication must be read or otherwise communicated at an ordinary meeting prior to publication.

39. A Publications Committee, appointed by the Council, shall recommend to the Council whether a paper presented to the Society shall be published in the Society's Journal. The Publications Committee may obtain an opinion from any person it may select on the suitability of any paper for publication.

40. Publication in the Society's Journal shall only be available to *(a)* Ordinary Members, *(b)* Honorary Members, *(c)* Non-members resident outside Western Australia, who must communicate the paper through an Ordinary or Honorary Member. No paper shall be accepted from a Non-member resident in Western Australia.

41. The original copy of every paper accepted for publication by the Society, with its illustrations, shall become the property of the Society, unless stipulation is made to the contrary, and authors shall not be at liberty to publish their communicated papers elsewhere prior to their appearance in the publications of the Society unless permission for so doing is given by the Society, or unless the Society fails to publish the paper in the Journal of the year in which it is read or otherwise communicated, or of the succeeding year.

Journal

of the

Royal Society of Western Australia, Inc.

Volume 41 1958

Part 3

Contents

10. Advances in the Knowledge of the Structure and Petrology of the Precambrian Rocks of South-western Australia. By Allan F. Wilson.

11. *Teichertia* in the Plantagenet Beds of Western Australia. By Brian F. Glenister and J. E. Glover.

Editor: J. E. Glover

Annual Subscription: Thirty Shillings

The Royal Society of Western Australia, Inc., Gledden Building,
731 Hay Street, Perth

16131/7/58—450

By Authority: ALEX. B. DAVIES, Government Printer, Perth