PRE-CAMBRIAN PROBLEMS IN WESTERN AUSTRALIA.

H. E. MCKINSTRY.

ABSTRACT. Present views differ from those of a decade ago in recognizing more clearly the importance of basic volcanics and clastic sediments. Recent work has established the stratigraphic succession in several districts. Generalized sequence of events (cf. Canadian shield): (1) Great outpouring of basic lava interrupted by minor periods of sedimentation (2) accumulation of many thousands of feet of clastic sediments with minor epochs of vulcanism (3) intense folding (4) granitic intrusion (5) peneplanation (6) deposition of clastic sediments (Nullagine) (7) minor folding (8) erosion.

Problems: (a) regional correlation of volcanic and sedimentary series (b) regional structure (c) separation of late intrusive granites from possible earlier granites and from para-gneisses (d) mechanics of granitic intrusion (e) metamorphism.

CONTENTS.

Introduction .................................................. 448
Geological Setting .......................................... 450
   Surface Features ........................................ 451
   Comparison with Canadian Shield ...................... 452
Kalgoorlie Series ........................................... 453
   Volcanics ............................................... 454
   Sediments in Kalgoorlie Series ....................... 455
Post-Kalgoorlie Sediments ................................. 457
Relations of Post-Kalgoorlie Sediments to Greenstones . 458
   Kalgoorlie District ................................... 458
   Yilgarn District ..................................... 458
   Other Districts ....................................... 458
Intrusive Rocks ............................................ 459
   Granite ............................................... 459
   Siliceous Porphyries .................................. 459
   Basic Intrusives ...................................... 460
Metamorphism ................................................ 461
Structure ................................................... 462
Ore Deposits ................................................ 463
Problems .................................................... 464
   Stratigraphic Correlations ............................ 464
   Mechanics of Granite Intrusion ...................... 464
   Metamorphism ........................................ 465
   Structure ............................................ 465
Acknowledgments ............................................ 465

INTRODUCTION.

THE accepted interpretation of the geology of one of the world's pre-Cambrian shield areas has changed notably during the past decade, but the newer views are as yet embodied in only a few recent publications, (1)\(^1\) most of which are not

\(^1\) Numbers in parentheses indicate references cited.

448
readily available outside of Australia. This summary of the
géology as it appears in the light of recent work may there-
fore be convenient to American readers.

The rather voluminous literature on Western Australia,
published before the early 1930's, conveys the impression that
the rocks older than the widespread granitic intrusives consist
largely of basic plutonics. For instance, the 1933 and earlier
editions of the state geologic map(2) show great areas of
"gabbro, dolerite, epidiorite, serpentine etc." So long as these
basic rocks were regarded as predominantly intrusive, the sedi-
mentary origin of thin bands of carbonaceous slate and banded
iron formation within them was difficult to accept, and such
horizons were interpreted (respectively) as graphite-impregn-
nated phases of the intrusives or as silicified shear zones.
Larger areas of unquestioned sediments were regarded as the
remnants of older formations (Yilgarn Series) intruded by the
basic rocks. The key to the revised interpretation was the
realization that much of the basic material is volcanic. Once
this fact was recognized, the interbedded sediments did not need
to be explained away. Where thick layers of sediments strad-
dled a core of greenstone, anticline-fashion, it became evident
that they were younger, not older, than the greenstone. Thus,
the necessity for the pre-greenstone Yilgarn series no longer
existed.

It would be unfair to the earlier investigators of Western
Australian geology to imply that the nature of these rocks had
not been suspected before. Actually, nearly every feature of
the present interpretation had been suggested at some time by
one author or another, but of the various alternative sug-
gestions the ones that are now regarded as "correct" had not
been selected and fitted together into a consistent picture.
This is hardly surprising in a region where unoxidized rocks are
rarely seen. That the present interpretation was reached
rather suddenly seems attributable in some degree to the arrival,
in 1933 and the years immediately following, of a succession of
geologists(2) who had been privileged to become thoroughly

(2) Among the foreign geologists who worked in Western Australia during
this period were several former students of Reginald A. Daly: John K.
D. H. McLaughlin, first a student and later a colleague of Daly's made an
extended tour of the region in 1935. The present director of the Western
Australia Geological Survey, F. G. Forman, spent a year in graduate study
under Daly and other members of the Harvard faculty in 1938 and 1939.
familiar in other continents with similar rocks in a much more favorable state of preservation and exposure. Questions raised by the newcomers and the willingness of the Western Australian geologists to re-examine former opinions and make further search for the correct answers led to rapid acceptance of the new ideas. The views that are presented here do not purport to be identical in all respects with those of the geologists now working in the state, but conversation and correspondence lead me to believe that their essential principles would no longer meet with pronounced disagreement.

GEOLOGICAL SETTING.

Pre-Cambrian rocks occupy two-thirds of the state. The remaining third is made up of three separate areas of Permian
to Tertiary sediments. Of the pre-Cambrian area rather more than half is underlain by the Nullagine Series, a succession of sediments which is little metamorphosed and only gently folded in comparison to the older rocks below it. This youngest pre-Cambrian series presents problems of its own, but the present paper is primarily concerned with the pre-Nullagine complex and its challenging questions of correlation, structure, metamorphism and intrusion.

Study of these older pre-Cambrian rocks is farthest advanced in what is known as the Central Goldfields region, an area 400 × 200 miles in dimensions and as large as the British Isles or as New England plus New York State.

Surface Features.

An understanding of the possibilities and difficulties of geological observation in the area, requires a brief consideration of the nature of the terraine. The Goldfields region corresponds approximately to the province that Jutson(3), in his excellent physiographic description, terms Salinaland. It is part of a plateau 1000 to 1500 feet above sea level. Most of it is flat—low ridges and mesas that rise at most a few hundred feet above the broad plain merit such names as Mt. Sir Samuel, Mt. Jackson and Mt. Charlotte, only by contrast to the general lack of relief. There are no permanent streams; the numerous “lakes” are playas that contain water only after the seasonal rains.

The climate is dry and hot. Technically, the northeastern part is desert of the rocky “hamada” type, rating as BWh and corresponding to Plateau Mexico. The southwestern part is technically steppe, rating BSh and corresponding to the Mojave desert of lower California.3

The water table is deep, usually 80 to 100 feet and the ground water, except in the northern part, is brackish to highly saline.

The rocks throughout large areas are concealed by the soil of the plains, by the silt of the dry lakes, by occasional sand dunes, or by surface crust (“duricrust” or caliche) consisting of CaCO₃ or of laterite. Because of the large covered areas, much of the broad-scale mapping, that has been done by the

3 For the designation, according to the Köppen world classification of climates, I am indebted to Prof. E. R. Dunn of Haverford College.
Western Australia Geological Survey, has of necessity been based on a shrewd interpretation of soil and vegetation and while this is undoubtedly correct in broader aspects, there are great areas in which only the separation of basic and silicic rocks has been possible. Recent mineralogical studies of soils by Dr. Dorothy Carroll(4) promise to be of great assistance in remapping such areas.

Even where the rocks are not concealed they are mostly thoroughly oxidized and, to the unpracticed eye, quite unrecognizable. However, the geologist does not need to rely entirely on soil geology or on deep mine levels, since surprisingly fresh rocks are sometimes found on the ridges, on the “breakaways” forming the shores of the lakes, and even on the floors of the plains themselves.

**Comparison with Canadian Shield.**

The rocks of the central Goldfields Region present a surprising resemblance, both in their physical nature and in their sequence, to those of the pre-Cambrian Shield in Canada. This is brought out by the following comparative table:

<table>
<thead>
<tr>
<th>Western Australian Shield</th>
<th>Canadian Shield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epidiorite</td>
<td>Basic Dikes</td>
</tr>
<tr>
<td>Nullagine Series</td>
<td>Little folded sediments, including conspicuous conglomerates</td>
</tr>
<tr>
<td></td>
<td>Cobalt Series</td>
</tr>
<tr>
<td></td>
<td>Great Unconformity</td>
</tr>
<tr>
<td>Granites and porphyries</td>
<td>Granitic Intrusions</td>
</tr>
<tr>
<td>Post-Kalgoorlie sediments</td>
<td>Slates, graywackes, tuffs, sandstones and some conglomerates. Some interbedded lavas.</td>
</tr>
<tr>
<td></td>
<td>Timiskaming</td>
</tr>
<tr>
<td>? Granites?</td>
<td>Granitic Intrusions</td>
</tr>
<tr>
<td>Kalgoorlie Series</td>
<td>Mainly basic volcanics: pillow lava and granular (now greenstone) flows. Interbedded iron formation, carbonaceous slate and tuff.</td>
</tr>
<tr>
<td></td>
<td>Keewatin</td>
</tr>
</tbody>
</table>

Such a table admittedly involves over-simplification in respect to both continents, yet the similarities are so striking that the geologist with experience in northern Ontario finds himself at home on Kalgoorlie and Wiluna.
KALGOORLIE SERIES.

The oldest series, according to present views, is a great thickness of volcanic greenstones with their interbedded sedi-

Fig. 2. Geological Sketch-Map of the Central Goldfields Region (compiled from maps of W. A. Geological Survey). Black dot between Menzies and Norseman indicates location of Kalgoorlie.

mentary horizons. In the Kalgoorlie district this is known as the Kalgoorlie Series and for convenience this name is used in the present paper for similar rocks throughout the region.
The basic rocks vary greatly from place to place in their texture and mineralogical composition, but the variation is of the sort that is commonly produced by metamorphism and hydrothermal alteration. There is no reason to believe that the original nature of the greenstones as a group, in any one part of the district, differed from that in another. That they are all of the same age is not proved, but wherever they are found they are the oldest rocks known.

The proportion of intrusive material is not easy to determine. Where shearing and metamorphism are not too strong, and where exposures are good, intrusive dikes and sills can generally be distinguished from the volcanics. There are large areas, however, in which exposures are so poor that massive greenstones cannot be shown to be either extrusive or intrusive, although their texture is no coarser than that of the thicker flows.

There are still larger areas of relatively coarse amphibolite which can be traced through all gradations into recognizable volcanics. Since this material is interbedded with metamorphosed sediments the inference is that it represents recrystallized basic lava.

Structures characteristic of lavas can be recognized wherever any extensive section of the greenstone series is exposed, provided metamorphism is not too intense.

Pillow structure has been observed by the writer in many places. These will be listed in detail because references to pillow lavas are rare in the local literature and because pillow structure is so characteristic of extrusive origin;

Wiluna: Well-preserved pillow-lava constitutes the wall-rock of the orebodies.

Cue: On the southwest slope of Trenton Hill, south of Day Dawn.

Mt. Magnet: In the open cut of the Big Lode workings of the Morning Star Mine.


Davyhurst: In a crosscut from the shaft north of the Callion Workings.

Kalgoorlie: In the “calc schist” in the mines on the east side of the district, e.g. Oroya-Brownhill, Associated and Union Jack Mines. (Photograph appears as fig. 14 of Gustafson and Miller’s paper, 6.)

4 One of the few references is by Honman (5, p. 26).
Kanowna: East of the lake, southeast of the town.
Yellowdine: On the west shore of the lake just east of the new mine workings.
Norseman: In the upper workings of the Viking Mine; also on the north side of Lake Cowan near the causeway.

In most of the places mentioned the pillows are so well preserved that their original convex upper sides can be distinguished from their flat or cusp-shaped bottoms.

Other characteristic volcanic textures are common. Some of the best examples may be listed:

Breccia flow-tops, beautifully preserved at Cue Hill, north of Cue Railway Station.
Definite flow-tops traceable for hundreds of feet, just northeast of Mount Hunt, 6 miles south of Kalgoorlie.
Amygdaloidal lava, in the cutting of the Transcontinental Railway 1½ miles east of Kalgoorlie Station.

Sediments in the Kalgoorlie Series.

Interbedded with the flows are tuffs, slates and banded iron formation. Tuffs are difficult to recognize where metamorphosed, since they are similar in composition to the greenstone. In a few localities, however, fine stratification can be recognized, for example, on the north shore of Lake Kookoorodine (north of Southern Cross).

Slate, much of it carbonaceous, is fairly common. Slates are to be seen, for example, in the upper workings of the Iron Duke and Associated mines in Kalgoorlie where slate lies between flows of pillow lava. Underground at Wiluna, a band of strongly carbonaceous slate, a few feet wide, has been dragged out and has developed lustrous slickensides along a shear zone. In the Cue district, about a mile west of Day Dawn, a band of bleached slate, a foot wide, can be traced for a quarter of a mile.

Banded iron formations have been seen in at least fifty

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5 H. J. C. Conolly and J. D. Campbell showed the Norseman localities to the writer.
6 The rocks of Cue Hill and Trenton Hill were recognized as lavas by Woodward (6) but were regarded by him as the products of relatively young volcanoes. The recent work of J. M. LaGrange (unpublished), however, shows that they conform in attitude to the folding of the region and, except for better exposure, differ in no way from the greenstone of the vicinity.
Fig. 3. Geological Sketch Map of Belt West of Kalgoorlie (after Honman, Talbot, Gustafson, Miller and others).
localities throughout the Goldfields Region. Known locally as “jasper bars,” these bands were formerly interpreted as silicified shear zones in the greenstone. The evidence for their sedimentary origin has been discussed at length elsewhere(7).

POST-KALGOORLIE SEDIMENTS.

The sedimentary rocks younger than the Kalgoorlie series, yet older than the Nullagine are mainly sandstones and quartzites with subordinate slates and graywackes. Limestones are rare if they exist at all.

W. H. B. Talbot(8) has worked out a very definite sequence in a previously unmapped area, 20 miles north of Kalgoorlie:

Kurrawang series Conglomerate and Sandstone 8000 ft. 

.......................... Unconformity ..............................

Kundana Series Sandstone and shale with basal conglomerate 7000 to 14000 ft.

White Flag Volcanics Andesitic and decritic lavas and sedimentary tuffs 12000 ft.

Black Flag Series Sandstone, shale and sedimentary tuff, rhyolitic lava and agglomerate 8000 ft. 

.......................... Unconformity ..............................

(Kalgoorlie Series) (Basic flows, chloritized to amphibolitized) (17000? ft.)

The relative ages are clearly indicated by structural relations. The Black Flag series forms the center of an anticline flanked by White Flag volcanics. To the west, the Kurrawang series occupies a syncline.

![Diagrammatic Cross Section through Kalgoorlie and the Belt to the West of it (looking northwest). Legend same as for Fig. 3.](image)
In other parts of the region the sedimentary system has not been subdivided stratigraphically. The existence of rocks similar to these and their relations to the greenstones will be noted in the ensuing paragraphs.

RELATIONS OF POST-KALGOORLIE SEDIMENTS TO GREENSTONES.

Kalgoorlie District.

Greenstone does not appear in the area mapped by Talbot, but emerges toward the south on the prolongation of Talbot's major anticline to form an elongated dome in the Kalgoorlie district proper. This dome, or anticline, is flanked by sediments similar to the Black Flag series, as indicated by observation of facing of flows (pillow lavas and amygdaloidal tops) and sediments (drag-folding, graded bedding and cross-bedding). A broad area surrounding the greenstone and mapped by earlier writers as "porphyrite," contains, besides the usual sedimentary types, certain horizons of bedded intermediate to acid tuff and dikes of quartz porphyry.

Yilgarn District.

The sedimentary rocks of the Yilgarn District, 100 miles west of Kalgoorlie, had been considered older than the greenstones(9). There, in one critical locality, K. J. Finucane and I mapped the underground workings of the Great Victoria mine and determined that the slate and quartzite (partly replaced by sulphides) formed the nose of an anticline, whose core was greenstone. Similarly in the Corinthian mine, four miles north of Southern Cross, sediments overlie greenstone on the east limb of an anticline. It remained, however, for the detailed work of H. A. Ellis(10) to assemble a consistent picture of the structure of the Yilgarn district. He distinguishes the Greenstone Series, consisting of volcanics with pillowed and amygdaloidal lavas and uncertain amounts of intrusive material, from the overlying Whitestone Series, consisting of metamorphosed sediments.

Other Districts.

In the Leonora District, 100 miles north of Kalgoorlie, Forman (1, p. 20) concludes that volcanic greenstones are the oldest recognizable rocks and are overlain without obvious unconformity by mica schists and slates.

North of the Goldfields region sediments, known as the Mos-
quito Creek Series, cover large areas. Forman concludes that they overlie basic and acid lava flows of the Warrawoona series, which he correlates with the Kalgoorlie (1, p. 20).

**INTRUSIVE ROCKS.**

**Granite.**

Granitoid intrusives, ranging from granite to diorite, occupy large portions of the Goldfields region. The commonest variety consists of quartz, microcline and oligoclase, with biotite or, in the less siliceous phases, hornblende. The many local textural varieties include normal granite, fine-granite and porphyritic granite, as well as varied types of granite-gneiss. The geographical distribution of these varieties has not been studied exhaustively; in fact, granite-gneisses and granitized sediments have not been separated from massive granites throughout most of the country.

Much, if not all, of the massive granite is certainly younger than the greenstones and younger than any of the pre-Nullagine sediments (except possibly, the Kurrawang). This is indicated by metamorphosed contacts and definite intrusive structures. Contacts cut across folds, and the granite (or at least some of it) lacks the shearing and schistosity that characterizes the folded rocks. Hence, the intrusive period was later than the last regional folding. Whether or not other granitic intrusions were earlier than the folding, has not been determined.

**Siliceous Porphyries.**

Quartz porphyries and albite porphyries are very common. Although most of them are later than the regional folding, there are some that have participated in at least the last phase of the deformation. A striking example is to be seen at White Flag Lake where lenses of quartz porphyry are enclosed in folded slate of the Black Flag formation. The slate shows exaggerated drag-folding in the neighborhood of these lenses, and the porphyry itself is sheared near its margins. The porphyry masses have the shape of pre-folding sills that have been torn apart during deformation.

It seems likely that the peculiar porphyry-bearing “conglomerates” of Kanowna represent intrusive dikelets that have suffered deformation along with the enclosing rock.

Dikes and sills of acid porphyry, younger than the folding,
are found in nearly every district. One example, that is unmistakably post-folding, is in Kalgoorlie District in the White Cliff Quarries where a dike of feldspar porphyry cuts directly across the vertical beds of tuff. Porphyries have selected weak sedimentary horizons in several instances as places to intrude and thus have confused the problem of the origin of the sediments. The most famous example is the "Boulder dike" in the midst of the Golden Mile at Kalgoorlie where a group of closely spaced porphyry dikes follows a tightly infolded tongue of slate and tuff between greenstone walls (11).

A similar association is to be seen in the railway cutting east of Coolgardie, where a porphyry dike is flanked by bands of black slate within the greenstone.

**Basic Intrusives.**

Like the acid porphyries, the basic intrusives comprise material of at least two ages, one earlier and one later than the latest regional folding. Of those which have been deformed, along with the country-rock, the most famous body is the "younger greenstone" sill at Kalgoorlie. Gustafson and Miller (11) have presented convincing evidence that it is not, as formerly believed (12, 13), a post-folding sill.

Similar sills which conform to folded bedding and have experienced alteration, are found in various parts of the region, e.g. coarse amphibolite many hundred feet thick in a broad fold between Coolgardie and Bonnievale and a series of amphibolite bands containing chromite grains in metamorphosed sediments in the Yilgarn District (10). A dike a thousand feet wide at Day Dawn (south of Cue) has been amphibolitized and subsequently altered to chlorite schist.

Other basic and ultrabasic intrusives are younger than the folding and some are younger than the granites. Some of them may be very late pre-Cambrian, since dolerites and epidiorites are known to intrude the Nullagine Series (14, p. 9).

Some of the rock-types that have been observed are:

Olivine diorite, mapped by Talbot, north of Kundana,
Fine-grained basic porphyrite dikes in the Kalgoorlie Mines.
Quartz gabbro, forming a ridge nearly three miles long northwest of Nungari.
A striking quartz-diabase (quartz-dolerite) consisting of feldspars up to ½ inch in diameter in a dark finely granular groundmass.
Because of its spotted appearance it is known as "native cat rock." It has been noted at Ora Banda and at several places near Black Flag.

A great dike of norite in the Norseman district, nearly a mile wide, has been traced for over twelve miles and is doubtless much longer. It cross-cuts the general trend of the structure at right angles.

Bodies of serpentine occur in many localities, notably near Mt. Hunt, six miles south of Kalgoorlie; also at Comet Vale, where there is a long narrow belt partly altered to talc schist. Whether the serpentines are earlier or later than the folding is not clear.

**METAMORPHISM.**

No studies have been made of metamorphism as a subject in itself, although minerals of metamorphic origin have been described in numerous petrographic reports.

In a broad way the intensity of metamorphism appears to increase from east to west. In the east, along the Kalgoorlie-Laverton belt, greenstones have in many places never passed the chlorite-carbonate stage of alteration. Specimens from Kalgoorlie examined by Stillwell (18, p. 21) consist of a formless aggregate of chlorite, sericite, carbonate and quartz. Some specimens show granular epidote, and a few contain chloritoid. Aluminous sediments associated with these greenstones are slates lacking conspicuous mica.

A hundred miles to the west, at Southern Cross, the White- stone sediments show medium to high-grade metamorphism and contain sillimanite, almandite and staurolite. The sediments can be traced into material that has been mapped as granite, as for example, in the Corinthian Mine, ten miles north of Southern Cross. Here argillaceous sediments inter-banded with thin-bedded ferruginous chert grade into gneiss containing lenses of quartz-feldspar-biotite pegmatite. A bed of cherty iron formation is still visible in the gneiss. An excellent example of incipient granitization is to be seen in the railway cutting east of Yellodine Station, where beds of sandstone and shale are locally converted into pseudo-granite; in the middle of a bed, granular quartz and feldspar appear with no clear-cut walls. In this region pegmatites are much more common than farther east.

Still farther west, near the extreme margin of the pre-Cambrian area, gneisses are predominant. Forman (1, p. 24) finds bands of quartzite traversing the gneiss and preserving the dips
and strikes of the Jimperding sediments (correlative of the Whitestone and Black Flag Series). He considers that the gneisses and migmatites represent sedimentary rocks altered by granitic magma.

In this western area the banded iron formations have been strongly metamorphosed. Recent work by Miles(15) has shown that the iron mineral is magnetite; hematite is prevalent only in the oxidized zone. As in parts of the Lake Superior District, the iron minerals have reacted with silica to form grunerite(16).

The general westward increase in metamorphic intensity is by no means regular; it is interrupted by strong metamorphism, near granite contacts where the sediments are converted to gneiss and the greenstones to amphibolite.

This conversion of chloritic greenstone to amphibolite is widespread. Commonly the amphibole is tremolite or actinolite, but hornblende rocks are not rare, and there are clear examples to indicate that hornblende may develop in lavas by metamorphism. On Trenton Hill at Cue there are hornblende plates 4 cm. in diameter in amygdaloidal greenstones and hornblende needles 1 cm. long in pillow lavas, rock types in which coarse hornblende as an original mineral, would be entirely out of place.

**STRUCTURE.**

Folding, in the pre-Nullagine formations, is tight and complex. The structure is of the type characterized by isoclinal folds, many of them overturned. Drag-folding is intense, especially in the incompetent members. On the limbs of folds, whole formations become thin or even disappear; on the noses, the same formations become greatly thickened. Even fairly "strong" formations behave incompetently but the most competent are likely to be crushed and brecciated on flexures, especially if they are thin.

Intricate outcrop-patterns are occasioned by abrupt changes in pitch. In the Kalgoorlie district, for instance, the pitch displays two major undulations within a strike-length of two miles, ranging from 45 degrees northward to 40 degrees southward. The complexity is increased by the existence of opposite pitches to be found in a traverse across the strike. Similar changes of pitch have been described by Ellis (10, p. 129) in the Yilgarn district and have observed in many other places.
Despite the variability of dip and pitch, the strikes of the axial planes are uniform over large areas, very little disturbed by granitic intrusions and, in general, independent of the granite contacts. In a very broad way, however, the regional strike swings from northeasterly on the west side of the region (Mt. Magnet, Cue and Nanine) through east-west at Sandstone to southeast on the eastern side (Laverton, Menzies, Kalgoorlie).

Faulting, for the most part, takes the form of strike faults or stretch-thrusts—zones in which formations are sheared out on the limbs of folds. Major faults that are later than the folding, are not common, or at least have not been widely recognized. A few, however, have been noted:

At Wiluna faults having an apparent horizontal displacement of a mile or more transect the post-granite structure. At Cue, an abrupt offset in the granite-greenstone contact suggests a displacement of about a mile on a northerly striking fault.

ORE DEPOSITS.

Although a description of the ore deposits is not within the scope of this paper, the gold mineralization can hardly be ignored. The production of about 53 million ounces has come mainly from mines in the lavas and intrusives of the Kalgoorlie series, though a few deposits are in granite, gneiss or sediments. The deposits are classed as hypothermal or deep mesothermal, and most of the structural and mineralogical types could be matched with counterparts in the Canadian Shield. Despite the contrast between certain extreme examples, there are enough intermediate or gradational types to suggest that all are closely related genetically. They are younger than the main granitic intrusion, although a few gold-bearing veins, especially in the west, are cut by sills of granite or pegmatite. So far as the evidence indicates they may all belong to a single general epoch of mineralization. Derivation from intrusives of every composition from siliceous porphyry to diorite and basalt has been advocated for the deposits in this or that district, but the thread of similarity in mineralization makes it seem probable that they were all derived from a single magma, presumably the granite.

*Playter, R. F.: Personal communication.*
As each new problem is solved it inevitably prompts still other questions. Some of those which remain to be answered may be discussed briefly.

Stratigraphic Correlations.

Are the great thicknesses of basic volcanics in widely separated districts to be correlated with the Kalgoorlie Series? If the series could be subdivided into formations characterized, say, either by absence or abundance of interbedded slate or iron formation there would be a basis for comparing typical sections. Any such subdivision would have to be based on a correct and detailed analysis of the intricate structure.

What is the basement underlying the lavas? The bottom of the Kalgoorlie Series, if it appears anywhere, should be seen in the cores of anticlinoria. In the Yilgarn district such positions are occupied by granite, whose contacts, wherever visible, appear to be intrusive (10, p. 90). Is there a basement gneiss or are all of the gneisses merely the metamorphic equivalent of greenstones and post-Kalgoorlie sediments?

Mechanics of Granitic Intrusion.

The geology of the region, as mapped at present, suggests a sea of late granite engulfing scattered remnants of greenstone and sediments. Since these remnants seem to preserve a regional structure undisturbed by the great invasion, they would plausibly be interpreted as pendants from the roof of a monster batholith. I suspect, however, that more complete investigation will greatly reduce the area shown as true intrusive and leave a series of moderate-sized batholiths intruding a complex of greenstone and sediments which is substantially intact except for invading sills and apophyses.

That substantial areas of sediments appear as granite on reconnaissance maps is scarcely surprising in view of the former tendency to show as granite any areas that are not definitely known to be underlain by sediments or greenstone. Although it is likely that most of the large greenstone areas have been recognized, it is known that sedimentary areas were overlooked. The reasons for this are understandable:

1. Much of the reconnaissance mapping was necessarily based on the nature of the soil. Sediments yield sands and soils very similar to those overlying granite.
2. Outcrops of any sort are scarce except on ridges. The sandstones and mudstones are not ridge-forming members, but underlie flats and afford few exposures.

3. Highly metamorphosed sediments, even if well exposed, are difficult to distinguish from gneissic granite without detailed study.

Thus, when it becomes possible to subdivide the areas now mapped as granite into intrusive granite, granite-gneiss (if any), sedimentary gneiss, and sediments, it is likely that revision of the size and shape of granite bodies will throw a new light on their mode of emplacement.

**Metamorphism.**

The problem of metamorphism is closely related to the distribution of intrusive granites. If there is a general westward increase in metamorphic intensity, as there now appears to be, it may prove to be related to increasing size and closeness of spacing of intrusions. The anomalous association of anti-stress minerals like andalusite with stress minerals like cyaitite and staurolite may turn out to be due to successive periods of metamorphism under contrasting conditions. It may become possible to distinguish the effects of broad regional metamorphism from those local intrusive contacts.

**Structure.**

The broader aspects of structure are now so vague that any speculation is hardly profitable. The full portrayal of the mechanics of folding and intrusion must await the deciphering of local structure in a host of localities and their coördination into the larger picture.

This by no means exhausts the list of problems but it may serve to convey an idea of the present state of progress. The rapid strides during the past few years encourage the hope that, in spite of an inevitable set-back under war conditions, the years of the near future will add significantly to the knowledge of Western Australian geology and thereby to a better understanding of world pre-Cambrian conditions.

**Acknowledgments.**

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