GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REPORT

FOR THE YEAR

1968

1969

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1968

EXTRACT FROM THE REPORT OF THE DEPARTMENT OF MINES

Minister: The Hon. A. F. Griffith, M.L.C.

Under Secretary: I. R. Berry

Director, Geological Survey: J. H. Lord.

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

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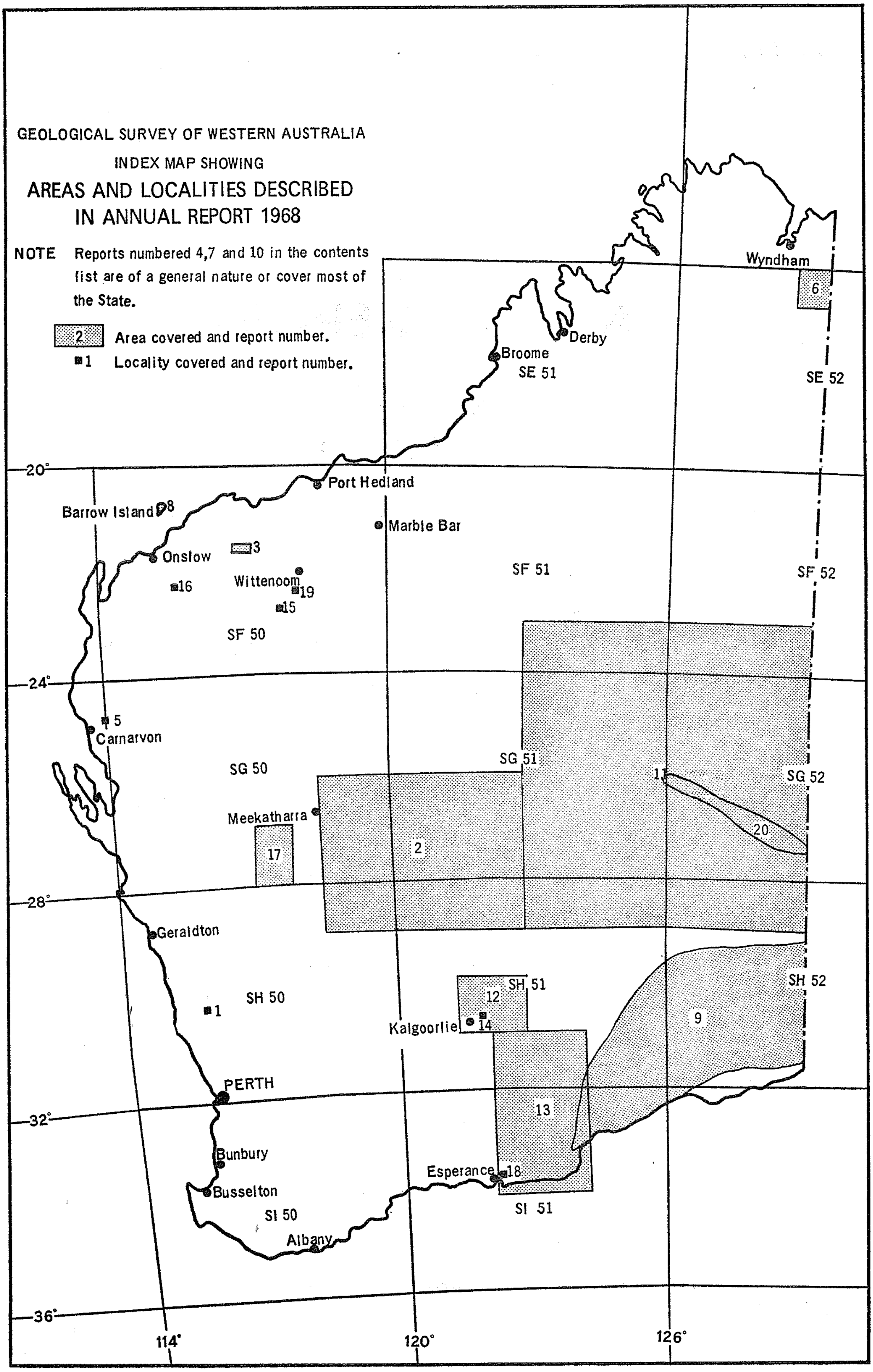
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
INDEX MAP SHOWING
AREAS AND LOCALITIES DESCRIBED
IN ANNUAL REPORT 1968
NOTE Reports numbered 4,7 and 10 in the contents list are of a general nature or cover most of the State.
2 Area covered and report number.
1 Locality covered and report number.
Wyndham
6
Derby
Broome
SE 51
SE 52
20°
Port Hedland
Barrow Island
8
Marble Bar
Onslow
3
SF 51
SF 52
16
Wittenoom
19
15
SF 50
24°
5
Carnarvon
SG 50
SG 51
11
SG 52
Meekatharra
20
17
2
28°
Geraldton
SH 51
SH 52
12
SH 50
9
1
Kalgoorlie
14
PERTH
13
32°
Bunbury
Esperance
18
Busselton
SI 50
SI 51
Albany
36°
114°
120°
126°

FIGURE 1

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1968

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DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1968

The Under Secretary for Mines

For the information of the Honourable Minister for Mines, I submit my report on the activities of the Geological Survey of Western Australia for the year 1968, together with some of the reports on investigations made for departmental purposes.

INTRODUCTION

The exploration boom in this State continued during 1968 and shows no sign as yet of slackening. Very few companies have reduced their activity while others are still establishing themselves.

Nickel continues to be the mineral most sought although some exploration companies are turning to other base metal and uranium possibilities.

The presence of a nickel ore body has been established at Scotia, 40 miles north of Kalgoorlie, while the investigation of nickel mineralization is continuing in the Mt. Martin, St. Ives, Widgiemooltha, Higginsville and Nepean areas to ascertain if mining is warranted.

A copper ore body which has been located at Mons Cupri near Whim Creek is still being evaluated. The testing and feasibility study on the bauxite near Admiralty Gulf has been completed and the company concerned has signed an agreement with the Government to proceed. An iron ore occurrence discovered several years ago at Paraburdoo was tested and proved to be high grade and of major dimensions.

There was an oil flow of interest in the Legendre No. 1 offshore well, some 70 miles north of Roebourne, while further significant gas was found south of Dongara in the Mondarra No. 1 well.

The continued unparalleled exploration activity in this State has maintained a great demand on the services of this Branch. The professional advice of the staff is continually sought by companies. The reference library, card indexes, and open files are being consulted continuously by those engaged in the search for minerals. The sale of Geological Survey publications increased from $4,500 in 1967 to $8,900 in 1968, which is eleven times greater than in 1963. The demand for all services has increased immensely.

Because of the company activity on mineral deposits the Survey has been able to accelerate the programme of regional mapping. At the end of 1968, mapping of 53 per cent. of the 178 1 : 250,000 sheets covering the State had been commenced while 34 per cent. of the sheets are available in a preliminary or published form, compared with 13 and 11 per cent. respectively in 1960. The co-operation of the Bureau of Mineral Resources in the Kimberley Division with joint field parties, and with printing of maps, is gratefully acknowledged.

The exploration companies are particularly interested in the results of regional mapping carried out by geologists of the Survey. However, after the completion of the field work there is a frustrating delay of at least two years while the map is compiled, drafted and published in the 1:250,000 geological series. In an attempt to relieve this situation, a lecture and two-day field excursion was arranged on the Kurnalpi sheet when the field work was completed, as an experiment to ascertain if this would assist the exploration companies. The attendance of 135 at the lecture in Kalgoorlie and of over 90 on the excursion showed that field geologists were keenly interested and there were requests for similar projects on other sheets,

Later in the year a similar project was carried out on the Menzies 1 : 250,000 sheet and again 125 attended the lecture and 72 the two-day excursion.

The success of these two ventures has proved that this is a suitable way of presenting results of mapping to interested persons while awaiting the publication. It is the Survey's intention to continue this service as suitable sheets are mapped and while the demand continues.

ACCOMMODATION

As the construction of Mineral House has commenced, the Survey anticipates having adequate and suitable accommodation by the end of 1969.

During this year the extension to the Dianella Core Library was completed, which greatly eased the storage situation until the transfer of a large quantity of drill core from the State Mining Engineers Branch used a consderable amount of the new space.

The sketch plans for the new equipment store and vehicle park have been completed and it is hoped that it will be built during the first half of 1969.

By the end of 1969 the accommodation and storage situation of the Survey should be adequate to cope with present requirements.

STAFF

Although the Survey has had up to to ten professional vacancies during 1968, the situation has improved toward the end of the year. There are only two vacancies remaining to which a suitable officer has not yet been appointed.

Of the eleven appointments made this year, nine were from overseas. It appears that while the current boom continues it will be necessary to rely on overseas sources for professional staff.

During the year six geologists resigned, mainly to accept more lucrative positions, and two more intend to resign early in the new year.

A Doctorate of Philosophy from the University of Western Australia was conferred on a member of staff, J. R. Passmore, for his hydrogeological research on the aquifers in the Rockingham area.

Dr. A. F. Trendall was awarded a Churchill Scholarship to study varved rocks in various parts of the world for comparison with the varving in the Precambrian banded iron formation of the Hamersley Range.

The establishment of the Branch is now 49 professional, 6 clerical, and 12 general officers.

PROFESSIONAL

Appointments

Name	Positions	Effective Date
W. A. Davidson, B.Sc.	Geologist, Grade 2	1/2/68
P. R. Koehn, B.Sc. (Hons.)	Geologist, Grade 2 (Temp.)	12/3/68
R. Peers, B.Sc. (Hons.)	Geologist, Grade 2 (Temp.)	29/5/68
B. R. Paterson, B.Sc.	Geologist, Grade 2	19/7/68
X. K. Williams, M.Sc.	Geochemist	19/8/68
J. D. Lewis, B.Sc.	Geologist, Grade 2	23/9/68
J. Newton-Smith, M.Sc.	Geologist, Grade 2	29/10/68
D. D. Boyer, B.Sc. (Hons.)	Geologist, Grade 2	11/11/68
J. Backhouse, M.Sc.	Geologist, Grade 2	26/11/68
A. S. Harley, B.Sc. (Hons.)	Geologist, Grade 2	3/12/68
J. C. Barnett, B.Sc. (Hons.)	Geologist, Grade 2	16/12/68

Resignations

L. N. Wall	Geologist, Grade 2	15/3/68
R. Lake	Geologist, Grade 2 (Temp.)	31/1/68
R. Peers	Geologist, Grade 2	9/1/68
D. H. Probert	Geologist, Grade 1	25/3/68
R. A. Farbridge	Geologist, Grade 2	26/7/68
H. Rutter	Geophysicist, Grade 2	2/8/68
M. J. B. Kriewaldt	Geologist, Grade 1	7/9/68

CLERICAL AND GENERAL

Appointments

H. F. Rettig	Core Librarian	27/5/68
J. M. Dyer	Stores and Transport Clerk	18/3/68
G. A. Squires	Laboratory Assistant	16/10/68

Resignations

H. F. Rettig	Core Librarian	15/3/68
R. J. Sorensen	Laboratory Assistant	28/6/68

Transfers

R. A. H. Stevenson	Clerk	15/11/68

OPERATIONS

HYDROLOGY AND ENGINEERING GEOLOGY DIVISION

E. P. D. O'Driscoll (Chief Hydrogeologist), K. Berliat, F. R. Gordon, T. T. Bestow (Senior Geologists), K. H. Morgan, J. R. Passmore, P. Whincup, C. C. Sanders, P. M. Hancock, W. A. Davidson, D. D. Boyer, A. S. Harley, J. G. Barnett, A. D. Allen (on leave without pay at London University), and R. S. Chaturvedi (Colombo Plan Fellow).

Hydrology

Exploratory rotary and percussion drilling has continued in the sediments of the Coastal Plain Basin west of Watheroo, in the search for additional groundwater for the Northern Comprehensive Water Supply Scheme. Work is expected to be completed early in 1969, and substantial reserves of potable water have been proved.

A further six exploratory bores have been drilled west of Albany in the Werillup area and have confirmed the low groundwater potential indicated by previous work.

To meet the demand for large supplies of water for industrial use at the new port of Dampier a hydrological investigation was made of an extensive area of calcrete at Millstream on the Fortescue River. Twenty-five boreholes were drilled and a comparatively large amount of usable water was located.

Drilling and test pumping shallow sand aquifers east of Lake Gnangara for the Metropolitan Water Board has continued. Advice has been given to the Board on future exploratory drilling in the new suburb of Hamersley and the North Lake Gnangara area.

A field reconnaissance of the calcreted drainages in the East Murchison District indicates that in the north some areas are fairly good potential sources of potable water, but rapidly become less valuable to the south.

Three calcrete areas near Cue have been test pumped as part of an arid zone research project. One bore was pumped at 125,000 gallons per hour, the highest rate yet achieved anywhere in the State from a shallow bore. Work on the hydrology of the Cue 1 : 250,000 geological sheet has continued.

Bore census work has been undertaken in a number of areas, one being Bunbury township, where the establishment of a net of observation bores has been recommended for future use in the assessment of over-pumpage.

Field hydrogeological surveys have also been made for the townships of Port Gregory, Ravensthorpe, Nabawa, Cervantes, Ledge Point, Horrocks Beach, Carnamah, Calingiri, Greenough River Mouth, Halls Creek, Bindi Bindi, Cranbrook, Mt. Tom Price, and on the North Lake Grace—Kulin areas. Properties inspected for private landholders numbered 164, including 17 in Kimberley Division, and advice was given on the prospects of obtaining underground water. Compilation of bore records throughout the State has continued.

Engineering geology

The Stonewall Creek spillway for the Ord River dam was mapped in detail, diamond drilling of the spillway, the river bed, and the proposed quarry areas supervised and reported on, and geological advice given to the designing engineers and also construction firms tendering for the work. Preliminary investigations of damsites on the Gascoyne River are complete and reports on the geology of the sites, and the area in general, have been prepared.

At the request of other Government Departments, twelve possible damsites have been the subject of written reports, another nine have been given a preliminary examination or a follow-on inspection. Detailed geological assessments of two more are almost complete, and field advice has been given to engineering construction teams on two others.

Subsequent to the Meckering earthquake, the nature and extent of the faulting and its associated effects have been investigated in some detail.

SEDIMENTARY (OIL) DIVISION

P. E. Playford (Supervising Geologist), A. H. Pippet (Production Geologist), G. H. Low, and D. C. Lowry.

During 1968 this Division was occupied to an increasing degree in the collation and appraisal of oil exploration and production data. A report was completed for departmental purposes on the Dongara gas field and an appraisal of the Barrow oilfield is in progress.

The mapping of the Phanerozoic portion of the Geraldton 1 : 250,000 sheet has been completed while mapping of the Moora and Hill River sheets in the Perth Basin is near completion. A report on the geology of the Moora Group is in preparation.

A detailed stratigraphic and palaeontological study of the Bugle Gap area in the Canning Basin was initiated during the year. The field work for the project is now complete.

The bulletin on the Eucla Basin is in preparation and the compilation of the 1 : 250,000 sheets of the basin is almost complete.

Remapping of the metropolitan area in association with the Regional Geology Division was completed and the four 1 : 50,000 sheets are being drawn for publication.

REGIONAL MAPPING DIVISION

R. C. Horwitz (Supervising Geologist), J. L. Daniels (Senior Geologist), I. R. Wiliams, J. J. G. Doepel, and P. R. Koehn.

Eastern Goldfields area

Geological mapping was completed on the Kurnalpi, Menzies, Zanthus, Balladonia and Malcolm 1 : 250,000 sheets which are now being compiled. Compilation is continuing also on the Esperance, Mondrain Island, and Cape Arid sheets, which were mapped in association with the Hydrology Division.

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

1 250,000 OR 4 MILE GEOLOGICAL MAPPING

1968

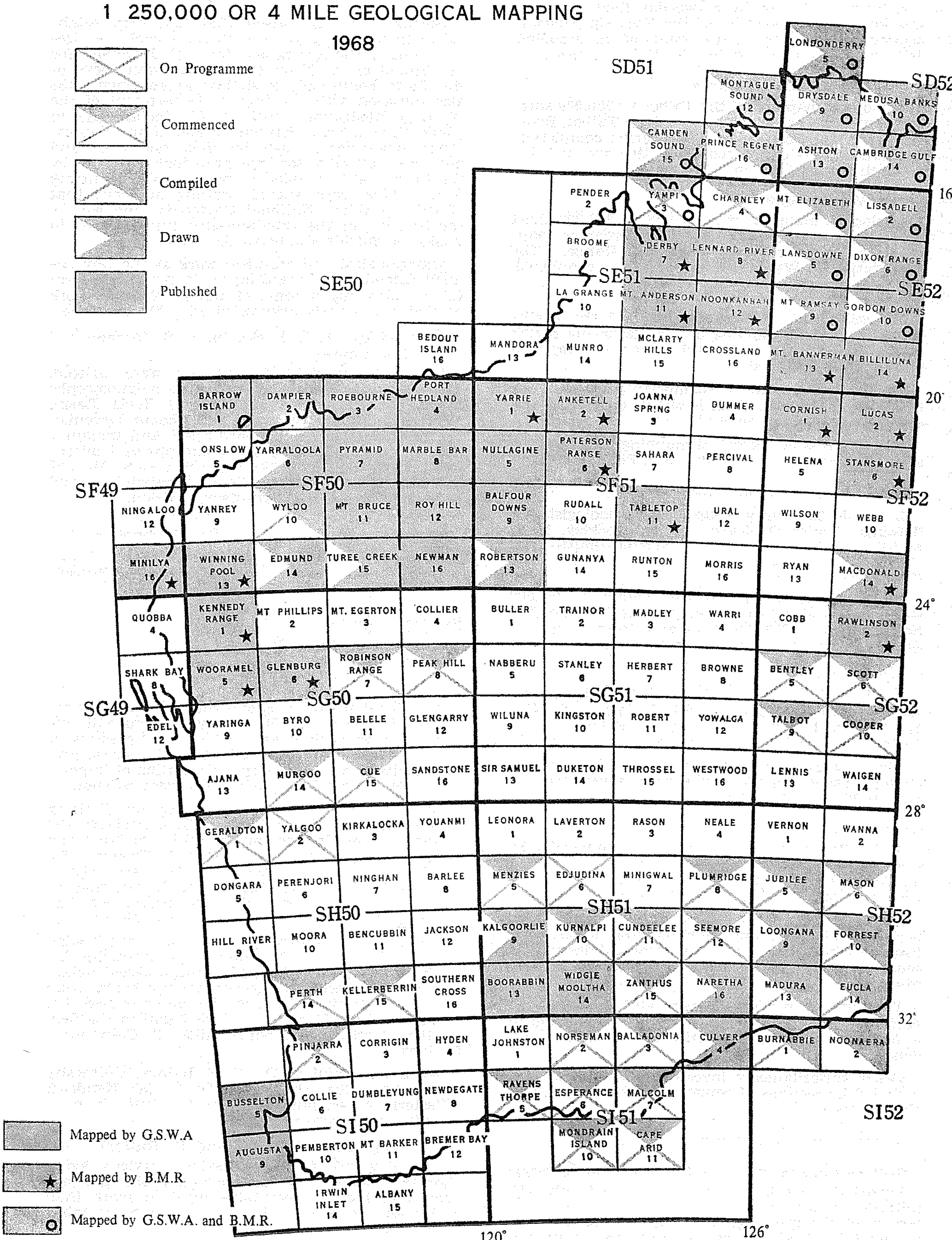


FIGURE 2

Geological mapping was commenced on the Norseman 1 : 250,000 sheet.

A lecture followed by a two-day field excursion was given on the geology of the Kurnalpi sheet to acquaint geologists with the results of the mapping. This was later repeated for the Menzies sheet.

Blackstone—Warburton area

Geological mapping of the Talbot 1 : 250,000 sheet was completed and compilation of the Talbot, Bentley, Scott and Cooper sheets is nearing completion. A detailed study of the geology of this area is being made in preparation for a Bulletin.

North-West Division

Geological mapping of Peak Hill 1 : 250,000 sheet was completed and compilation is in progress. Mapping has commenced on Robinson Range. The compilation of Wyloo and Edmund was completed.

General

To assist with the investigation of the earthquake, geological mapping in the Meckering region on the Kellerberrin 1 : 250,000 sheet was completed and is being compiled.

The mapping of the Precambrian portion of the Geraldton 1 : 250,000 sheet is almost completed and compilation has commenced.

The progress of geological mapping at 1 : 250,000 scale to the end of 1968 is shown in Figure 2.

MINERAL RESOURCES DIVISION

L. E. de la Hunty (Supervising Geologist), J. Sofoulis (Senior Geologist), J. G. Blockley, P. C. Muhling, J. L. Baxter, and J. Newton-Smith.

Kimberley Division

Record compilations on the Yampi 1 : 250,000 sheet area and on the Pillara Range Inlier of the Noonkanbah 1 : 250,000 sheet area were completed as part of the Kimberley Mapping Project.

North-West Division

Field work was completed on the mineral resources, regional geology, and hydrology of the Cue and Murgoo 1 : 250,000 sheet areas. Record reports on both areas are in preparation.

Diamond drilling programmes at Thaduna and Green Dragon copper mines were supervised for British Metal Corporation.

General

A detailed geological investigation supported by geophysical and geochemical work was completed on Ministerial Reserve 4538H at Lake Yindarlgooda, Bulong District east of Kalgoorlie.

Approximately 160 prospects in the Pilbara, Kimberley, Ashburton, and Northampton areas were inspected in the course of preparing a Mineral Resources Bulletin on silver-lead-zinc deposits of the State.

Tin deposits in the Kimberley and Pilbara Goldfields were investigated for eventual compilation of a Mineral Resources Bulletin on the State's tin deposits.

Other miscellaneous investigations during 1968 included inspections of copper, nickel, asbestos, and clay prospects.

COMMON SERVICES DIVISION

Petrology (A. F. Trendall, J. D. Lewis, and R. Peers)

Petrological work during 1968 did not involve the initiation of any new major projects, but consisted largely of the provision of service to the Divisions of the Geological Survey, in the form of unpublished reports and advice by personal discussion. Twenty file reports were written, fewer than in immediately preceding years; the decrease reflects partly changes in staff, partly greater detail in the content of reports, and partly a continued policy of encouraging field staff to use the microscope wherever possible. A total of 1,170 thin-sections and 52 polished sections were prepared by the laboratory staff.

Dr. Trendall visited the Warburton—Blackstone area in July and the Hamersley Range area in August.

During 1968 the liaison that had been established in preceding years with the Geophysics Department of the Australian National University for geochronology work on the Precambrian rocks of the State continued; a similar arrangement was also initiated with the Physics Department of the Western Australian Institute of Technology, in which their mass spectrometer and X-ray fluorescence spectrometer will be used on rocks and minerals collected for geochronological study by the Survey and supplied in powder or concentrate form. This work should usefully augment that of the Australian National University, and will be the first use of the rubidium-strontium method in Australia outside Canberra for some years.

Mineralogical and chemical work at the Government Chemical Laboratories again provided a useful complement to some of the petrological work carried out, and is acknowledged with gratitude.

Palaeontology (A. E. Cockbain, B. S. Ingram, and J. Backhouse)

In 1968 fifty-eight file reports were written. These included studies of Cretaceous palynomorphs in the northern Perth Basin and Eucla Basin, Miocene nautiloids from the Eucla Basin, Devonian brachiopods from the Lennard Shelf, and examination of various Tertiary palynomorphs and microfossils from the Denmark—Esperance area. Most of the reports were in the field of palynology and were written for the Hydrology Division.

Reports written for	Field of Palaeontology		
	Palynology	Micropalaeontology	Macropalaeontology
Hydrology/Engineering	30	6	....
Sedimentary (Oil)	8	2	2
Regional Mapping/Mineral Resources	2	....	1
Miscellaneous	5	1	1

Additional to these reports and in order to provide geologists in the Hydrology Division with information as rapidly as possible, a new series of Palaeontological Notes was instituted. These give the results of a preliminary examination of important samples; some 34 such notes were written.

Dr. Cockbain is continuing work on Tertiary fossils from the Eucla Basin with a study of the systematics of Cheilostomatous Bryozoa from the Eucla, Eundynie, and Plantagenet Groups. He spent three months in the Bugle Gap area (Kimberley Division) with Dr. Playford, assisting in the detailed biostratigraphical and palaeoecological examination of the Devonian reef complexes.

As well as attending to the routine examination of borehole samples, Mr. Ingram is continuing his work on the systematic and stratigraphical palaeontology of Lower Cretaceous palynomorphs from the Perth Basin. In July he accompanied Dr. Macurda of the University of Michigan in the field to the classical Permian locality at Callytharra Springs.

We are grateful to Dr. B. E. Balme (University of Western Australia) and Mr. G. W. Kendrick (Western Australian Museum) for their help in examining certain samples.

Geophysics (D. L. Rowston and H. Rutter)

The demand for well-logging services again showed a substantial increase over the previous year, and logging operations involved more than 17,000 miles of travel. Logging statistics are tabulated below:

	1968	1967	1966
Individual bores	80	42	26
Logging operations	99	72	35
Logged footage	73,350	51,700	38,000
Footage of final logs to total depth	52,600	29,600	N.A.*
Reports compiled	29	12	8

* Figure not available.

On the deeper bores intermediate logs are made and the logged footage, by including these intermediate logs, is higher than the footage of final logs to total depth. Also one logging operation may involve several runs into the hole to measure different parameters; the logged footage does not include individual runs and another 29,000 feet could be added to the 1968 total footage to account for this factor.

Field salinity measurements were made on 722 water samples received in the laboratory. Laboratory facilities have been extended to include magnetic susceptibility measurements and rock densities, and these properties were determined for 322 core samples from the Upper Mantle Project diamond drill holes.

A gravity survey was carried out in the Millstream area to assist hydrogeological investigations, but the environment proved to be more complicated than anticipated and an acceptable interpretation of the results appears unlikely.

Magnetic, electromagnetic, self-potential, and gravity methods were used on Ministerial Reserve 4538H, northeast of Kalgoorlie, in the exploration for base metal sulphides.

Geochemistry (X. K. Williams)

Geochemical work within the Survey commenced at the end of August with the appointment of a geochemist.

A study was made of an extensive gossan in Ministerial Reserve 4538H; the results of this work are discussed later.

Plans were made to build a mobile field laboratory caravan and equip it for routine trace element analyses by atomic absorption spectroscopy. It is hoped that this will be ready for use during the 1969 field season.

Technical Information (R. R. Connolly, M. E. Redman, and S. M. Fawcett)

The resources of the section have again been strained by increasing requests for released information, advice, and specimen identifications, but a satisfactory service was maintained.

Library loans to staff totalled 2,333 and loans to other than staff 806. The number of visitors using the library doubled, and this, together with the natural increase in book stock, resulted at times in severe overcrowding and difficult working conditions.

Requisitions to the Survey and Mapping Branch for drafting services and photocopying totalled 1,207 which is also a significant increase. Three publications were edited, printed and distributed and several other publications are at intermediate stages of printing. Twenty-two Records were prepared, duplicated, and assembled and, as one particular issue required 900 copies, this became a major task.

Considerable time was spent planning the detailed layout of the three floors to be occupied by this Branch in Mineral House.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES

The geological and geophysical projects carried out by the Bureau of Mineral Resources included the following:

(1) Compilation of 1 : 250,000 geological maps and bulletins on the Kimberley Division as a joint project with this Survey.

(2) An examination of the conodonts in the Bugle Gap area of the Canning Basin in conjunction with Survey's studies.

(3) Aeromagnetic and radiometric survey of the Sandstone and Youanmi 1 : 250,000 sheets at 1 mile spacings.

(4) Regional helicopter gravity survey of a large area of the North-West and Canning Basin.

PROGRAMME FOR 1969

HYDROLOGY AND ENGINEERING DIVISION

Hydrology

1. Continuation of the hydrological survey of the Perth Basin including deep drilling.
2. Hydrogeological investigation and exploratory drilling for groundwater in the following areas:
   (a) Watheroo—Agaton area (continuation)
   (b) Albany (continuation)
   (c) Lake Gnangara (continuation)
   (d) Mandurah—Pinjarra (continuation)
   (e) Wiluna district
   (f) Esperance for industrial supplies
   (g) Port Hedland
   (h) Others may be added.
3. Kimberley—hydrological assistance to pastoralists.
   (a) bore site selection as required
   (b) completion of compilation of hydrogeological mapping in conjunction with the Bureau of Mineral Resources.
4. Continuation of bore census work in selected areas.
5. Miscellaneous investigations as requested by other Government departments and the public.

Engineering

1. Ord River Dam—geological supervision during construction (if staff available).
2. Helena River Dam Site—detailed investigation of site near Piesse Brook.
3. North and South Dandalup Dam Sites—further investigation.
4. Pilbara—further investigation of possible dam sites.
5. Moochalabra Creek dam site—supervision of construction.
6. Meckering earthquake—completion of investigation and compilation of report.
7. Other dam site investigations for Public Works Department, if staff available.

SEDIMENTARY (OIL) DIVISION

1. Maintain an active interest in the progress and assessment of oil exploration in Western Australia.
2. Assessment of the oil and gas discoveries, and assessment of resources in the State.
3. Continuation of the mapping programme in the Perth Basin.
4. Continuation of the detailed biostratigraphic study of material collected at Bugle Gap.
5. Miscellaneous investigations as required.

REGIONAL GEOLOGY DIVISION

1. Continuation of the mapping of the Norseman 1 : 250,000 sheet.
2. Complete compilation of Balladonia, Malcolm, Zanthus, Kurnalpi, and Menzies 1 : 250,000 sheets.
3. Commence mapping the Edjudina 1 : 250,000 sheet in the Eastern Goldfields.
4. Commence mapping the Robinson Range 1 : 250,000 sheet.

MINERAL RESOURCES DIVISION

1. Continuation of the mineral survey of the Yalgoo and Murchison Goldfields.
2. Completion of a Mineral Resources Bulletin on the silver-lead-zinc deposits of Western Australia.
3. Preparation of a Mineral Resources Bulletin on the tin deposits of Western Australia.
4. Detailed investigation including geochemical work of the Twin Peaks copper prospect.
5. Detailed investigation of the Robinson Range Iron deposit.
6. Miscellaneous investigations as required.

PUBLICATIONS AND RECORDS

Issued during 1968

Annual Report 1967.

Geological map of Pyramid 1 : 25,000 Sheet (SF/50-7 International Grid) with explanatory notes.

Geological map of Busselton and Augusta Sheets (SI/50-5 and SI/50-9 International Grid) with explanatory notes.

In press

Report 1, Devonian carbonate complexes of Alberta and Western Australia, a comparative study.

Geological map of Yarraloola 1 : 250,000 Sheet (SF/50-6 International Grid) with explanatory Notes.

Geological map of Turee Creek 1 : 250,000 Sheet (SF/50-15 International Grid) with explanatory notes.

Geological map of Edmund 1 : 250,000 Sheet (SF/50-14 International Grid) with explanatory notes.

Geological map of Robertson 1 : 250,000 Sheet (SF/51-13 International Grid) with explanatory notes.

Geological map of Kalgoorlie 1 : 250,000 Sheet (SH/51-9 International Grid) with explanatory notes.

In preparation

Bulletin 119, Iron formations of the Precambrian Hamersley Group, Western Australia with special reference to the associated crocidolite.

Bulletins are being prepared on the Eucla Basin; Blackstone Range Area; silver-lead-zinc deposits of Western Australia; and Devonian coral faunas of the Canning Basin.

Geological maps 1 : 250,000 with explanatory notes, the field work having been completed: Wyloo, Kurnalpi, Menzies, Peak Hill, Cue, Murgoo, Scott, Cooper, Bentley, Talbot, Culver, Naretha, Madura, Loongana, Jubilee, Noonaera, Eucla, Forrest, Esperance—Mondrain Island, Zanthus, Balladonia, and Malcolm—Cape Arid.

Geological maps 1 : 50,000 Perth metropolitan area (4 sheets).

Records produced

1968/1 Erosion at Bandicoot Bar diversion dam, Kimberley Division, by F. R. Gordon (*restricted*).

1968/2 The geology of the Ord River dam and associated works, by F. R. Gordon, with supplements 1 and 2 (*restricted*).

1968/3 Explanatory notes on the Edmund 1 : 250,000 geological series sheet SF/50-14, Western Australia, by J. L. Daniels.

1968/4 Geology of the area around the Kennedy Range dam site, by J. L. Baxter (*restricted*).

1968/5 Preliminary hydrologic report on the Moora Group, by L. N. Wall.

1968/6 The hydrology of the Scott, Cooper Bentley, and Talbot 1 : 250,000 Sheets, by R. A. Farbridge.

1968/7 Hydrogeology of the lower Gascoyne River, by J. L. Baxter.

1968/8 Geological reconnaissance of Cooya Pooya dam site, Harding River, by F. R. Gordon (*restricted*).

1968/9 Explanatory notes on the Wyloo 1 : 250,000 geological sheet, by J. L. Daniels.

1968/10 The geology of the Pillara Range Precambrian inlier, Noonkanbah 1 : 250,000 sheet, by J. Sofoulis and D. C. Gellatly.

1968/11 Lower Gascoyne River, possible flow losses downstream from Kennedy Range dam site, by J. R. Passmore.

1968/12 Geological investigations at Rocky Pool dam site in 1967, by P. M. Hancock (*restricted*).

1968/13 Review of grouting procedures, Ord River Main Dam, by F. R. Gordon (*confidential*).

1968/14 Reconstruction of Meckering town a geological appraisal, by F. R. Gordon.

1968/15 Dongara gas field estimates of reserves and economics of piping gas to Geraldton and Perth, by A. H. Pippet (*confidential*).

1968/16 Explanatory notes on the Culver 1 : 250,000 geological sheet, SI/51-4, Western Australia, by D. C. Lowry.

1968/17 Report on Ministerial Reserve 4538H, Lake Yindarlgooda, Bulong District, Western Australia, by J. Sofoulis, X. K. Williams, and D. L. Rowston.

1968/18 Wells drilled for petroleum exploration in Western Australia in 1968, by P. E. Playford and G. H. Low.

1968/19 Petrology and metamorphism in the Fraser Ranges, by P. R. Koehn.

1968/20 The hydrogeology of the Tumblagooda Sandstone near Horrocks Beach and Port Gregory, by P. Whincup.

1968/21 Groundwater prospects in the Mallee Districts, Esperance 1 : 250,000 sheet, by C. C. Sanders.

1968/22 Nooka Lead Mine—M.L. 284—Northampton Mineral Field, by J. G. Blockley.

Reports in other publications

Cockbain, A. E. 1968, Distribution of the nautiloid *Aturia* in the Eocene: Jour. Palaeont, v. 42, p. 1309.

McCall, G. J. H., Braybrooke, J. C., Middleton, D. D., and Muhling, P. C., 1967, Sedimentology of some eugeosynclinal rocks of the early Precambrian Kalgoorlie System, Western Australia: International Sedimentological Congress, 7th.

Trendall, A. F., 1968, Three great basins of Precambrian banded iron formation deposition: a systematic comparison; Geol. Soc. America Bull. v. 79, p. 1527-1544.

Lowry, D. C., 1967, Halite speleotherms from the Nullarbor Plain, Western Australia: Helictite, v. 6, No. 1, p. 14-20.

22nd January, 1969

J. H. LORD,
Director,
Geological Survey.

EXPLORATORY DRILLING – AGATON PROJECT, WATHEROO AREA PRELIMINARY REPORT

by J. R. Passmore

INTRODUCTION

Groundwater resources of part of the Perth Basin are being investigated by drilling in the Watheroo area, about 140 miles north of Perth. A supply of 5 million gallons per day is required for distribution to towns in agricultural country to the east. The project, which takes its name from a spring in the southern part of the area (Plate 1), is an extension of a drilling programme comprising a line of exploratory bores west from Watheroo (Bores WL1 to WL4). Investigations are not yet complete, and interpretations may be modified later.

Including the Watheroo line of bores, 26 sites have been drilled, the total footage being 41,390 feet, of which 30,435 feet were drilled with rotary and 10,955 feet with percussion rigs. Most bores were completed with screens or slotted casing and eight were test-pumped for at least 48 hours.

A summary of data from the bores is presented in Table 1.

GEOLOGY

The drilled area is in the northern half of the Perth Basin, a sedimentary trough over 400 miles long on the western side of the Western Australian Precambrian Shield. The Darling Fault Zone forms the eastern margin of the basin and in the Watheroo area separates the basin sediments from jointed quartzite and chert of the Moora Group.

The sediments penetrated by the bores are of Cretaceous age, overlain in some places by superficial Quaternary sand. They are commonly weathered, leached, or lateritized near the surface. The following units are recognized:

Upper Cretaceous marine formations (Ku) comprise the Poison Hill Greensand, Gingin Chalk, Molecap Greensand, and Osborne Formation. The Osborne Formation has been dated as Albian—Cenomanian and the others as Senonian. The sequence consists of green glauconitic sandy clay and silt with minor grey calcareous siltstone; formation boundaries within it are seldom distinct.

Marine member of the South Perth Formation (Klsa) is of Lower Cretaceous age, and consists of green and grey glauconitic sandstone and siltstone overlying the rest of the South Perth Formation. It forms a distinctive marker bed over the eastern part of the area, and has been dated as Neocomian—Aptian on fossil microplankton.

South Perth Formation (Kls) is also of Lower Cretaceous age, being predominantly grey and greenish sandstone, siltstone, and shale of non-marine origin, some parts well-bedded and others poorly bedded. The beds are lenticular, and it is often difficult to correlate between bores three or four miles apart. The well-bedded sandstones are predominantly coarse-grained and moderately well-sorted.

The three units appear to be separated by disconformities, although detailed correlations could show up angular unconformities. In some places either the Osborne Formation or the marine member of the South Perth Formation is overlapped by younger beds, indicating non-deposition or erosion during Cretaceous times.

Over most of the area the beds strike north and dip to the east at one to three degrees (see Plate 1). Near the eastern edge of the basin they are either synclinal or faulted, as the section in Bore WL1 is displaced upwards relative to that in Bore A19. The anticline near the western end of the section is based on correlations between Bores WL3, WL4, and others north of the section, although it is possible that the strata are faulted. Faulting may explain the lack of correlation between Bore A7 and A24-WL2, but as yet there is no confirmatory evidence.

HYDROLOGY

Aquifers

The superficial Quaternary deposits are too thin to warrant large scale development, although in some places they do provide stock water supplies. There are thin aquifers within the Upper Cretaceous sediments, containing only salty water.

Aquifers within the South Perth Formation and its marine member are capable of yielding large supplies of water. They are lightly consolidated sandstones of variable grain size, sorting, and silt content. These properties change laterally and the best aquifers occur at different stratigraphic levels, but generally in the upper 1,000 feet of the South Perth Formation. The marine member of the South Perth Formation is in most places medium-grained and fairly well sorted, and is therefore moderately permeable.

The most promising area for groundwater development is the central to eastern part, because farther westward only the lower, less permeable, part of the formation is intersected.

Bore yields

Bores were generally completed with five-inch screens or six-inch slotted casing, and most of those capable of yielding large supplies were test-pumped for at least 48 hours. Several were abandoned because of technical difficulties. The results of pumping 10 bores, listed in Table 1, indicate that bores with slotted casing gave the largest supplies, up to 20,000 gallons per hour. This resulted from the slotted sections tapping several aquifers and the total thickness of the production zones being greater than in the screened bores. Test-pumping rates were less than the maximum, and the small drawdowns in Bores A12, A13, A16, and A17 indicate that much larger supplies are available. Transmissivity values listed in Table 1 were calculated from drawdown and recovery measurements in the pumped bores. They ranged widely, from 880 to 12,800 ft^2/day, partly because of the different thicknesses of the production zones.

TABLE 1.

AGATON PROJECT BORE DATA

Bore No.	Depth drilled	STRATIGRAPHY				Production zones	Screen (S) or slotted casing (Sc)	Total screened or slotted	Pump test	Pumping rate	D/down after 48 hrs.	Calculated transmissivity	S.W.L. below ground surface	Salinity prod. zones	Status
		Q	Ku	Klsa	Kls										
	ft *	ft	ft	ft	ft	ft		ft	hrs	gph	ft	ft/day	ft	ppm	
A1	1773 R	....	....	....	0–1773	460–760	Sc	....	....	....	....	....	210	1000	Obs
A2	233 P	0–76	....	....	76–233	....	....	....	....	....	....	....	....	....	Abd
A2a	1000 P	0–76	....	....	76–1000	....	....	....	....	....	....	....	....	....	Abd
A3	2320 R	....	0–319	319–480	480–2320	381–752	Sc	86	48	15,000	105	880	98	430	Obs
A4	556 P	....	....	....	0–556	536–548	S	12	24	8,700	....	....	253	700	Abd
A5	1000 P	....	0–318	318–538	538–1000	430–743	Sc	133	....	....	....	....	181	980	Obs
A6	594 P	....	....	....	0–594	570–594	S	24	24	7,600	....	....	204	500	Obs
A7	1000 P	....	....	....	0–1000	666–696	S	30	48	11,000	123	1,500	147	570	Obs
A9	890 R	....	0–652	....	652–890	....	....	....	....	....	....	....	....	....	Abd
A9a	1800 R	....	0–652	....	652–1800	779–787	S	8	....	....	....	....	207	1000	Obs
A10	1000 P	....	....	....	0–1000	590–650	Sc	60	....	....	....	....	180	480	Obs
A11	623 P	....	....	....	0–623	....	....	....	....	....	....	....	252	....	Obs
A12	2325 R	....	....	....	0–2325	824–1104	Sc	120	48	19,000	26·4	6,400	202	480	Obs
A13	1024 P	....	0–475	475–697	697–1024	668–698	S	30	48	18,200	40	2,330	113	740	Obs
A14	1000 P	....	0–590	....	590–1000	854–865	S	11	....	....	....	....	197	1170	Obs
A15	2410 R	....	....	....	0–2410	....	....	....	....	....	....	....	....	....	Abd
A15a	547 R	....	....	....	0–547	410–530	Sc	80	....	....	....	....	247	....	Obs
A15b	592 R	....	....	....	0–592	416–546	Sc	85	67	11,000	86	1,200	246	500	Obs
A16	1465 R	....	0–70	70–150	150–1465	....	....	....	....	....	....	....	....	....	Abd
A16a	400 R	....	0–70	70–150	150–400	....	....	....	....	....	....	....	....	....	Abd
A16b	1360 R	....	0–70	70–150	150–1360	1019–1299	Sc	149	48	20,000	42	1,750	142	470	Obs
A17	2460 R	....	0–365	365–495	495–2460	598–818 1340–1610	Sc	230	48	20,000	23·5	12,800	114	360	Obs
A18	926 P	....	0–478	478–620	620–926	853–895	S	42	....	....	....	....	....	750	Incomplete
A19	1930 R	....	0–571	571–700	700–1930	710–1051	Sc	90	....	....	....	....	....	820	Obs
A20	1000 P	....	0–551	551–686	686–1000	620–640	S	20	....	....	....	....	180	900	Obs
A21	1000 P	....	0–613	613–732	732–1000	934–952	S	18	48	10,700	164	....	63	540	Obs
A23	1200 R	...	0–203	203–330	330–1200	310–960	Sc	240	....	....	....	....	....	....	Incomplete
A24	1200 R	....	0–110	110–220	220–1200	300–480	Sc	130	....	....	....	....	Abt. 160	....	Obs
WL1	1810 R	....	0–343	343–435	435–1810	....	....	....	....	....	....	....	....	....	Abd
WL2	2090 R	....	0–310	310–440	440–2090	470–540	....	....	....	....	....	....	168	640	Obs
WL3	1980 R	....	....	....	0–1980	495–525	S	30	....	....	....	....	317	560	Obs
WL4	1883 R	....	....	....	0–1883	427–581	Sc	70	....	....	....	....	375	480	Obs

* P = percussion rig ; R = rotary rig.

Water quality

The waters pumped from all but three of the bores had salinities less than 1,000 ppm and were therefore suitable for domestic use. The thickness of fresh groundwater is controlled by the disposition of permeable aquifers, for those of low permeability tend to contain salty water. The deep low-permeability aquifers in the western part of the area are saline, whereas in the central part of the area the deep aquifers are more permeable and contain fresh water. In the eastern part the zone of fresh water decreases (Bore A19), and at Bore WL1 the groundwater is all saline. This is the result of recharge with salty water from the east.

Groundwater movement

Contours of the potentiometric surface (Plate 1) were constructed from water levels measured on November 30, 1968. The contours indicate that the groundwater moves southeastward from the fresh-water recharge areas in the northwest, to within four to six miles of the Darling Fault. The groundwater is then deflected to the southwest, along a narrow zone through Agaton Spring, by water entering the aquifers close to the Darling Fault.

The open spacing of the potentiometric contours in the north confirms that the aquifers are more permeable in that area.

DEVELOPMENT

The northern part of the area is most suitable for development; because it is near the fresh-water intake area, the aquifers have high permeability, and salinities are low. Production bores would best be drilled within the area bounded by Bores A16, A17, A18, and A24. They could most likely produce at 40,000 to 50,000 gallons per hour each, in which case 4 to 6 bores would be needed to obtain 5 million gallons per day. These supplies could be produced from less than 1,500 feet below ground surface, and possibly less than 1,000 feet.

Whether the aquifers can yield water at this rate over a long period of time has not yet been determined. Calculation of storage coefficient awaits the results of a controlled pumping test planned for site A23, and the modes of recharge of both fresh and salt water require evaluation.

HYDROGEOLOGICAL RECONNAISSANCE OF CALCRETE AREAS IN THE EAST MURCHISON AND MT. MARGARET GOLDFIELDS

by C. C. Sanders

ABSTRACT

Calcrete valley fills of the East Murchison yield in places large supplies of potable or near potable groundwater. At Wiluna 1,000,000 gallons per day were extracted for 13 years without noticeable lowering of the water table.

A survey to locate similar calcrete deposits elsewhere in the East Murchison and Mt. Margaret Goldfields has been undertaken with little success. However, some alluviated valleys may yield sufficient groundwater for future town and industrial use. Several areas are suggested for further hydrological study.

INTRODUCTION

Calcrete is defined as a deposit of surface limestone and opaline silica generally associated with fluviatile sediments both in broad fossil valleys and in existing main drainage systems.

The calcrete deposits of the East Murchison district are very extensive and in places are known to yield large supplies of potable or near potable groundwater. The rapid expansion of mining activities in the Eastern Goldfields has caused an increased draw on the Goldfields Water Supply Scheme and these calcrete areas have been suggested as possible sources of additional water.

An investigation was made during September and October, 1968, in the hope of locating extensive calcrete formations close to projected mineral developments. The area surveyed extended over nine 1: 250,000 topographical sheets as shown on Plate 2. The area between Leonora and Kalgoorlie had previously been mapped but no calcrete deposits were recognized.

Calcretes in the East Murchison have been described by Mabbutt and others (1963), and major occurrences at Wiluna and Lorna Glen have been studied by Ellis (1953), de la Hunty (1959), Chapman (1962), Morgan (1966) and Sofoulis (1963). Ellis (1953) reported that consumption of water at Wiluna during the peak of gold mining operations was at least 1,000,000 gallons per day of potable or slightly brackish groundwater, obtained from 34 shallow wells. There was no apparent drop in the water table over 13 years at this extraction rate. The highest reported test yield from any one well was 115,000 gallons per day for seven days, the water rest level remaining steady during the test. Ellis estimated the catchment area for the Wiluna aquifer at 547 square miles. Chapman (1962) altered this to 150 square miles giving an annual recharge of the aquifer of at least 2,350 acre feet with an annual safe yield of 1,350 acre feet, equivalent to 1,000,000 gallons per day.

Brookfield *in* Mabbutt and others (1963) reporting the results of a 1958 census of all bores and wells in the Meekatharra—Wiluna—Lake Carnegie area, found that groundwater from calcrete deposits was generally of good quality and excellent for stock purposes and restricted irrigation. Water of higher salinity is often associated with formatons of low effective porosity, the lower parts of valleys, and near salt lakes. The reported yields from bores and wells are not considered reliable as supplies are usually governed by equipment used and yields reflect demand rather than potential.

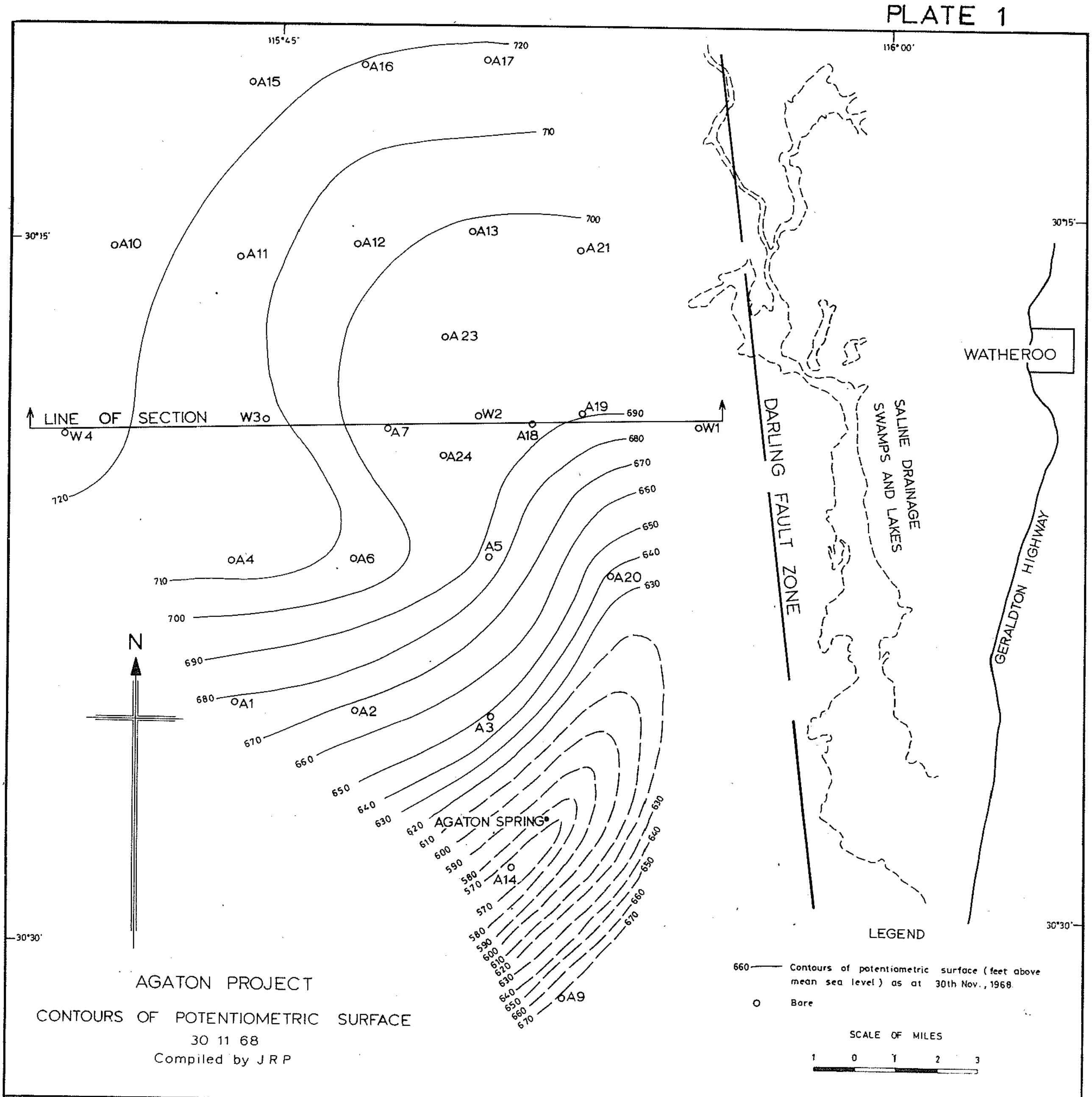
The hydrogeology of the area between Sandstone and Leonora was summarized by Morgan (1966). He showed that calcrete deposits are not common in this area and where present they occupy the slower drained main valleys or the lower parts of main tributaries, and are frequently close to salt lakes. The groundwater quality is generally poor, with a high nitrate concentration and a high hardness factor.

GENERAL GEOLOGY

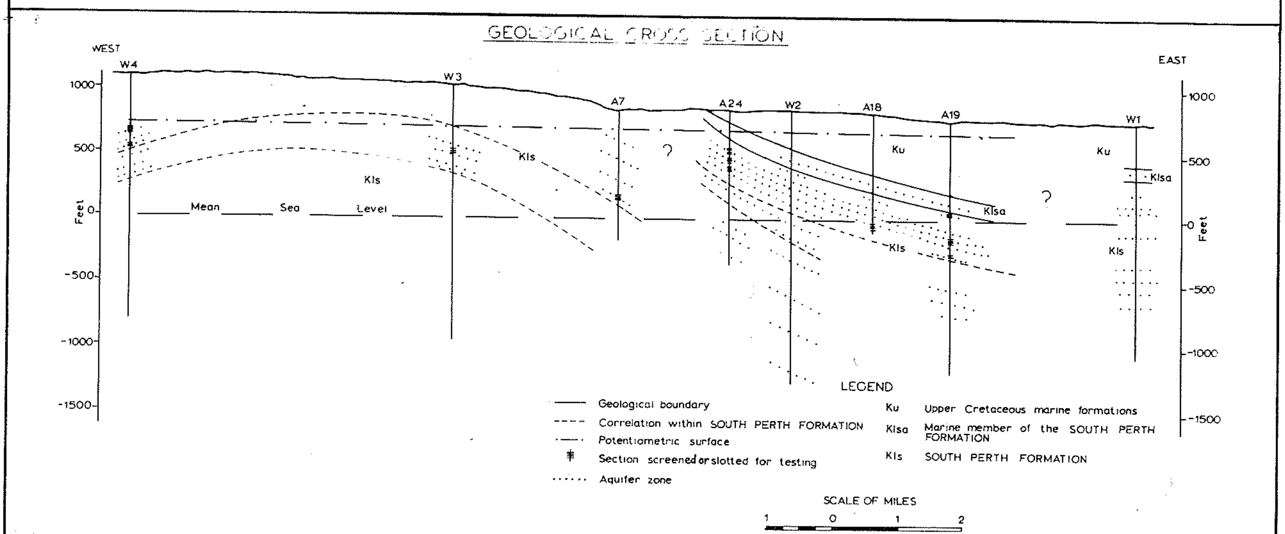
The geology of the East Murchison—Mt. Margaret Goldfields has been documented by many authors but the rocks are still poorly known and little mapped. The present intense mineral search should augment the geological information of this region.

The region falls within the Salinaland physiographic division of Jutson (1950) characterized by internal drainage terminating in salt lakes. The division forms part of the Precambrian plateau of Western Australia, underlain by Archaean granite and gneiss with belts of altered sediments and volcanic rocks and remnants of Proterozoic sediments. Capping these rocks are Tertiary and Quaternary developments of laterite and alluviated valleys. The fluviatile deposits occupy about 30 per cent. of the land surface as tributary alluvial plains and alluvial fans, calcrete valley fills and down-valley salt pans. Most of the drainage is by sheet flooding which produces smooth surfaces with minor drainage runnels, except at the watersheds where channelling is severe.

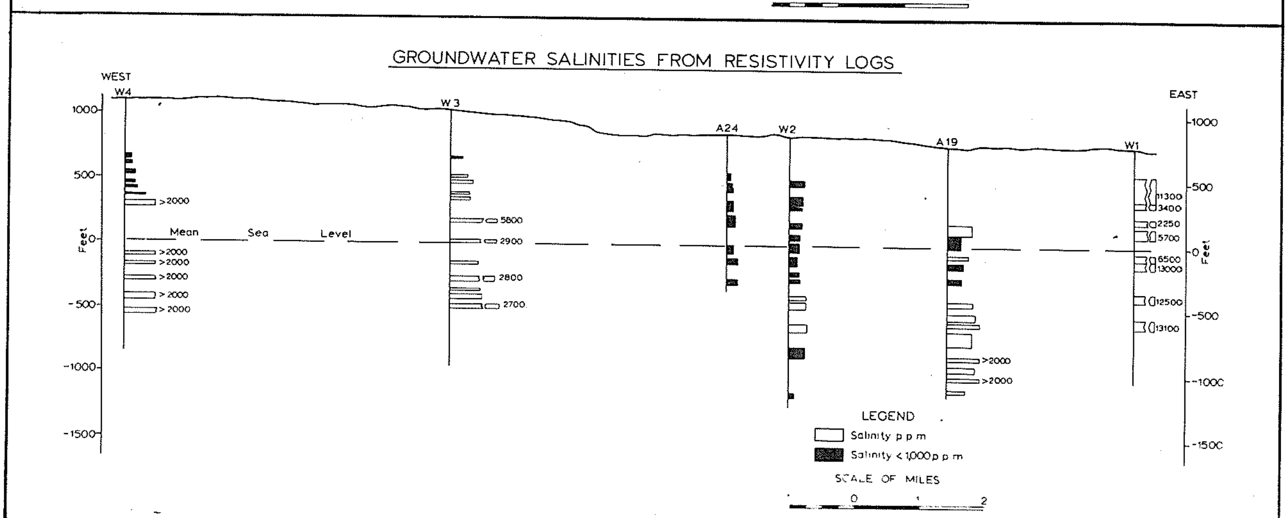
PLATE 1



115°45'
116°00'
30°15'
30°30'
A15
A16
A17
A10
A11
A12
A13
A21
A23
LINE OF SECTION
W3
W4
A7
W2
A18
A19
W1
A24
A5
A20
A4
A6
A1
A2
A3
AGATON SPRING
A14
A9
N
DARLING FAULT ZONE
SALINE DRAINAGE SWAMPS AND LAKES
WATHEROO
GERALDTON HIGHWAY
AGATON PROJECT
CONTOURS OF POTENTIOMETRIC SURFACE
30 11 68
Compiled by J R P
LEGEND
660 Contours of potentiometric surface (feet above mean sea level) as at 30th Nov., 1968
Bore
SCALE OF MILES



GEOLOGICAL CROSS SECTION
WEST
EAST
W4
W3
A7
A24
W2
A18
A19
W1
Feet
Mean Sea Level
Kls
Ku
Klsa
LEGEND
Geological boundary
Correlation within SOUTH PERTH FORMATION
Potentiometric surface
Section screened or slotted for testing
Aquifer zone
Ku Upper Cretaceous marine formations
Klsa Marine member of the SOUTH PERTH FORMATION
Kls SOUTH PERTH FORMATION
SCALE OF MILES



GROUNDWATER SALINITIES FROM RESISTIVITY LOGS
WEST
EAST
W4
W3
A24
W2
A19
W1
Feet
Mean Sea Level
LEGEND
Salinity p p m
Salinity < 1,000 p p m
SCALE OF MILES

Calcrete valley fills

The main valleys and some fossil drainage channels in the Meekatharra—Lake Carnegie area are in places filled with 50 feet or more of fluviatile sediments ranging in grade from fine silt and clay through sand to coarse gravel. These are overlain in places by rubbly calcrete up to 30 feet thick with occasional bands of cellular opaline silica. Wide valley-tracts of calcrete are often continuous for many miles with low ridges parallel to the main drainage channels. Smaller developments appear as discontinuous valley trains separated by alluvium, and as isolated patches in restricted basins.

South of Wiluna calcrete is restricted to the main fossil drainages and around the larger lakes, for example, Lake Miranda at Sir Samuel. It often appears as a dissected remnant of a once much larger deposit. In the Youanmi—Leonora—Laverton area calcrete is uncommon and is found only in scattered relict patches fringing the salt lakes which now occupy the courses of the major ancient drainages.

In most areas calcrete is partly masked by the subsequent development of brown calcareous earths and in places obscured by alluvial wash. A fossil drainage system about eight miles north of Meekatharra provides an excellent example of this. There is no apparent surface indication of calcrete, although indications of it may be discerned from aerial photographs, but recent boreholes have penetrated about 35 feet of water-saturated calcareous rock. The full extent of any calcrete formation can only be found by drilling.

Calcrete probably formed as a primary chemical precipitate from solution in ground and surface waters. Sofoulis (1963) suggested that calcrete formations at different elevations along the same drainage system were deposited from "ponded" sections of the drainage after the cessation of a past period of high rainfall. The high calcium ion concentration in the waters may have been due to slow movement over calcium-rich basic igneous and metamorphic rocks.

HYDROLOGY

All main drainage tracts and calcrete areas were identified on air-photographs, prior to field inspection and sampling waters from bores and wells in their vicinity. Calcretes are extensive in the area between Meekatharra and Lake Carnegie but their occurrence and importance as aquifers diminishes towards the south. On the other hand, alluvium-filled valleys are common throughout the region and some of these appear to have good prospects of yielding fairly substantial supplies.

The occurrence and present utilisation of calcrete and alluvial valley fills are indicated in Tables 1 and 2, and positions and water salinities are shown on Plate 2. Some areas worthy of further groundwater investigations are listed below:

Glengarry 1 : 250,000 Sheet

1. The *Karalundi Mission*, 36 miles north of Meekatharra, is sited on a broad calcrete drainage system. Four wells deliver domestic and irrigation water; one well yields 15,000 gallons per hour.

2. *Hillview and Murchison Downs Stations* are traversed by a large calcrete deposit which is fed from nearby uplands and wide tributary plains. Brookfield *in* Mabbutt and others (1963) calculated the catchment area at about 590 square miles with a potential annual recharge of 8,000 acre feet.

TABLE 1. OCCURRENCE AND PRESENT UTILISATION OF CALCRETED VALLEY FILLS

1 : 250,000 Sheet	Calcrete occurrence town, station, mission	Water quality parts per million TDS	Present use	Number of bores or wells in calcrete (approximate)	Maximum reported yield in gallons per hour (gph) or gallons per day (gpd)
Glengarry	Karalundi Mission	Potable	Domestic and irrigation	4	1 well, 15,000 gph
	Meekatharra Town Bores	Potable	Exploratory	3	3 bores, 4,800 gph
	Sherwood Station	Brackish	Stock	3	*2 wells, 3,000 gpd
	Polelle Station	Brackish	Stock	5	*1 well, 5,000 gpd
	Hillview Station	1000–3000 ppm	Stock	5	*2 wells, 20,000 gpd
	Killara Station	2000–3000 ppm	Stock	3	*3 wells, 4,000 gpd
	Munarra Station	Brackish	Stock	6	*1 well, 15,000 gpd
	Diamond Well Station	Brackish	Stock	2	*1 well, 10,000 gpd
	Murchison Down Station	1000–3000 ppm	Stock	3	*1 well, 5,000 gpd
	Paroo Station	700–1750 ppm	Stock	8	*8 wells, 4,000 gpd
	Yandill Station	1750–14,000 ppm	Stock	6	1 well, 120,000 gpd
Wiluna	Cunyu Station	350–950 ppm	Domestic and stock	2	*1 well, 20,000 gpd
	Wiluna Town Bores	740–860 ppm	Domestic	6	1 well, 115,000 gpd
	Millbillillie Station	900–4000 ppm	Stock	8	*1 well, 8,640 gpd
	Lake Way Station	5000 ppm	Stock	1	*1 well, 10,800 gpd
	Albion Down Station	2142 ppm	Stock	1	....
	Lake Violet Station	750–3000 ppm	Stock	5	*3 bores, 3,000 gpd
	Millrose Station	Brackish	Stock	3	*2 wells, 5,000 gpd
	Lorna Glen Station	Saline	Stock	3	1 well, 20,000 gpd
Kingston	Lorna Glen Station	600 ppm	Domestic and irrigation	4	*1 well, 280,000 to 480,000 gpd
	Windidda Station	Saline	Stock	3	*1 well, 9,000 gpd
	Bonython Creek Station	....	Stock	2	....
Sandstone....	Hillview Station	1500–5500 ppm	Stock	7	*7 bores, 4,000 gpd
	Cogla Downs Station	2000–5900 ppm	Stock	4	*1 bore, 5,000 gpd
	Lake Mason Station	2000–6000 ppm	Stock	5	*5 bores, 4,000 gpd
	Yeelirrie Station	2200–11,000 ppm	Stock	4	*3 bores, 5,000 gpd
Sir Samuel	Yeelirrie Station	1750–9000 ppm	Stock	5	*5 wells and bores, 5,000 gpd
	Depot Springs Station	650–10,000 ppm	Stock	3	....
	Yakabindie Station	2000–6000 ppm	Stock	10	*2 bores, 4,000 gph
	Leinster Downs Station	3000–4000 ppm	Stock	2	....
	Weebo Station	440–5200 ppm	Stock and irrigation	3	*1 well, 5,000 gph
	Yandal Station	3000 ppm	Stock	2	....
	Barwidgee Station	650–5900 ppm	Stock	3	*1 well, 14,000 gpd
Duketon	Banjawarn Station	350–5000 ppm	Stock and minor irrigation	7	*1 bore, 50,000 gpd
Youanmi	Yuinmery Station	1000–7000 ppm	Stock	5	*1 well, 24,000 gpd
	Dandaraga Station	1750–5000 ppm	Stock	5	....
	Cashmere Downs Station	Saline	Stock	2	....
Leonora	Pinnacles Station	2500–8000 ppm	Stock	5	....
	Sturt Meadows Station	500–1200 ppm	Stock	5	*5 bores, 5,000 gpd
	Clover Downs Station	3000 ppm	Stock	1	....
Laverton	Nambi Station	8000 ppm	Stock	2	....
	Erlistoun Station	2500–10,000 ppm	Stock	3	*1 bore, 4,000 gpd
	Korong Station	2400 ppm	Stock	1	....

* Indicates pump capacity rather than potential yield of well or bore.

TABLE 2. OCCURRENCE AND PRESENT UTILISATION OF ALLUVIAL DRAINAGES

1 : 250,000 Sheet	Alluvial occurrences town, station, mission	Water quality parts per million TDS	Present use	Number of bores or wells in alluvium (approximate)	Maximum reported yield gallons per hour (gph) or gallons per day (gpd)
Glengarry	Meekatharra Town Bores	740–1280 ppm	Town supply	9	2 wells, 1,100 gph
	Sherwood Station	Brackish	Stock	19	*19 wells and bores, 1,000 gpd
	Polelle Station	800–3000 ppm	Stock	14	*10 wells and bores, 8,000 gpd
	Hillview Station	800–3000 ppm	Stock	7	*1well, 4000 gpd
	Killara Station	800–2500 ppm	Stock	3	*3 wells, 4,000 gpd
	Munarra Station	1250–3000 ppm	Stock	15	*4 wells, 10,000 gpd
	Diamond Well Station	Brackish	Stock	2	*1 well, 20,000 gpd
	Mooloogool Station	? Brackish	Stock	10	*1 well, 28,000 gpd
	Murchison Down Station	1000–Brackish	Stock	10	*2 wells, 5,000 gpd
	Paroo Station	710–Brackish	Stock	12	*9 wells, 2,000–4,000 gpd
	Yandil Station	1350–Brackish	Stock	10	1 well, 100,800 gpd
	Albion Downs Station	1000–Brackish	Stock	8	*2 bores, 7,000 gpd
Wiluna	Wiluna Agriculture Research Station	1360 ppm	Irrigation	2	1 bore, 11,000 gph 1 bore, 7,000 gph
	Millbillillie Station	1750–3000 ppm	Irrigation	3	1 bore, 3,750 gph
	Millbillillie Station	1500–2750 ppm	Stock	11	*7 wells, 2,000 gpd
	Lake Way Station	1000–Brackish	Stock	16	*1 well, 20,000 gpd 1 well, 12,000 gpd
	Lake Violet Station	1500 ppm	Irrigation	3	2 bores, 5,000 gph
	Lake Violet Station	1500–3000 ppm	Stock	12	*1 well, 2,000 gph
	Millrose Station	1000–Brackish	Stock	6	*6 wells, 2,000 gpd
	Jundee Station	1000–3000 ppm	Irrigation and stock	5	1 well, 216,000 gpd 1 well, 116,000 gpd
	Barwidgee Station	750–1025 ppm	Stock	4	....
	Lorna Glen Station	620–2000 ppm	Stock	4	*2 bores, 36,000 gpd
Kingston	Lorna Glen	580–2300 ppm	Stock	3	1 well, 100,000 gpd
	Windidda Station	Brackish	Stock	2	....
Sandstone	Hillview Station	650–1500 ppm	Stock	3	....
	Yarrabubba Station	Brackish	Stock	7	....
	Cogla Down Station	2000–5000 ppm	Stock and minor irrigation	5	*1 bore, 15,000 gpd
	Lake Mason Station	150–5250 ppm	Domestic and stock	4	*1 bore, 3,000 gph
	Yeelirrie Station	750–1800 ppm	Stock	2	*2 bores, 5,000 gpd
Sir Samuel	Yeelirrie Station	400–5800 ppm	Minor irrigation and Stock	4	*1 well, 15,000 gpd
	Albion Downs Station	900–3000 ppm	Irrigation and stock	12	6 bores, 3,000–5,000 gph
	Depot Springs Station	900–1500 ppm	Stock	4	....
	Yakabindie Station	790–5200 ppm	Stock	9	*2 wells, 150 gph
	Yandal Station	1250 ppm	Stock	2	....
	Weebo Station	666 ppm	Domestic	1	....
	Barwidgee Station	650–4000 ppm	Minor irrigation and stock	7	....
Duketon	Banjawarn Station	800–2000 ppm	Stock	4	....
Youanmi	Yuinmery Station	295–5800 ppm	Stock	8	*1 well, 24,000 gpd
	Dandaraga Station	1150–2500 ppm	Stock	14	....
	Cashmere Downs Station	Brackish	Stock	2	....
Leonora	Pinnacles Station	500–5990 ppm	Stock	18	....
	Pinnacles Station	1400 ppm	Irrigation (abd)	7	7 bores, 40,000 gpd
	Sturt Meadows Station	620–2900 ppm	Minor irrigation and stock	12	*1 well, 7,000 gph
	Clover Downs Station	2000–4000 ppm	Stock	4	....
	Leonora Town Bores	1300 ppm	Domestic	4	3 wells, 2,000 gph 1 well, 1,000 gph
Laverton	Nambi Station	790–1800 ppm	Minor irrigation and stock	4	....
	Erlistoun Station	2500–5500 ppm	Stock	9	*3 wells, 5,000 gpd
	Korong Station	2500–5500 ppm	Stock	5	*3 wells, 5,000 gpd

* Indicates pump capacity rather than potential yield of well or bore.

3. *On Paroo and Yandil Stations* extensive calcrete and alluvial aquifers give groundwater containing 700 to 1,750 ppm, total salts; one well has been tested at 120,000 gallons per day, and another at 100,800 gpd. This system is probably the largest in the East Murchison, far exceeding the Wiluna aquifer in dimension and catchment area. Brookfield estimates the catchment area to cover 1,270 square miles with a potential annual recharge of 25,500 acre feet.

Wiluna 1 : 250,000 Sheet

1. At *Cunyu Station,* 40 miles north of Wiluna, potable water is obtained from calcrete at the rate of 20,000 gpd, but no adequate pump-test has been carried out. The catchment area is at least 240 square miles with an estimated annual recharge of 4,500 acre feet (Brookfield in Mabbett and others, 1963).

2. The *Wiluna* aquifer, six miles east of the town, is reported to have yielded 1,000,000 gpd without noticeable lowering of the water table. The catchment area is about 150 square miles and annual recharge has been calculated by Chapman (1962) as 2,350 acre feet.

3. At *Lorna Glen Station,* 100 miles northeast of Wiluna, potable water is pumped from calcrete at up to 480,000 gpd. Chapman reported a catchment area of about 50 square miles and an annual recharge of 350 acre feet.

Sir Samuel 1 : 250,000 Sheet

1. On *Albion Downs Station* a localized alluvial aquifer is used for irrigation and domestic supply. Six bores are reported to yield between 3,000 and 5,000 gallons per hour.

2. On *Yakabindie and Leinster Downs Stations* three fossil calcrete drainages terminate in Lake Miranda. Salinities are rather high (2,000 to 6,000 ppm TDS) but the amount of available water is probably quite large. No adequate pump-testing has been done.

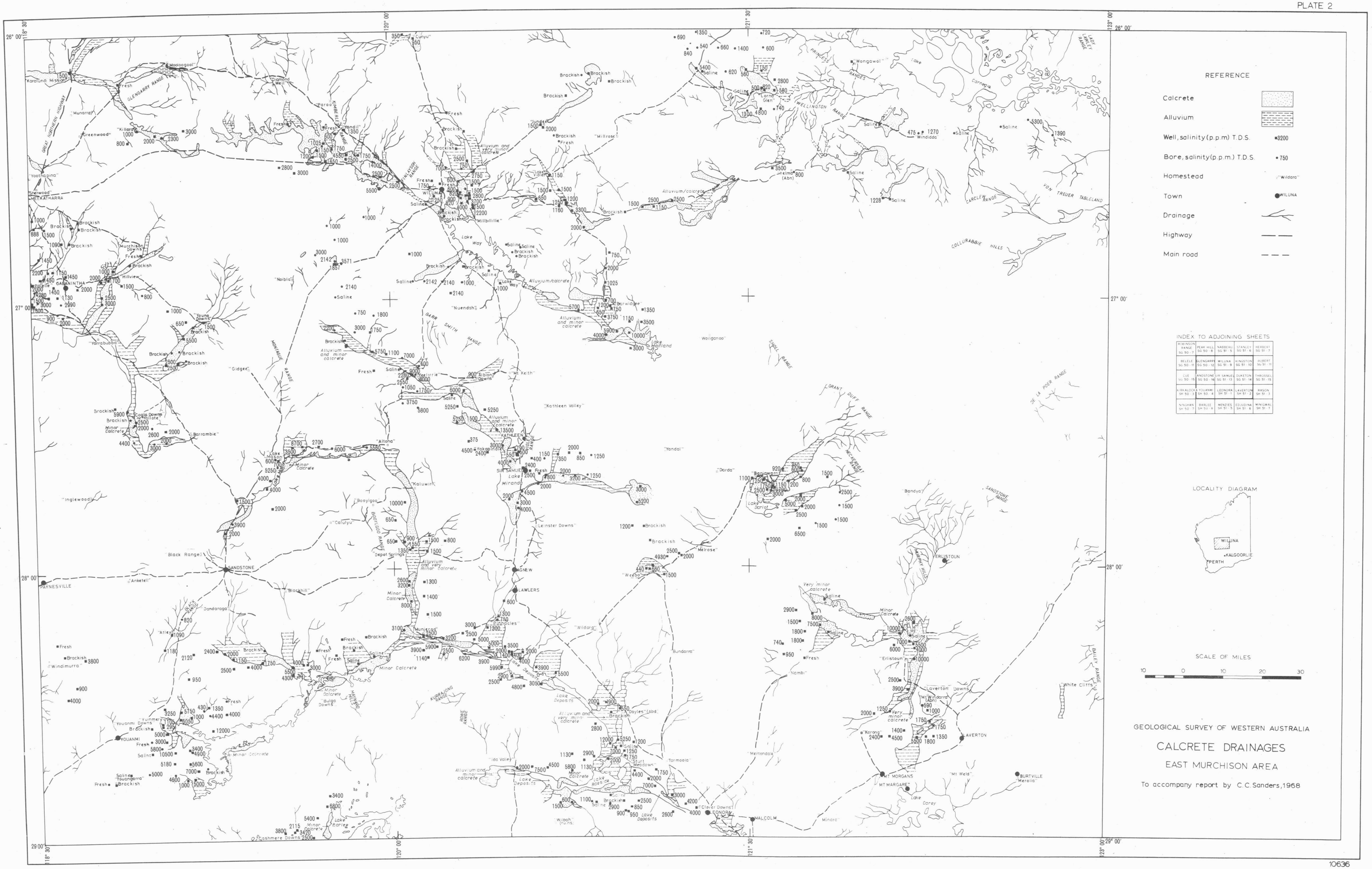
Duketon 1 : 250,000 Sheet

1. *Banjawarn Station* on Lake Darlot is sited over calcrete and alluvial aquifers associated with the Erlistoun and Vickers Creek drainage system. Salinities range from 350 to 5,000 ppm TDS, and one bore yields at least 50,000 gallons per day.

Leonora 1 : 250,000 Sheet

1. Many suggesions have been made over the last 60 years to dam or intensively bore the Wilson Creek drainage system on *Sturt Meadows Station,* some 40 miles northwest of Leonora. The system is an alluvial area of about 50 square miles fed from numerous creeks draining nearby uplands. From about 1920 to 1940 potable water at a 'great supply' was obtained from Doyles Well on Wilson Creek for a now abandoned hotel and swimming pool.

PLATE 2



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2. *Leonora Townsite* and the *Sons of Gwalia Goldmine* were supplied with groundwaer containing 1,000 to 2,000 ppm TDS from bores sunk in alluvial areas around the town. The present Leonora supply is near Four Mile Creek from four wells, 60 to 70 feet deep, each yielding up to 2,000 gph. All bores can be pumped out. Additional supplies could be obtained by drilling farther downstream.

3. An unusual underground water occurrence not related to calcrete and which might be exploited has been reported from the *Emu Goldmine* at Agnew. Slightly brackish pressure water was struck at the 960 feet level, the water rose about 700 feet, and was pumped from the mine at the rate of 1,000,000 gpd for three months before the water was controlled.

CONCLUSIONS AND RECOMMENDATIONS

Calcrete valley fills are not persistent throughout the East Murchison—Mt. Margaret Goldfields, although they form important but mainly untested aquifers in the Meekatharra—Lake Carnegie area, their importance diminishing toward the south. Some alluvial drainage tracts may provide usable groundwater in the southern region. Further hydrological studies, following by drilling, could be under taken with advantage in such areas as Karalundi Mission, Hillview and Murchison Downs Stations, Paroo and Yandil Stations, Cunyu Station, Lorna Glen Station, and at Wiluna in the East Murchison Goldfield; Albion Downs Station, Yakabindie Station and Banjawarn Station in the Sir Samuel —Lake Darlot area; and at Doyles Well on Sturt Meadows Station, Leonora. The Emu Goldmine at Agnew and alluviated areas near Leonora could give additional supplies.

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MILLSTREAM HYDROGEOLOGICAL INVESTIGATION

by W. A. Davidson

ABSTRACT

Exploratory drilling of calcretes in the vicinity of Millstream, on the Fortescue River, has shown that they are situated in a trough and have an average saturated thickness of 35 feet. The calcrete aquifer covers an area of at least 80 square miles and has limited interconnection with the Fortescue River.

Approximately 8 million gallons per day of potable water, suitable for town supply, can be pumped from the calcrete without reducing the volume of water in storage, if normal recharge takes place. It is estimated that about 80 x 10^9 gallons are in storage.

INTRODUCTION

Millstream Station homestead is on the Pyramid 1 : 250,000 Sheet, about 85 miles southeast of Dampier.

Following a geological reconnaissance during February, 1968, the Geological Survey, at the request of the Public Works Department, investigated the possibility of obtaining from the Millstream calcretes 10 million gallons per day of potable water for industrial and domestic use. This is required at Dampier by iron ore companies.

The calcretes are situated in an arcuate strip of country convex to the north, approximately 35 miles long and 5 miles wide, the centre being about 2 miles south of Millstream homestead.

INVESTIGATIONS

Gravity survey

A gravity survey was made to help delineate the bedrock and as an aid to selecting bore sites. Results are at Appendix I.

Drilling programme

Twenty-five bores were drilled on eight cross-sections (Plate 4), and accurately levelled. Depths ranged from 60 feet to 195 feet, total footage drilled being 3,506 feet. Three percussion cable tool rigs and one rotary percussion rig were used. Fourteen bores were pump-tested for 8-hour periods.

Drilling samples were collected at 10 feet intervals and at changes of strata. However, in cavernous calcrete, samples were often unobtainable by the rotary percussion rig.

The drilling results have been summarized in Table 1.

GEOLOGY

The Millstream area has been regionally mapped by M. Kriewaldt and G. R. Ryan (1965) on the Pyramid 1 : 250,000 Sheet and by I. R. Williams (1968) on the Yarraloola 1 : 250,000 Sheet.

Regional setting (Plate 3)

Surrounding and underlying the calcrete is a Proterozoic sequence with a regional southerly dip of less than 3 degrees. The succession in the Millstream area is thus:

Hamersley Group	Wittenoom Dolomite (Phd) Marra Mamba Iron Formation (Phm)	
	———conformity———	
Fortescue Group ..	Roy Hill Shale Member (Pfjr) Warrie Member (Pfjw)	Part of the Jeerinah Formation

Bedrock

Wittenoom Dolomite. At the base of the Hamersley Scarp, and to the south of the calcrete valley fill, grey to light brown calcitic dolomite may be seen in outcrop. It is thin to thick bedded and is often compact and well indurated.

TABLE 1. MILLSTREAM DRILLING RESULTS

Bore name	Total depth	Estimated valley fill calcrete and clay	Thickness saturated aquifer	Bedrock or basement	Reduced static water level		Pump—Test			Salinity pumped sample	Total casing	Remarks
					Feet	Date	g.p.h.	Hrs.	Drawdown			
	ft	*ft*	*ft*						*ins*	*ppm*	*ft ins*	
Line 1—A	134	45	38	Pfjr	963·925	19/10/68	14,900	8	2	670	58 10¾	Prospective calcrete
B	91⅓	58	36	Phm	964·405	3/10/68	14,900	8	Nil	720	43 3	Prospective calcrete
C	136	93	57	Weathered Phm	964·527	19/10/68	14,900	7½	123	600	60 4¼	Prospective calcrete
D	148¼	102	34	Weathered Phm	964·513	19/10/68	14,900	7	Nil	570	91 2¼	Prospective calcrete
Line 2—A	¾	Unknown		Unknown	Dry	30/9/68	....	....	....	590	....	Abandoned
B	181	94	24	Pfjr	964·452	30/9/68	15,000	8	Nil	500	94 10¾	Prospective calcrete
C	195	150	74	Weathered Pfjr	964·418	30/9/68	....	....	....	630	138 4½	Prospective calcrete
D	148	98	21	Weathered Pfjr	964·478	1/10/68	25,600	8	13	470	101 3¼	Prospective calcrete
Line 3—A	120	80	55	Weathered Pfjr	964·445	15/10/68	25,600	5	Nil	1150	53 8	Prospective calcrete
Line 4—A	187	105	31	Weathered Pfjr	964·309	1/10/68	25,600	8	10½	520	95 0½	Prospective calcrete
B	150	100	23	Phm	964·399	1/10/68	....	....	....	560	99 1	Prospective calcrete
C	175	130	55	Phd	964·469	1/10/68	....	....	....	570	139 6¾	Prospective calcrete
D	154	100	23	Weathered Phm	965·416	1/10/68	6,600	8	112½	720	94 7¾	Unprospective calcrete
Line 5—A	152	110	73	Weathered Phm or Pfjr	964·840	16/9/68	....	....	....	1040	115 6	Prospective calcrete
B	150	135	70	Weathered Phm	964·770	12/9/68	25,600	4	Nil	940	93 10	Prospective calcrete
C	120	90	39	Possibly weathered Phd	964·892	16/9/68	....	....	....	530	81 7	Prospective calcrete
Line 6—A	100	45	....	Pfjr	974·446	2/10/68	....	....	....	500	81 6¾	Unprospective Phm
B	116	88	16	Weathered Phm	964·356	2/10/68	1,500	1	160	740	86 4¾	Unprospective calcrete
Line 7—A	125	90	42	Weathered Phm	964·101	30/9/68	....	....	....	540	97 11½	Prospective calcrete
B	156	100	31	Weathered Pfjr	964·434	3/10/68	25,600	8	30½	580	102 4¼	Prospective calcrete
C	175	165	93	Weathered Pfjr	964·420	6/9/68	....	....	....	480	122 0	Prospective calcrete
D	148	105	29	Weathered Pfjr	964·411	3/10/68	25,600	7⅜	26	510	99 3¾	Prospective calcrete
Line 8—A	60	40	Nil	Phm	Dry	6/9/68	....	....	....	Dry	....	Dry
B	145	90	27	Weathered Phm	964·356	6/9/68	....	....	....	1010	97 4	Prospective calcrete
C	162	130	53	Weathered Phm and Pfjr	964·621	6/9/68	23,700	8	31½	570	103 1	Prospective calcrete

Pilot holes drilled partly by rotary percussion rig and later reamed and deepened by cable tool plant.

Samples obtained during the drilling of Line 4-C bore indicate that the dolomite is well bedded and in general not very permeable, though it may be cavernous in places.

Dolomitic shale and thin chert bands are present at the top of the formation.

Marra Mamba Iron Formation. In the Millstream area the Marra Mamba Iron Formation has been deeply dissected and eroded to form thin caps, approximately 20 to 40 feet thick, overlying the Roy Hill Shale. The formation is characterized by a dominance of blue-black chert and subordinate jaspilite, often with pinch and swell structures.

Roy Hill Shale Member. This member lies at the top of the Jeerinah Formation and is a leached white shale, silicified in places, up to 120 feet thick. Drilling has shown that the shale is capped by an ironstone layer 5 to 10 feet thick, which sometimes contains pyrite nodules with hematite pseudomorphs after pyrite.

In some of the bores, fresh bedrock was encountered during drilling, but most bores terminated in weathered bedrock.

Calcrete and associated sediments

Although most of the calcrete aquifer lies south of the Fortescue River, there is a substantial outcrop of calcrete northeast of Deep Reach Pool. However, the base of the calcrete in this direction is thought to be mainly above the groundwater table and hence it is not water bearing. The base of the calcretes which straddle the watershed between the Fortescue and the Robe catchment is above the water table, except for a narrow zone confined to the westward extension of the main sedimentary trough.

The sediments in the trough follow the general sequence:

Calcrete and silcrete often covered with a thin veneer of clay-loam gilgai.

Clays (generally with some silica).

Weathered bedrock and variegated clay.

Bedrock (Wittenoom Dolomite, Marra Mamba Iron Formation, or Roy Hill Shale).

The highly cavernous and permeable calcrete, as shown in outcrop, generally overlaps the underlying clays which are often calcrete and/or silcrete impregnated. Impure calcrete then rests directly on weathered bedrock, the contact being poorly defined by the presence of weathering products such as grit and variegated clays.

Towards the western margins and in particular the margin southwest of Jones Creek Well and the breakaway near Palm Creek Spring, the calcrete often passes downward into a conglomerate in a lime matrix, which would tend to indicate that at least part of the calcrete valley fill contains alluvial material. Between 115 and 135 feet in Bore 5-B coarse-grained, moderately sorted, calcareous and siliceous fragments were encountered during drilling, suggesting an ancient river channel.

The base of the calcrete is very irregular and it is estimated that the reduced levels of the base extend over the range 871 to 1,004 feet. The upper surface of the calcrete, although generally fairly flat, lies at elevations between 1,040 and 970 feet. The greatest topographical relief is near the northeast and southwest margins. The total thickness of calcrete, therefore, varies considerably, the maximum being about 150 feet between Bore 2-C and Bore 7-C. The saturated thickness also varies widely, reaching a maximum of about 93 feet.

The trough

The shape and depth of the trough is a reflection of the ease of erosion of the various types of bedrock, their degree of resistance being:

Marra Mamba Iron Formation	Most resistant.
Wittenoom Dolomite.	
Roy Hill Shale	Least resistant.

The trough is therefore deepest where erosion has cut into the Roy Hill Shale.

The transition from calcerous clays to weathered bedrock to fresh bedrock prevents accurate determination of bedrock relief, but a good approximation of the form of the sedimentary trough may be made by using the base of the calcareous clay as a reference (Plate 4).

Drilling samples show that there is a general deepening of the trough towards the Hamersley Range drainage slope and particularly in the vicinity of Bore 7-C. To the southwest the centre of the trough rises gradually to at least 1,040 feet within the Robe catchment area. East of Line 5 the form of the trough is unknown. Between Line 2 and Line 7 the form of the trough is complicated by the development of a ridge as indicated on Plate 4.

The general form of the trough, therefore, supports the theory that the calcrete was deposited in an ancient channel and that there has been river piracy by the Fortescue River capturing the headwaters of the Robe River.

The present Fortescue River flows westward following the less resistant Roy Hill Shale and then cuts through a water gap breaching the more resistant Proterozoic rocks in the Gregory Gorge area to continue on the coast.

HYDROLOGY

Rainfall

Millstream Station has an annual rainfall of between 13 and 14 inches mostly from summer cyclones, although about 7½ inches of unseasonal winter rains were recorded by the Public Works Department during 1968.

Aquifers

Bedrock. The Marra Mamba Iron Formation contains small quantities of water in fractures and weathered zones, and supplies some station wells. The water in Bore 6-A comes from the same formation, but the supply is not good. The Roy Hill Shale is also not very permeable. The Wittenoom Dolomite in Bore 4-C is well below the present water table, but appears too impermeable to be a likely source of water unless it proves cavernous in places.

Calcrete. Around its margins, and in particular to the northeast and southwest, the floor of the calcrete rises above the present water table so that the saturated area of 80 square miles or so is much less than the surface extent.

The calcrete often contains bands of very hard opaline silica, but is usually very pervious and sometimes cavernous. Towards its base the permeability is much less because of a higher clay content. The average saturated thickness has been calculated at 35 feet of which possibly only 30 feet will yield much water.

Alluvium. The aquifer in the vicinity of Howlett's Well is possibly a river alluvium consisting largely of clays and having a low-to-moderate porosity, which possibly accounts for the wide variations in rest levels. In this well fluctuations in excess of 10 feet are known to occur.

Hydraulic Surface

Static water levels have been measured accurately. The water table in the saturated calcrete is substantially flat with a range of elevations between 963.93 and 965.42 feet (Plate 4). Towards the margins of the calcrete and in weathered bedrock zones the range of elevations is generally higher, from 971.22 to 974.45 feet.

Pools associated with springs from the calcrete, and in particular Deep Reach Pool in the Fortescue River, show elevations less than those found in the main body of calcrete. Deep Reach Pool had an elevation of 958.39 feet on the 15th October, 1968. This may indicate low permeability within the calcrete aquifer in its vicinity, or more likely, that the pools are fed by springs. These rise in small erosion channels cut in the bedrock which subsequently have been infilled with calcrete rubble and clay, and connect the main body of the aquifer to the pools.

During dry season conditions the water level in Deep Reach Pool falls to a level at least 5 feet below that in the calcrete and as the nearest borehole tapping the main aquifer is about 3,000 feet away a comparatively steep hydraulic gradient is established. This is much steeper than the gradient within the main mass of calcrete where it seems unlikely to exceed 1 foot in 25,000 feet. It may be assumed, therefore, that the transmissivity in the main body of the aquifer is very much higher than that near the banks of the Fortescue. This may indicate that river alluvium or weathered bedrock, or both, separate Deep Reach Pool from the calcrete aquifer.

Before recharge to the calcrete south of Deep Reach Pool could take place from the river, the water level of the pool would have to rise more than 5 feet. As this very seldom occurs, recharge to the calcrete from this source will only take place during exceptionally high floods. During normal river flow and minor flooding, recharge to the calcrete will not take place at this locality.

The hydraulic gradient of 2 feet in 300 feet between Bore 1-A and the pool at Millstream Spring in conjunction with the general form of the trough, as shown on Plate 3, indicates that the general flow of water within the calcrete is towards Millstream homestead.

TABLE 2. MILLSTREAM GROUNDWATER—GOVERNMENT CHEMICAL LABORATORIES—STANDARD ANALYSES

Source	Specific conductivity micromhos 20° C.	pH	Appearance	Colour	Odour	MINERAL MATTER—PARTS PER MILLION																
						T.D.S. evaporation	T.D.S. conductivity	NaCl (calc. from chloride)	Total hardness (calc. as $CaCO_3$)	Total alkalinity (calc. as $CaCO_3$)	Ca	Mg	Na	K	Fe	F	HCO_3	CO_3	SO_4	Cl	NO_3	SiO_2
Line 1—A	950	7·2	Clear	Colourless	Nil	660	660	214	380	305	72	49	93	18	0·1	0·7	396	Nil	71	137	7	59
B	1040	7·4	Clear	Colourless	Nil	720	730	242	417	335	86	49	85	12	0·1	0·7	408	Nil	70	147	3	58
C	890	7·5	Clear	Colourless	Nil	600	620	207	386	271	72	50	62	9	0·1	0·8	330	Nil	80	126	1	41
D	810	7·4	Clear	Colourless	Nil	570	560	171	336	270	68	40	63	10	0·1	0·6	329	Nil	59	104	8	57
Line 2—B	760	7·4	Clear	Colourless	Nil	500	530	154	303	260	57	39	61	7	0·1	....	317	Nil	39	93	15	44
C	920	7·3	Clear	Colourless	Nil	630	640	222	392	260	76	49	63	9	0·1	....	317	Nil	86	135	1	24
D	640	7·6	Clear	Colourless	Nil	470	450	150	256	231	48	33	64	7	0·1	....	281	Nil	29	91	17	61
Line 3—A	1660	7·4	Clear	Colourless	Nil	1150	1160	542	552	325	99	74	178	22	0·1	....	396	Nil	165	329	7	60
Line 4—A	730	7·2	Clear	Colourless	Nil	520	510	198	254	195	49	32	73	5	0·1	....	238	Nil	48	120	7	51
B	900	7·4	Clear	Colourless	Nil	560	630	274	359	225	58	52	76	5	0·1	2·1	274	Nil	47	166	27	7
C	850	7·4	Clear	Colourless	Nil	570	600	180	319	260	60	41	80	8	0·1	0·8	317	Nil	79	109	9	10
D	1010	7·5	Clear	Colourless	Nil	720	710	227	364	290	75	43	99	10	0·1	....	354	Nil	87	138	22	56
Line 5—A	1440	7·9	Clear	Colourless	Nil	1040	1010	450	470	276	73	70	166	16	0·1	....	336	Nil	179	273	6	51
B	1370	7·1	Clear	Colourless	Nil	940	960	417	469	295	84	63	140	18	0·1	....	360	Nil	134	253	6	56
C	750	8·0	Clear	Colourless	Nil	530	520	178	275	215	44	40	68	8	0·1	....	262	Nil	57	108	7	50
Line 6—A	740	7·8	Clear	Colourless	Nil	500	520	199	217	170	54	20	83	5	0·1	....	207	Nil	48	121	17	61
B	1020	7·6	Clear	Colourless	Nil	740	710	366	400	170	79	49	83	7	0·1	....	207	Nil	88	222	15	51
Line 7—A	780	7·6	Clear	Colourless	Nil	540	550	152	317	266	56	43	62	10	0·1	....	324	Nil	60	92	9	46
B	810	7·4	Clear	Colourless	Nil	580	570	185	253	276	69	44	67	10	0·1	....	336	Nil	65	112	14	54
C	640	7·5	Clear	Colourless	Nil	480	450	140	278	210	52	36	47	8	0·1	....	256	Nil	51	85	10	47
D	700	7·6	Clear	Colourless	Nil	510	490	142	295	266	59	36	63	8	0·1	....	323	Nil	45	86	11	53
Line 8—A	— — —	— —	— — —	— — — — —	— —	— — —	— —	— — —	— —	— —D	R	Y—	— —	— —	— — —	— —	— — —	— —	— —	— — —	— —	—
B	1400	7·8	Clear	Colourless	Nil	1010	980	553	411	189	82	50	177	8	0·1	....	232	Nil	128	336	10	51
C	860	7·7	Clear	Colourless	Nil	570	600	190	302	231	55	40	72	8	0·1	....	281	Nil	64	115	12	53
Irvine Well	1750	8·2	Clear	Colourless	Nil	1270	1220	626	614	305	101	88	185	20	0·1	....	372	Nil	186	380	9	54
Bloom Well	1770	8·2	Clear	Colourless	Nil	1290	1240	626	528	266	83	78	215	23	0·1	....	324	Nil	210	380	5	54
Chinaman Well	1010	7·7	Clear	Colourless	Nil	840	710	242	532	361	104	66	56	11	0·1	....	440	Nil	65	147	40	48
No. 3 Bore	980	7·6	Clear	Colourless	Nil	680	690	257	367	266	76	43	92	10	0·1	....	324	Nil	80	156	14	51
Pans Well	550	8·1	Clear	Colourless	Nil	430	380	109	248	225	58	25	48	4	0·1	....	274	Nil	26	66	14	55
Jones Ck. Well	1040	7·7	Clear	Colourless	Nil	700	730	313	461	295	109	46	64	13	0·1	....	360	Nil	43	190	11	51
Johnsons Well	770	8·1	Clear	Colourless	Nil	540	540	181	297	236	53	40	66	8	0·1	....	287	Nil	44	110	19	41
Pump Bore No. 14	900	7·5	Clear	Colourless	Nil	630	630	206	368	295	70	47	76	9	0·1	....	360	Nil	61	125	11	45
No. 4 Bore	1610	8·0	Clear	Colourless	Nil	1170	1130	542	545	310	96	74	187	20	0·1	....	378	Nil	189	329	6	65
Deep Reach Pool	1820	7·8	Clear	Colourless	Nil	1180	1275	610	570	290	92	83	196	20	0·1	....	353	Nil	200	368	6	59

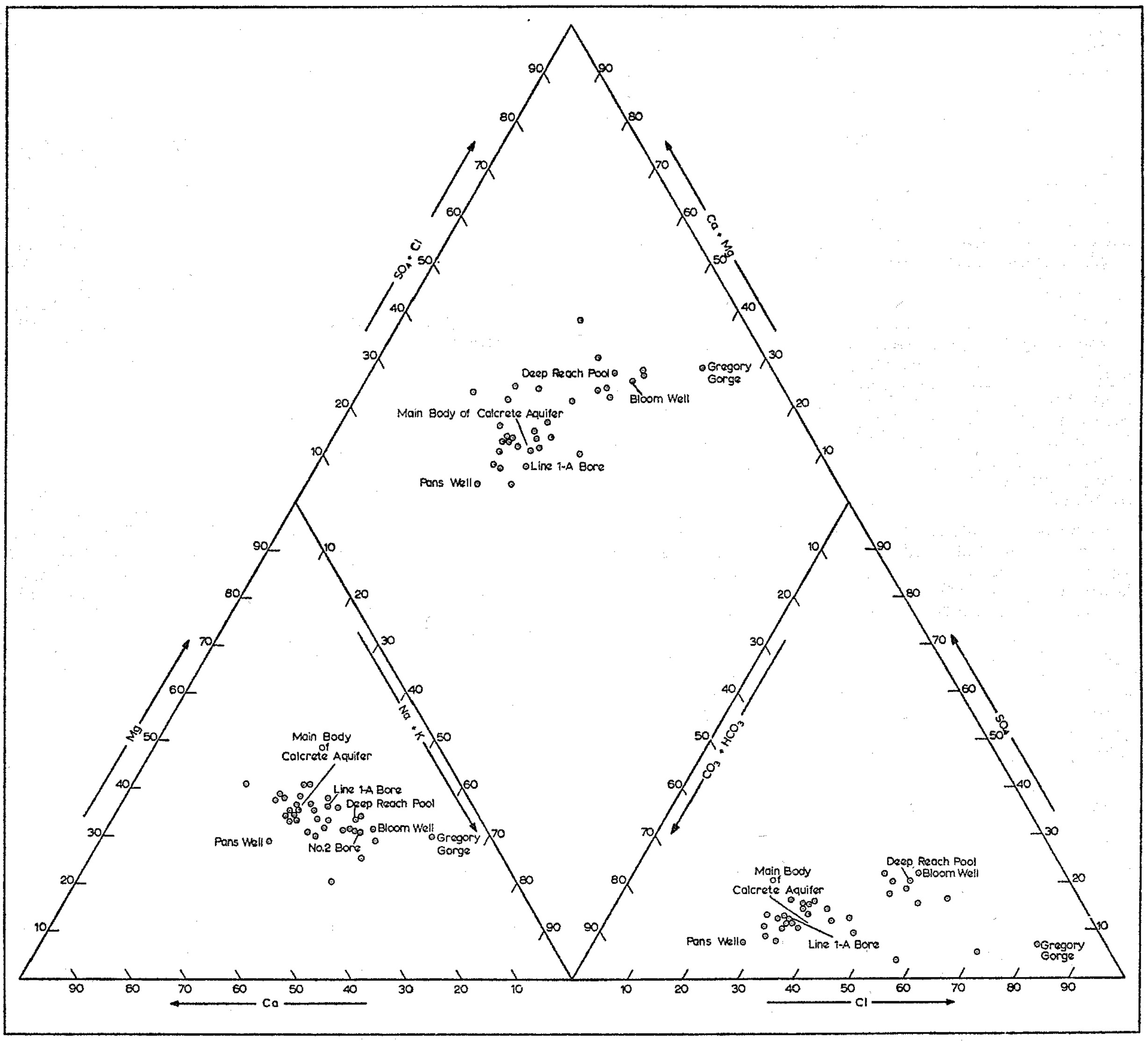


Figure 3. Hydrochemistry of Millstream groundwater.

Hydrochemistry

Standard analyses. Water sample analyses (Table 2) show that there is a high proportion of sodium and chlorine ions in water associated with weathered bedrock. A high concentration of these ions also occurs in the various pools and in particular the pool at the Gregory's Gorge. In the central part of the calcrete aquifer where concentration of sodium and chlorine ions is lower, there is a tendency for the water to be relatively high in bicarbonate and hence hard.

A trilinear diagram (Figure 3) illustrates the variations in chemical composition.

Salinity pattern (Total Dissolved Solids). From a study of the isohalsines drawn on Plate 4 the following deductions have been made:

(1) Groundwater in the large central area of the calcrete aquifer has a salinity range of approximately 450 to 750 ppm.

(2) Towards the margins of the calcrete and into the surrounding Proterozoic Formations the salinity range is higher, the range being 750 to 1,380 ppm. A sample from Gregory's Gorge had a salinity count of 2,180 ppm, undoubtedly the result of evaporative concentration.

(3) The immediate runoff from the bare drainage slope of the Hamersley Range has produced an area of low salinity shown on the southern central portion of the plan.

(4) To the southwest and in the vicinity of Pans Well the groundwater has a very low salinity of about 430 ppm suggesting direct intake from rainfall.

(5) The comparatively high salinity of groundwater associated with Proterozoic rocks is probably the result of low permeability of these strata, and that of the river pools is almost certainly the result of evaporation.

(6) At the eastern limits of the area there is a low salinity tongue extending eastward, which approximately follows the axis of the calcrete trough shown on Plate 3.

(7) The low salinity near Howlett Well results from local intake of rainwater and posibly some flow in Howlett Creek.

(8) The groundwater in station bores 1 and 2 show a fluctuation in salinity due to the winter rains.

	Before Rains	After Rains
Bore 1	1,380	430
Bore 2	1,200	230

Pump-Tests

Of the 25 exploratory boreholes, 14 were pump-tested for about 8 hours. The results (Table 1) indicate that low permeability or a low storage coefficient may be the cause of low pumping rates and comparatively large drawdowns in the calcrete aquifers in Bores 1C, 4D and 6B.

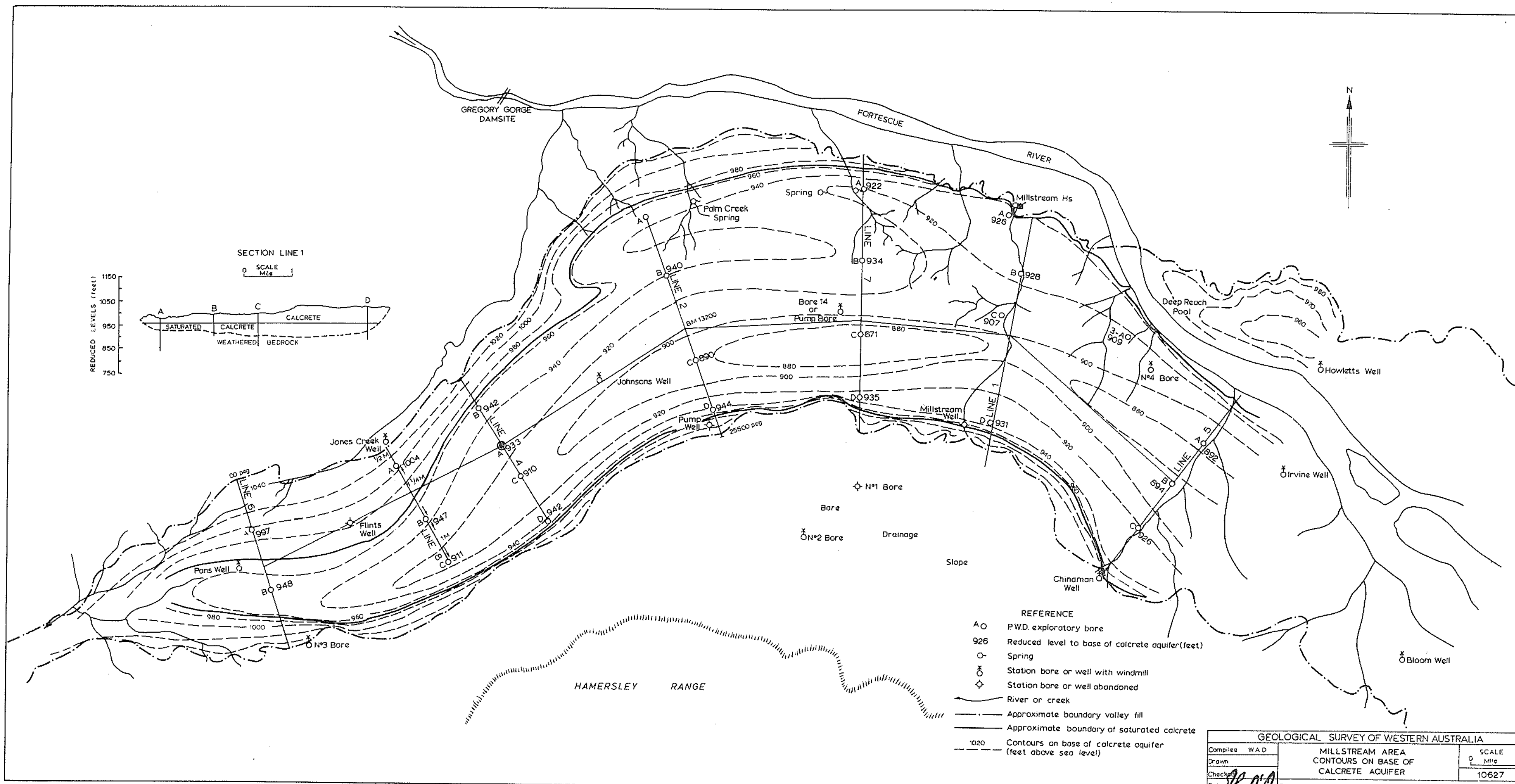
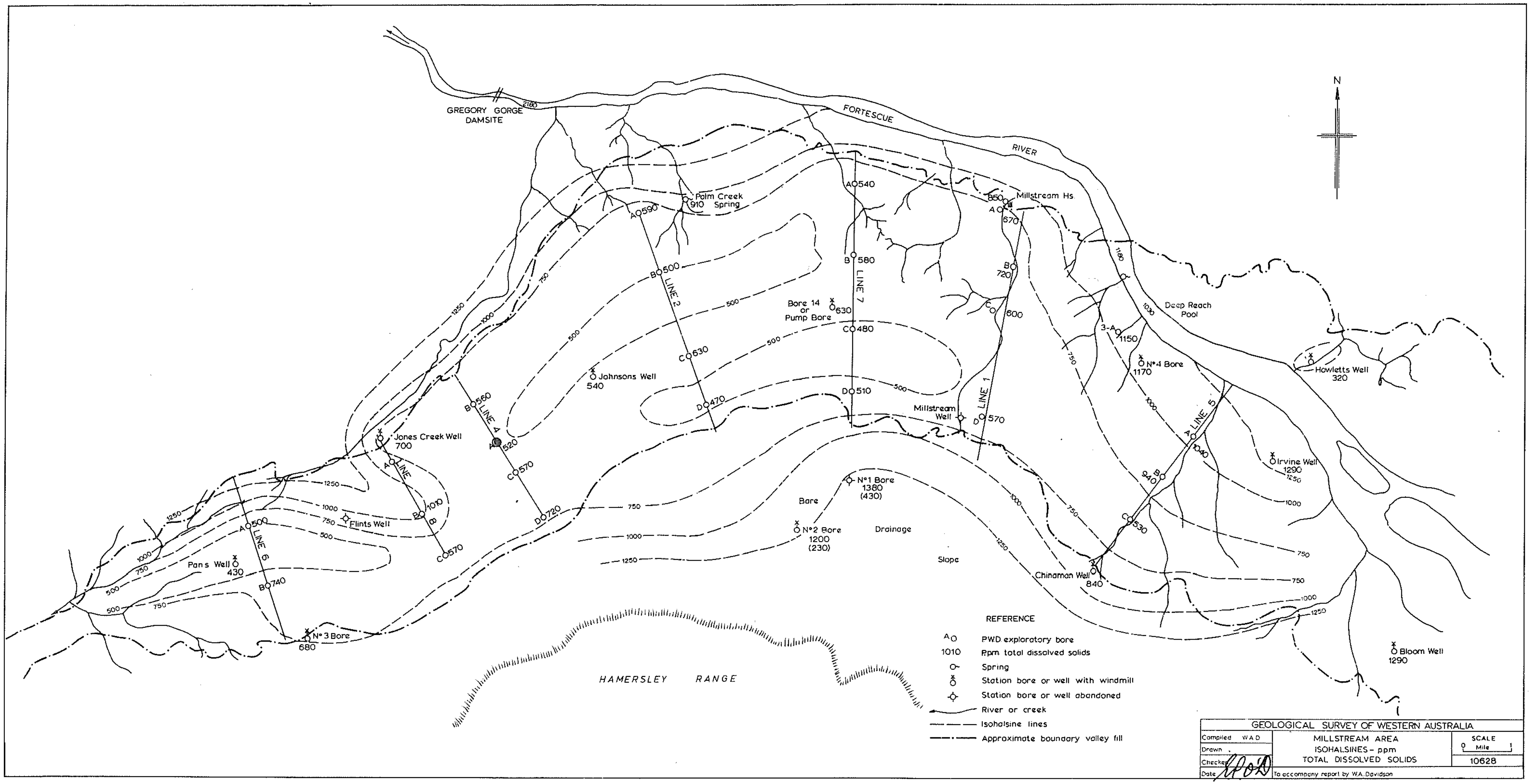

GREGORY GORGE DAMSITE
FORTESCUE RIVER
Millstream Hs
Palm Creek Spring
Spring
Bore 14 or Pump Bore
Deep Reach Pool
Howletts Well
N°4 Bore
Johnsons Well
Millstream Well
Pump Well
Jones Creek Well
Flints Well
Pans Well
N°3 Bore
N°1 Bore
N°2 Bore
Bore Drainage Slope
Chinaman Well
Irvine Well
Bloom Well
HAMERSLEY RANGE
SECTION LINE 1
SCALE 0 Mile 1
REDUCED LEVELS (feet)
1150
1050
950
850
750
SATURATED CALCRETE
CALCRETE
WEATHERED BEDROCK
REFERENCE
A○ P.W.D. exploratory bore
926 Reduced level to base of calcrete aquifer (feet)
Spring
Station bore or well with windmill
Station bore or well abandoned
River or creek
Approximate boundary valley fill
Approximate boundary of saturated calcrete
1020 Contours on base of calcrete aquifer (feet above sea level)
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
MILLSTREAM AREA
CONTOURS ON BASE OF CALCRETE AQUIFER
Compiled W.A.D.
Drawn
Checked
Date
SCALE 0 Mile 1
10627
To accompany report by W.A. Davidson

PLATE 3

PLATE 4



GREGORY GORGE DAMSITE
FORTESCUE RIVER
N
Palm Creek Spring
Millstream Hs.
Deep Reach Pool
Bore 14 or Pump Bore
Johnsons Well
Jones Creek Well
Flints Well
Pans Well
N° 3 Bore
Millstream Well
N°1 Bore
N°2 Bore
N°4 Bore
Howletts Well
Irvine Well
Chinaman Well
Bloom Well
LINE 1
LINE 2
LINE 4
LINE 5
LINE 6
LINE 7
LINE 8
Bore Drainage Slope
HAMERSLEY RANGE
REFERENCE
PWD exploratory bore
1010 Ppm total dissolved solids
Spring
Station bore or well with windmill
Station bore or well abandoned
River or creek
Isohalsine lines
Approximate boundary valley fill
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Compiled W.A.D.
Drawn
Checked
Date
MILLSTREAM AREA
ISOHALSINES - ppm
TOTAL DISSOLVED SOLIDS
SCALE
Mile
10628
To accompany report by W.A. Davidson

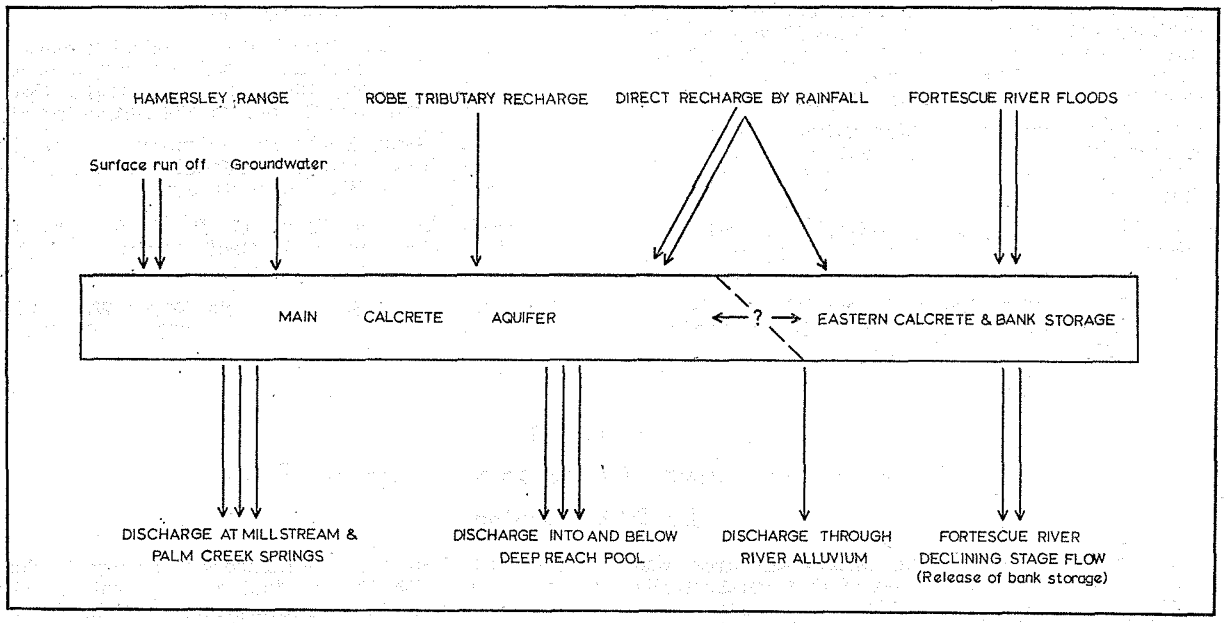


Figure 4. Millstream area, recharge—discharge relations.

GROUNDWATER RESOURCES

Recharge—discharge regime

The recharge—discharge regime is illustrated by Figure 4, the relative importance of each element being shown by one, two or three arrows.

During wet season conditions the hydraulic gradient in the vicinity of Deep Reach Pool would tend to flatten, as the water level in the river rose, to the extent of a possible reversal, in which case, recharge to the calcrete aquifer would take place. During dry season conditions the level of the pool would once more drop, the hydraulic gradient would steepen and discharge by springs from the calcrete would once more be established.

At the present water table level the Millstream calcretes must be regarded as an almost closed groundwater reservoir with limited inter-connection with the Fortescue River.

Natural discharge

Seasonal variations of discharge from the system as recorded by the Department of Public Works are as follows:

Date	Millstream Spring *Cusecs*	River Pools *Cusecs*	Total
16/5/64	6·20	10·35	16·55
2/6/65	7·64	6·31	13·95
11/1/68	9·70	....	....
15/4/68	8·33	9·53	17·86
15/5/68	7·94	....	16·83
1/6/68	....	8·89	....
3/7/68	8·93	....	....
10/8/68	7·42	....	....
3/9/68	8·75	10·14	18·89
30/10/68	6·65	9·04	15·69

The mean rate of discharge is about 16 cusecs per day or say 3,000 million gallons per annum.

Very minor discharge may also take place through the sands and gravels of the main Fortescue channel downstream of Deep Reach Pool.

Recharge

The overall general conclusion from the isohalsines is that there has been very little recharge to the calcrete body by groundwater movement from Proterozoic rocks and that most of the recharge has resulted from direct intake of rainfall, surface runoff from the Hamersley scarp, and groundwater movement from the southwest and northeast. Those areas of the calcrete aquifer which have been influenced by the infiltration of groundwater from the Proterozoic rocks have higher salinity counts. Some recharge to the calcrete by groundwater movement from the vicinity of station bore No. 1 may take place after heavy rains.

Groundwater storage

Large quantities of potable water are stored within the Millstream calcretes. Owing to the high porosity and permeability of the calcrete shown by small drawdown during uncontrolled pump-tests, a rough estimate of the storage coefficient may be made so that an approximate assessment of the total groundwater storage is possible. If a value of 20 per cent. is taken and applied to the estimated 80 square mile area over which the mean saturated calcrete thickness is about 30 feet, the volume of water stored becomes $80 \times 5280^2 \times 30 \times 0.2$ cubic feet, or approximately 80,000 million gallons. This is equivalent to approximately 25 times the total measured annual discharge at the surface.

An average discharge of 4 million gallons per day from Millstream Spring and 4 million gallons per day from surface flow downstream of Deep Reach Pool indicates that a total of 8 million gallons per day or roughly 3,000 million gallons per year discharges from the system, which corresponds to the annual recharge. Therefore, the maximum rate at which water may be withdrawn by pumpage without depleting storage is 8 million gallons per day, of which 4 million should come from the calcrete and 4 million from Deep Reach Pool. As the calcrete is probably a source of water to Deep Reach Pool a pumping rate in excess of 4 million gallons per day from the calcrete would tend to reduce leakage into the pool by a lowering of the hydraulic gradient. This could result in a lowering of the salinity of the mixture of water obtained from the two sources together.

If the estimated storage is 80,000 million gallons and the annual recharge is approximately 3,000 million gallons, a pumping rate of 19 million gallons per day will completely dewater the calcrete in about 20 years. However, if the storage coefficient in the lower parts of the aquifer is less than 0.2 dewatering will occur much sooner.

SUMMARY AND CONCLUSIONS

1. The Millstream calcretes provide a natural groundwater reservoir with limited inter-connection with the Fortescue River.

2. The areal extent of the calcrete aquifer although not fully known is at least 80 square miles, and for an assumed storage coefficient of 0.2 and an average thickness of 30 feet the trough contains approximately 80,000 million gallons.

3. Approximately 8 million gallons per day can be pumped from the aquifer without reducing the volume of water in storage, providing normal recharge takes place.

4. The trough is mainly recharged directly from rainfall and by surface runoff from the Hamersley Ranges.

5. The investigation is incomplete as the relationship between river flow and the groundwater body is still open to conjecture.

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Appendix 1

MILLSTREAM UNDERGROUND WATER PROJECT—GRAVITY SURVEY

by D. L. Rowston

A gravity survey of the Millstream area was made by the Geological Survey of Western Australia in the early stages of the underground water investigations in an attempt to detail the bedrock topography of the Fortescue valley, and thus delineate possible ancient river channels. Seismic refraction work was advocated as the most effective geophysical method of obtaining the information, but in the absence of suitable equipment the gravity survey was carried out as a second choice.

Prior to the recently completed exploratory drilling the Fortescue Valley was thought to be underlain by a southerly dipping sheet of Wittenoom Dolomite and infilled with alluvium containing some calcrete. It was therefore assumed that an adequate density contrast between bedrock and valley fill would apply and facilitate a simple and accurate interpretation of the results.

A total of 522 gravity observations were made at stations 300 feet apart along six traverses across the valley. The complementary topographic survey, necessary for the gravity reductions, also provided accurate locations and levels for the exploratory bores. Bouguer anomaly profiles were computed using elevation correction factors ranging from 0.06 to 0.073 mgl/ft. The latter value was adopted as near correct on the basis of least correlation with topography and is equivalent to a surface density of 1.6 gms/cc. Density measurements were also made on samples of the various rock types in the area.

Early drilling results from bores along Line 1 indicated that the original assumption could be erroneous, and the interpretation of the gravity profiles was re-oriented to satisfy the existing geological data. The correlation of gravity highs with the thicker calcrete suggested that the gravity configuration could be due to variations in the thickness of calcrete, and a model, based on the drilling information and not unreasonable density difference of 0.4 gm/cc., gave a theoretical curve in close agreement with the residual gravity profile. The remaining profiles were interpreted accordingly and presented in a preliminary report.

Whilst this plausible solution was substantiated in part by subsequent drilling many discrepancies between the bore data and gravity predictions indicate that the interpretation is far more complex than anticipated.

Strata logs of the bores show that many of the basic assumptions required for a simple interpretation are untenable. For instance, the weathered materials in which most bores terminated indicate that the bedrock is by no means uniform and may be derived from the Wittenoom Dolomite (2.68 gms/cc), Marra Mamba Iron Formation (2.53 gms/cc), or the Roy Hill Shale (2.28 gms/cc). Further, the calcrete which extends over most of the area, exhibits a variable composition ranging from the massive form, with a measured density of 2.51 gms/cc, to highly porous and water filled kankar with a bulk density perhaps as low as 1.6 gms/cc. As none of the bores penetrated fresh bedrock, the effects of the bedrock relief must also be added to the list of factors influencing the Bouguer gravity. These factors cannot be separated with any confidence and any interpretation of the gravity results must be considered highly speculative.

CONCLUSIONS

The relatively complex environment of the Millstream area precludes a realistic interpretation of the Bouguer gravity. Even with all the drilling information now available, it is not possible to reduce the number of variables to the stage where even qualitative predictions of the subsurface geology can be made. The failure of the method in this locality does not rule out its application elsewhere and each area should be considered on its own merits.

GEOLOGY AND EXCAVATION METHODS IN CUTTINGS

by F. R. Gordon

ABSTRACT

The manner in which a rock mass is excavated is strongly influenced by the site geology, especially the geological weaknesses. This affects the successful development of the site, which is critical in the case of highway or railway cuttings where close adherence to a designed shape is necessary for both economy and stability.

The slope of the cutting walls, the provision of benches or berms, and the digging of vertical-walled drainage ditches at the toe of the slope are all design matters for which geological conditions must be known. The presence of sheet and cross joints, and variations in weathering and rock type are masked geological defects which often have strong influence on the final shape of the excavation. The pattern of blast holes, the number of repeated shocks, and the technique of presplitting are blasting methods liable to cause damage if used in the wrong environment.

INTRODUCTION

A standard (4 foot 8½ inch) gauge railway 390 miles long is under construction from Kalgoorlie to Fremantle and Kwinana, through the iron ore deposits of Koolyanobbing. Most of the cuttings evaluated are situated on the Avon Valley Deviation which follows the Swan-Avon river valley through a dissected, uplifted, granite block of the Darling Range between Northam and Midland Junction (Gordon, 1968).

GEOLOGY AND PLANNING

Quarrying and cuttings

A railway cutting ideally has smooth slopes at precise angles, whereas in an open quarry the concern is to remove rock, not to shape walls. Contractors tend to regard a cutting as a quarry to supply rock to adjacent fills, and this fundamental difference in outlook means that the finished product is at best a compromise. The system of payment usually offers no incentives for precisely defined shapes, and bulk excavation methods modified by the skill and experience of the contractors' forces and the experience and persistence of the principals' representatives are all factors influencing the final shape.

Slope angles

The basis of selection of slope angles for various cuttings along the standard gauge route ranged from calculations by computors in London programmed on the notion of solid homogenous granite to full-scale joint surveys and rock-mechanics analysis. The use of rock-mechanics methods was tempered by the presence of folded structures, and of curved sheet joints not amenable to the mathematical methods available. A further insufficiency was the fact that rock-mechanics methods assumed no effect from blasting on slope stability. In practice this factor was often critical.

Berms

Berms are benches to arrest falling rock on a high slope. Their production proved a major problem because the berm surface once formed part of the floor of a higher lift damaged by blasting (rose of joints). Excavation of the lower lift has caused further breaks, and where the final shape has been achieved by trimming holes, the outer edge of the berm has been attacked three times. (Plate 6A.) Where sheet joints are within five feet of a berm, it is not possible to retain the berm; likewise where there is dominant local vertical jointing (Gordon, 1966).

Ditches

The provision of a drainage ditch immediately at the foot of a batter slope is a negation of the purpose of designing batter slopes at a certain angle, as the vertical slot over-steepens the toe at its weakest point (Gordon, 1967).

Conceptions

The quantity and quality of information available or gained by the contractor governs the method that is proposed, and thus the final cost of the work. Fundamental misconceptions are often made such as equating a museum specimen material 'granite' with the actual rock mass of varying composition, affected by weathering and with many structure defects. Initial engineering reconnaissances are often coloured by examining topographically prominent outcrops of resistant rock, whereas the weakest rocks are often not seen.

GEOLOGICAL STRUCTURES AND EXCAVATION

Influence of cross joints

Cross joints are steeply dipping joints that intersect the walls of the cutting at between 45° and 90°. Prominent joints striking across a cutting pose few problems if the joints are closed, and there are no intersections by other big joints. Control of open-cross-jointed rock is quite difficult, as the openings tend to channel the effect of the explosive, accentuating the opening, causing overbreak, and damaging the walls (Plate 5A).

A similar channelling effect occurs when prominent, cross joints are intersected. A 'toe' is often produced, and this is often subsequently reduced with further damage to the slope (Figure 5).

Influence of sheet joints

In Western Australia, sheet joints exercise a profound influence on the condition of granite masses, and on the stability of excavations in them (Gordon, 1968). A further effect of these master joints is on the control of blasting. The incidence of sheet joints is greatest close to the rock surface; in the first 5 feet joints may occur every foot. This means a restriction is imposed on the height to which a blast hole may be loaded. In addition, these joints control the movement of water through the rock mass, which in turn controls the amount of chemical weathering. If the lower joint surface is impervious, the rock between the rock surface and the joint may become completely weathered, leaving an abrupt transition to fresh rock. Alternately, the rock on either side of the joint plane may be completely reduced to a sandy clay, enclosed in only slightly weathered rock. Those near-horizontal differences in weathering mean that large overhangs are often developed on blasting, where softer rock is overshot, usually in the top 10 feet of the cutting (Plate 5B).

Sheet joints also often determine whether a berm or bench can be successfully produced.

Overshooting the toe of a batter

At the toe of a rock slope, either at the foot of a cutting or at a berm, there are high concentrations of stress. Consequently, weakening of the slope by overbreak and over-steepening accentuates the possibility of slope failure. Overshooting the toe may be caused by faulty excavation methods, or by unknown variations in site conditions, such as:

(1) the presence of softer bands of rock either as a change of rock type or from physical or chemical weathering, may allow the toe to be overshot;

(2) the blast holes may be overloaded or the blasting pattern unsuitable for the rock type, e.g. vertically foliated rock across the cutting will break back more readily than massive rock;

(3) the method of securing the shape may be faulty with regard to rock type. e.g. box excavation followed by angled trimming shots may be preferable to block excavation or pre-splitting. (Figure 6)

(4) a pre-existing structure may guide the explosive effect (Plate 6A);

(5) a slope may be left at an overflat angle because of layout or drilling variations, and later trimming shots of necessity make the lower part of the slope oversteep (Plate 6B);

(6) a vertical drainage ditch may be excavated at the toe of the slope.

Variations in rock type

Where the rock type is changing frequently, as in a vertical, banded gneiss sequence, the response of each rock type to a set pattern of blasting varies greatly. This means that if the pattern of holes and the loading are not varied, some of the bands will be overshot, with the batters sustaining damage, while in other sections, the rock may be undershot, leaving a toe, often to be reduced with further damage to the batter. The variety of rock types is often accentuated by chemical weathering, and folding, faulting, or jointing has often emphasised differences of mechanical properties.

During the early stages of excavation, it is not always possible to predict with certainty the composition and condition of the next slice to be excavated, and uniform loading of shot holes means that softer and weathered areas are overloaded and the batters are damaged. At depth, in a second lift for example, the nature of the rock to be excavated can often be predicted with some accuracy from observations of the cutting walls and floor, and overshooting can be minimized by lighter loading of holes and variations of the blast hole pattern.

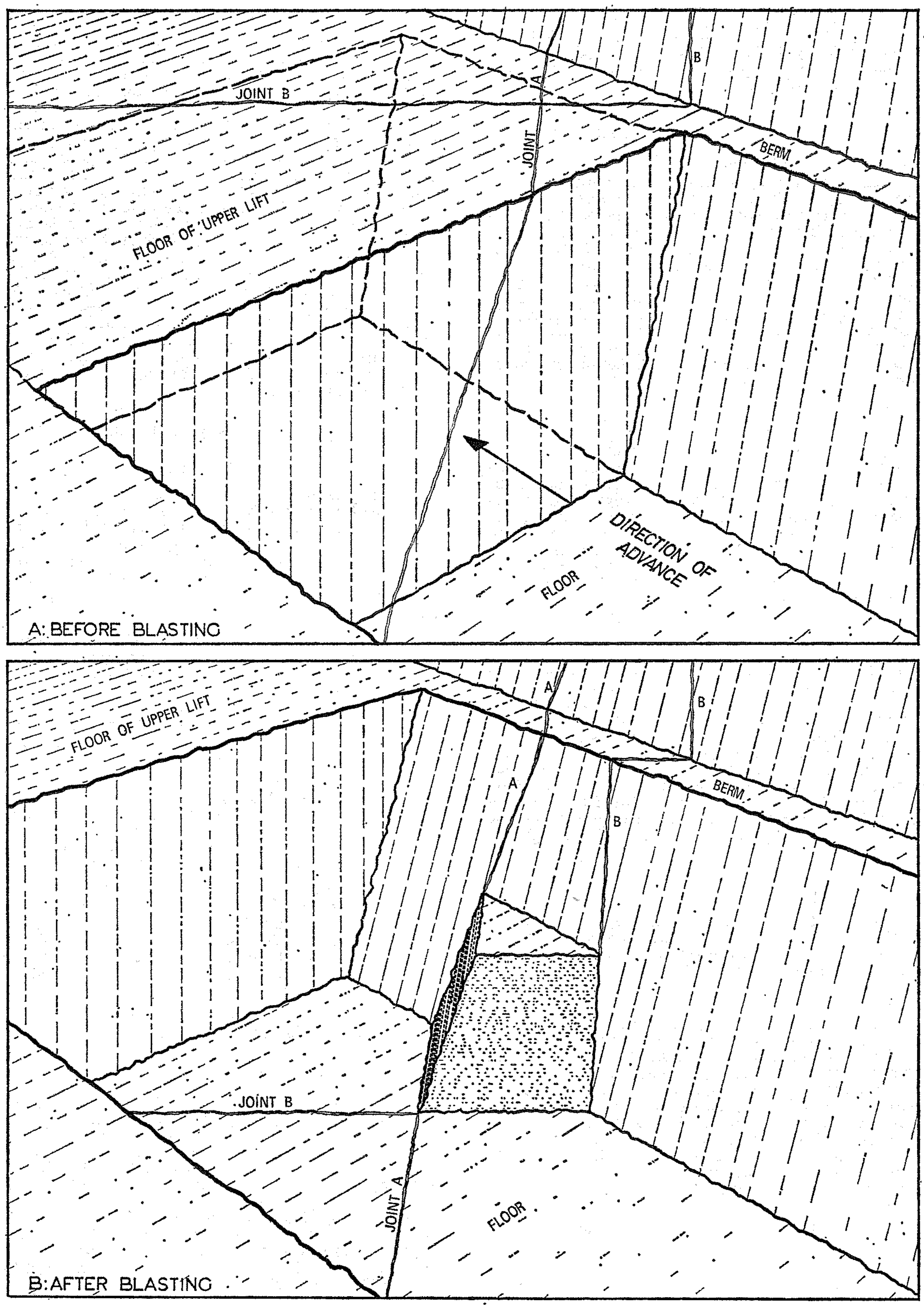
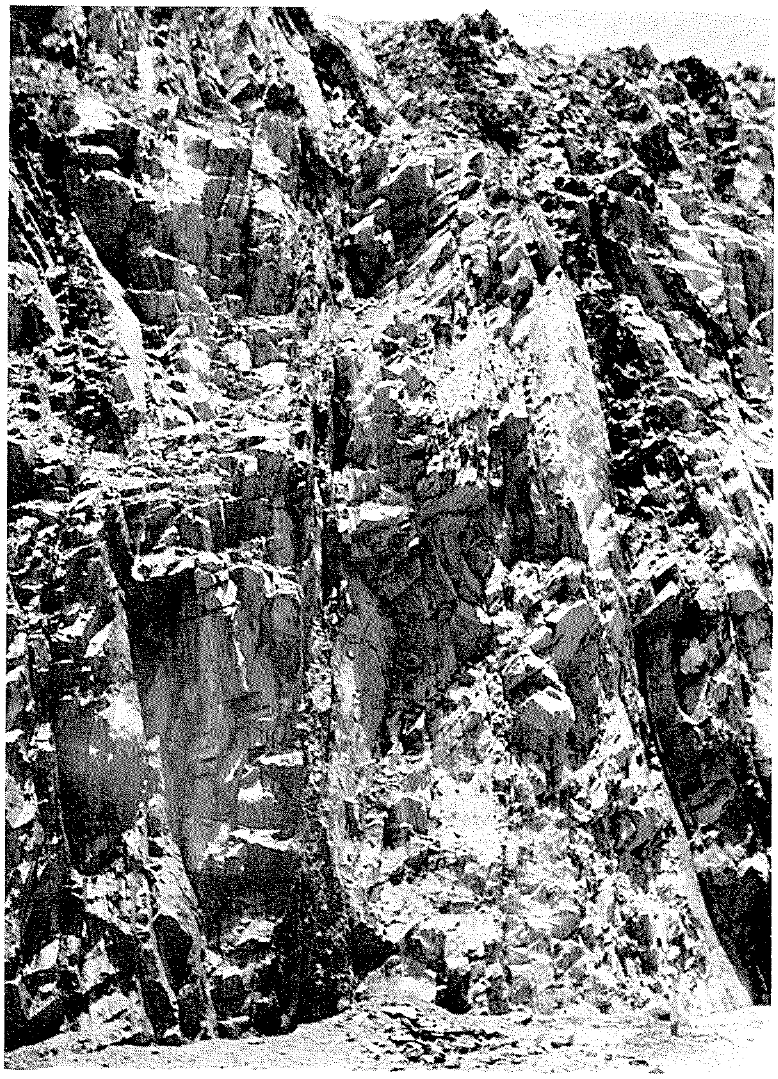


Figure 5. Toe formed by cross joints during cutting excavation. Standard Gauge Rail Project.



A. Overbreak caused by the channelling effect of open cross joints, in this case foliation joints; FN 1239.

B. Prominent sheeting causing large overhangs after blasting. Abrupt transition from weathered to fresh rock because of control of water movement on the top sheet joint; FN 1240.

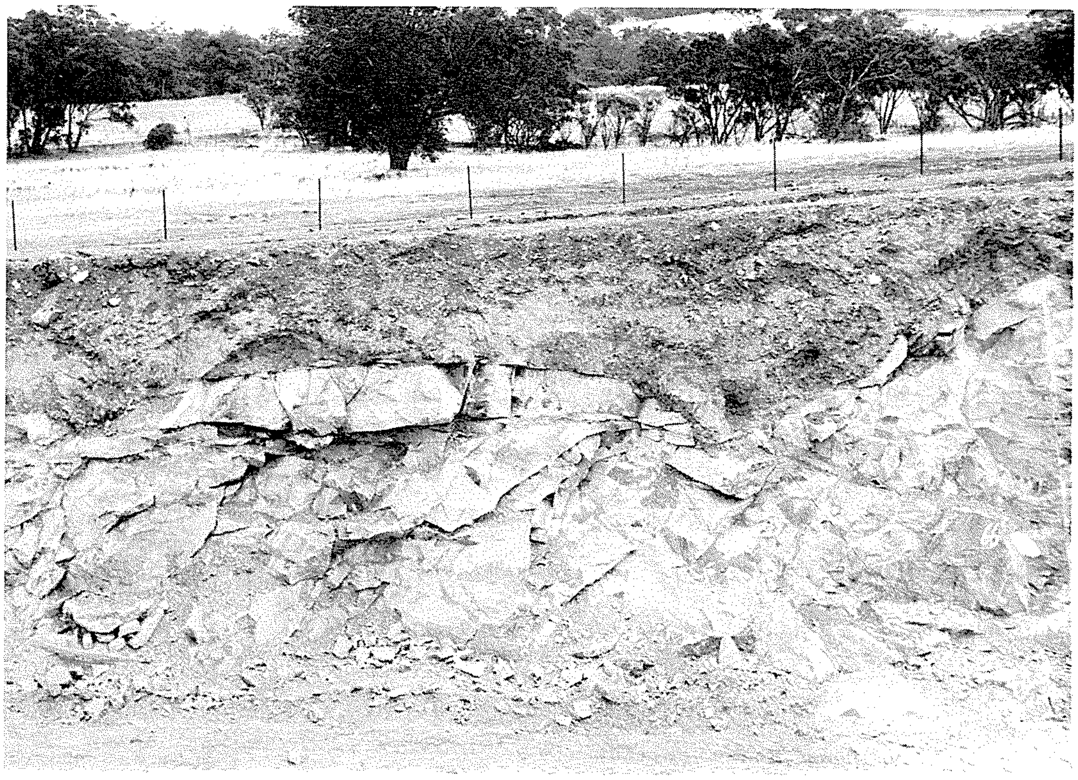
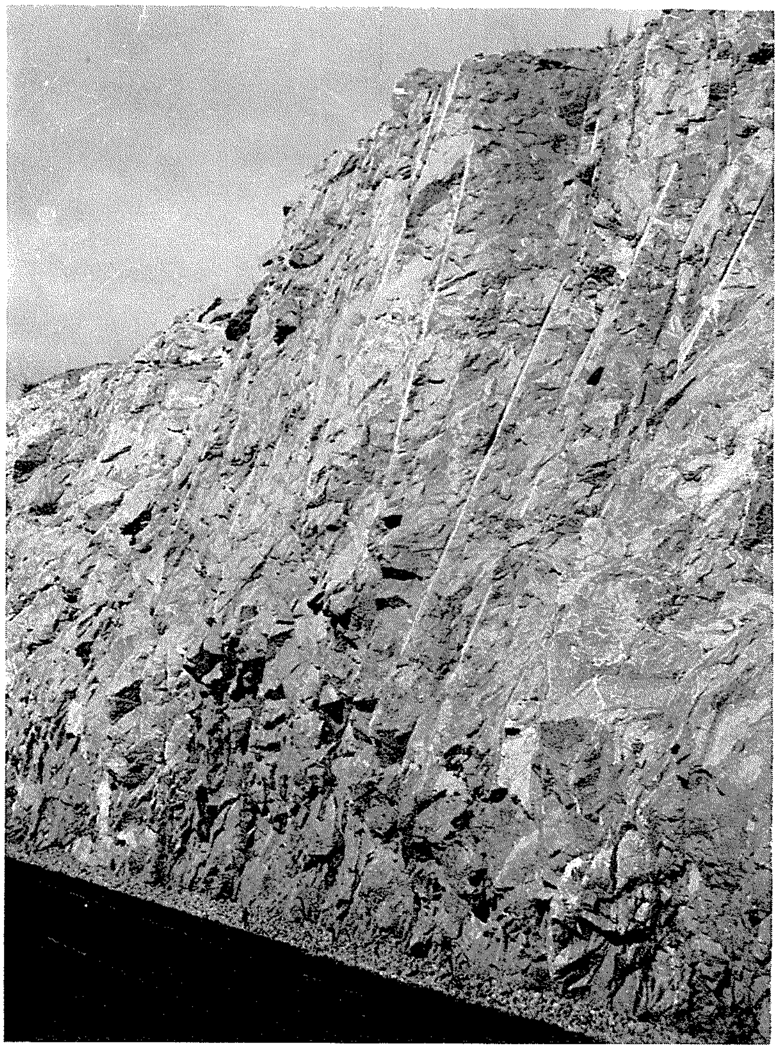


PLATE 6

A. A steeply dipping joint plane has caused overbreak at the toe of a batter. Note also the loss of the berm edge, now filled with rubble, because of numerous blasting cycles; FN 1241.

B. Overflat slope has been reshot at toe to give proper clearance. Oversteep toe is now highly stressed; FN 1242.



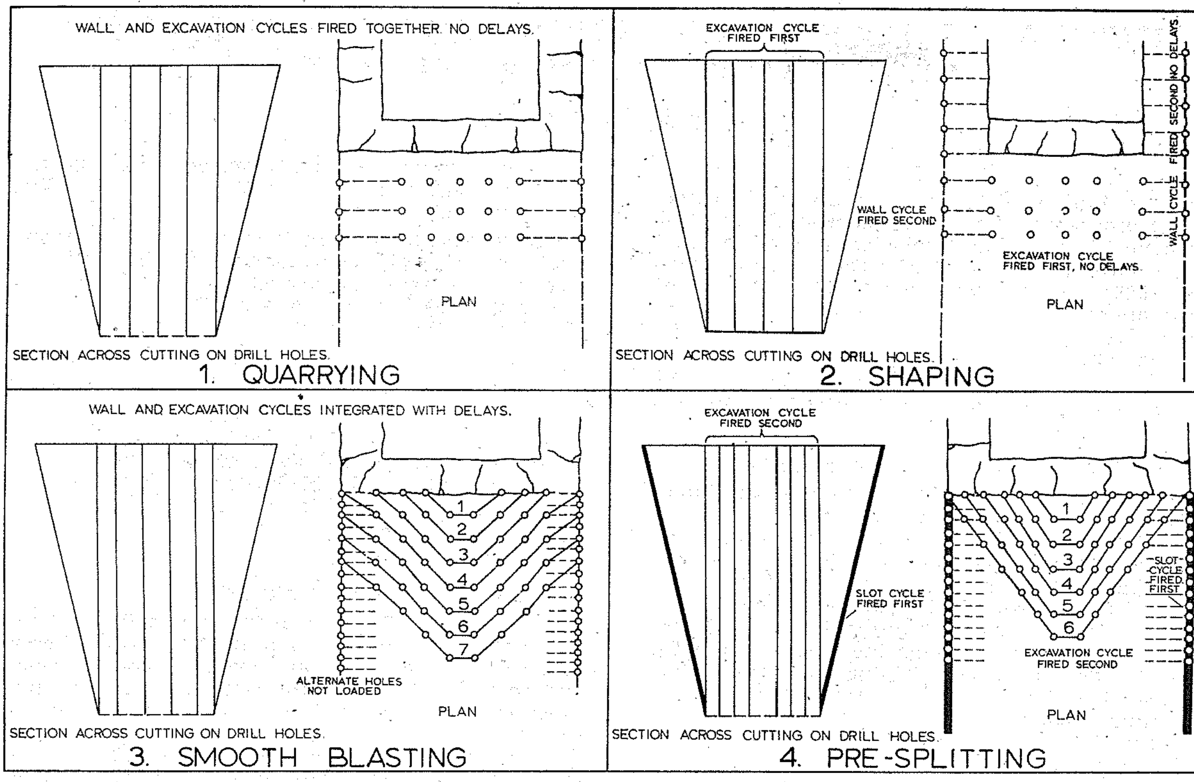


Figure 6. Standard Gauge Rail Project, methods of shaping cut walls. All numbers on the plans refer to millisecond delay intervals. (Drawing not to scale.)

BLASTING METHOD AND GEOLOGY

Variation of method

It has been emphasised that minor variations in the hole pattern and loading of holes are essential to meet the geological variations of a site. Changes in excavation methods are desirable and are often necessary where weathered rock may be removed with scrapers in the initial stages with a minimum of blasting. It is equally necessary to affirm that any major alteration to the blasting procedure should not be carried out until all the effects of site geology have been considered. The bottom lift of a deep cutting is no place for experiments, as the implications of failure are too serious.

Attempts are often made to retain scrapers by the increased use of explosives as fresher rock is encountered at depth. Often in the attempt to keep rock pieces at manageable size, the rock is overshot, and the slopes suffer.

Pre-splitting

Pre-splitting is a modern shaping technique in which the boundaries of the excavation are defined by a slot, blasted out before the site is excavated by normal methods. (Figure 6) The formation of an opening on the batter line undoubtedly serves to protect the face from damage resulting from the geological defects outlined above. However, in certain cases along the standard gauge route it was found that the formation of the slot caused such damage to the walls as to negate the benefits. This was particularly true in fresh, medium to fine-grained granite outcrops of small topographic relief, divided by defined sheet joints, where the pre-splitting method had to be discontinued. It was found that numerous individual blocks of rock, that either were separated by normal jointing or stood out from the cutting walls, had steeply dipping exfoliation-type cracks at the rear, parallel to the batter slope. It is not quite clear whether the cracking parallel to the initial shot was produced at the time of slot formation or not, but observation seems to indicate that these are post-excavation relaxation features.

Rock fabric and blasting repetition

When a choice of blasting patterns is available, consideration should be given to the nature of the rock fabric, and whether it would break down during several cycles of blasting, and thus make it preferable to shape and excavate in one operation, rather than with several. In the illustration, some of the blast-hole patterns used in excavating the railway cuttings on the standard gauge line are given (Figure 6).

In cut areas where the walls were of highly to moderately weathered granite, it was found that shaping and excavation were best done in one cycle, rather than by block excavation followed by shaping. Likewise, in outcrops of coarse-grained porphyritic granite, it was found that cracking of the quartz grains allowed accelerated breakdown of the rock under successive blasting cycles.

CONCLUSION

Geological factors must be taken into account during excavation of cuttings just as much as in the exploration, feasibility, and design stages. The problems created also call for further geological work during the maintenance period.

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REGIONAL GEOLOGICAL IMPLICATIONS, ROCKY POOL DAM SITE INVESTIGATIONS, CARNARVON BASIN.

by P. M. Hancock

INTRODUCTION

During 1967 a detailed mapping and auger-drilling programme was undertaken at Rocky Pool, Gascoyne River, by the Geological Survey in association with the Public Works Department (Hancock, 1968). In addition to information relevant to the appraisal of a dam site, several features of regional geological significance emerged from the investigation.

Except for the Toolonga Calcilutite and the Nadarra Formation all units described in this report are informal units.

CRETACEOUS—TERTIARY BOUNDARY

Continuous marine sedimentation from Upper Cretaceous into Paleocene times characterizes much of the western part of the Carnarvon Basin. However, at Rocky Pool and on Brickhouse Station no marine Tertiary material has been found, and unfossiliferous presumed-Tertiary sediments, probably of deltaic origin, unconformably overlie Upper Cretaceous (Campanian) marine clays, (Plate 7). At Rocky Pool an auger-drilling programme has demonstrated that the unconformity between the Campanian Toolonga Calcilutite and the overlying unfossiliferous presumed-Tertiary material is one of strong relief.

The presence of thin gypsum deposits overlying the thickest sections of the green clay (Kutg of Toolonga Calcilutite) at the dam site indicates an emergence of the marine sediments and the onset of arid, evaporative conditions similar to that of Lake MacLeod today. The green clay (Kutg) was probably eroded during the early Tertiary as a result of uplift and river rejuvenation. The unfossiliferous presumed-Tertiary sediments overlying the green clay are probably river alluvium.

ANTICLINE AT ROCKY POOL IN RELATION TO ANTICLINES FARTHER NORTH IN CARNARVON BASIN

The western central part of the Carnarvon Basin, which is bounded to the east by the Kennedy Range, has been subjected to north-south faulting along which the western blocks were downthrown as much as 10,000 feet after the Permian period but before the onset of Cretaceous times. During the Cretaceous period, marine sandstones, shales, and clays were deposited on the downfaulted blocks. Sedimentation continued with interruptions into the Tertiary period, with the deposition of marine and deltaic sediments. Late Cretaceous east-west compression which continued through Miocene to possibly Pleistocene and even post-Pleistocene times, reversed the original displacement, uplifting the western blocks. However the Upper Cretaceous, presumed-Tertiary, and probable Quaternary sediments which mantled the faulted older rocks were merely folded into superficial asymmetrical anticlines with north-south axes parallel to the strike of the underlying fault planes. Seismic investigations and exploratory drilling north of latitude 24° 30′S have found several asymmetrical anticlines, each one with a north-south axis parallel to and just west of a fault plane, showing reversal of movement by post-Late Cretaceous uplift. The anticlines generally have dips of up to 10° on the western flanks and steeper dips of up to 30° on the eastern flanks, with a core of Upper Cretaceous sediments, and envelopes of Tertiary and Quaternary sediments.

It seems likely that these superficial anticlines, which extend in en echelon arrangement from Cape Range to latitude 24° 30′ S, probably continue southwards at least to the Gascoyne River, but are masked by Pleistocene to Recent superficial cover.

The small anticline at Rocky Pool has not been previously recorded and is probably a part of the en echelon system. A line of travertine outcrops trends northeastwards from Rocky Pool for a distance of 30 miles, apparently representing a northeasterly continuation of the Rocky Pool anticline (Condon, 1962).

Future seismic work in this area should demonstrate a southerly continuation of the anticline system with axes subparallel to the coastline in the west, and parallel to the "Basement Ridge" (Condon, 1965) in the east.

CORRELATION OF THE BROWN SANDSTONE (QT) WITH THE NADARRA FORMATION

The brown sandstone unit (QT) has a lithology comparable with the type section of the Nadarra Sandstone as described by Condon, (1967). The Quaternary age of the Nadarra is in keeping with the stratigraphical position of the brown sandstone which unconformably overlies the folded lateritized red siltstone (Tk).

LATERITIZATION AT ROCKY POOL

The presumed-Tertiary sediments at Rocky Pool demonstrate a lateritization profile with a lower pallid leached zone, an intermediate mottled zone, and an upper dark red lateritized ferruginous zone. Chemical analyses up the profile from the pallid leached zone to the lateritized ferruginous zone show an increase in iron from 1.81 to 4.18 per cent and aluminium from 2.01 to 6.20 per cent, and a reduction in silica from 89.4 to 74.8 per cent. Petrological examination of the lateritized red siltstone (Tk) and the white siltstone (Ts) reveals almost identical heavy mineral assemblages of detrital tourmaline and zircon, suggesting that these two units are the lateritized and leached equivalents of the same original siltstone.

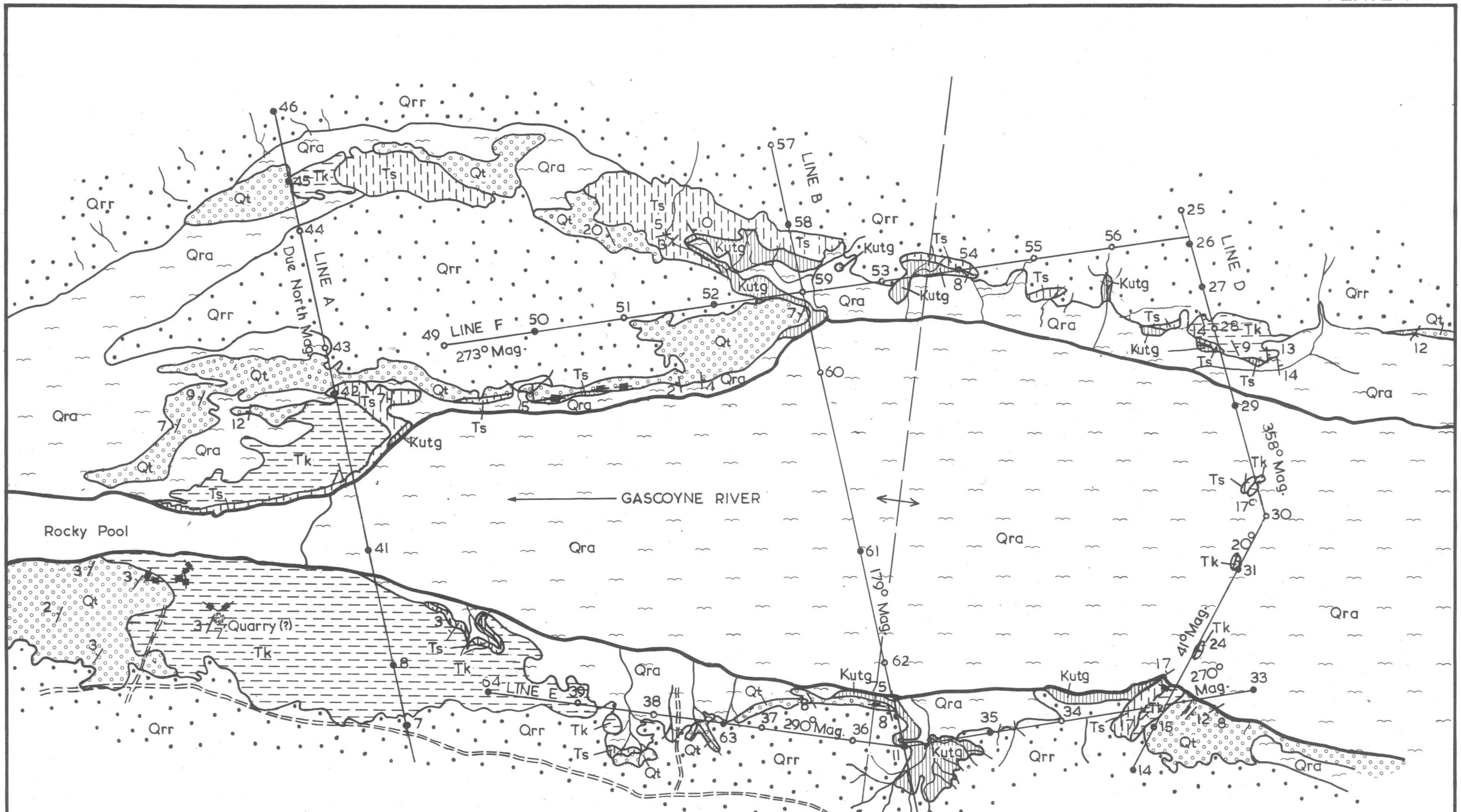
The evidence suggests an upward movement of iron and aluminium to the lateritized zone from the pallid zone. The silica 'billy' capping on the lateritized siltstone suggests an upward movement of silica from that bed.

The red lateritized siltstone unit (Tk) becomes a leached white siltstone where it dips below the present-day water table, while the overlying silty soils appear to be undergoing present-day lateritization. This suggests the formation of the lateritized red siltstone (Tk) by an upward movement of aluminium and iron in solution, with the base of the lateritized zone corresponding with the lowest seasonal level of the water table.

The fact that the lateritization of the siltstone pre-dates the folding of the anticline is shown by boudins, necking, and shearing-out of beds caused by the differential movement of the competent lateritized red siltstone (Tk) over the relatively incompetent white siltstone (Ts). Where differential movement has caused shearing along the contact between the pallid white siltstone and the lateritized red siltstone, the intermediate mottled zone is thinned or absent. A low-angle shear zone on the left bank of the Gascoyne River at line D, which was probably caused by a differential movement on the steeply dipping eastern limb of the asymmetrical anticline, cuts both the pallid white siltstone and the lateritized red siltstone. Thus, plastic and brittle deformation caused by fold movements post-date the lateritization. The lateritization has increased the relative competency of the lateritized zone at the expense of the now less competent underlying pallid zone. Furthermore, the leaching out of the lateritized red siltstone to a pallid siltstone where it dips below the present water table, and the angular uncomformity between the laterized red siltstone (Tk) and the overlying brown sandstone (Qt), indicates that at least one period of anticlinal folding occurred after the lateritization of the siltstone.

The brown sandstone (Qt) on the eastern limb of the anticline dips at 8° to 12°, while the lateritized red siltstone, which it overlies, dips at 14° to 24°. This suggests a second and later period of folding of the laterized red siltstone.

PLATE 7



REFERENCE

QUATERNARY	Qra	Red, yellow, sandy, silty river deposits thin, red, silty, alluvial cover.
	Qrr	Red, silty, sandy dune material; thin pebble wash and consolidated soil cover.
	Qt	Brown sandstone and grit with minor conglomerate
		UNCONFORMITY
TERTIARY	Tk	Lateritized red siltstone (lateritized zone)
	Ts	White siltstone (pallid zone)
		UNCONFORMITY
CRETACEOUS	Kutg	Green calcilutite clay

SYMBOLS

- Anticlinal axis
- 12 Bedding—strike and dip
- 80 Jointing—strike and dip
- Outcrop boundary
- ○46 P.W.D. Gemco auger drillhole—Proposed
- ●46 P.W.D. Gemco auger drillhole—Completed
- Depression showing depth
- Track

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ROCKY POOL DAM SITE
SIMPLIFIED GEOLOGICAL PLAN

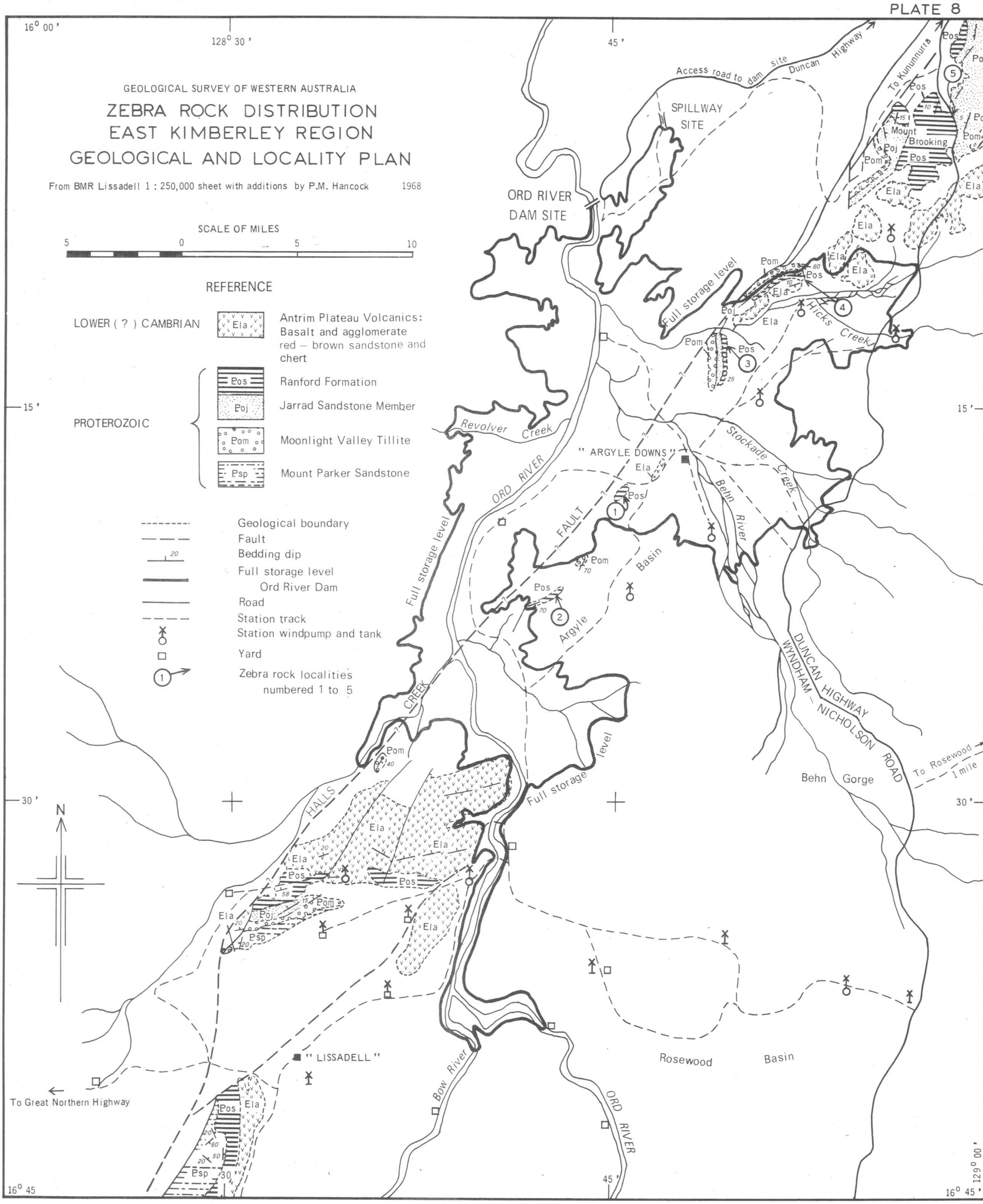
To accompany report by P.M. Hancock, 1968.

SCALE OF FEET

600 300 0 600 1200

10751

PLATE 8



10630

The age of the folding, if identified, would restrict the age range of lateritization and vice versa. Evidence from Giralia and Marrilla anticlines suggests up to four periods of folding viz (1) between upper Eocene and lower Miocene, (2) during lower Miocene, (3) between lower Miocene and Pleistocene, (4) and in the Pleistocene or post-Pleistocene time. If any of these fold movements were synchronous with the folding at Rocky Pool, then folding of the Quaternary brown sandstone (Qt) would have been in the Pleistocene or post-Pleistocene.

In the Carnarvon Basin lateritization is considered to have commenced in mid-Eocene (Condon, 1967), thus accommodating a folding of the lateritized red siltstone (Tk) in post-Eocene times.

The major fold movements at Cape Range and Rough Range, and Giralia and Marrilla anticlines, occurred between the Pliocene and post-Pleistocene periods, that is in the latter part of the lower Miocene—Pleistocene (3), and during the Pleistocene—post-Pleistocene (4) periods of folding. A major fold movement is required to account for the plastic and brittle deformation of the sediments at Rocky Pool. If the brown sandstone (Qt) which unconformably overlies the lateritized red siltstone (Tk) was folded during the Pleistocene—post-Pleistocene (4), then the siltstone (Tk) was probably initially folded in the latter part of the lower Miocene—Pleistocene period.

There is no suggestion or evidence of more than two periods of Tertiary—Quaternary folding at Rocky Pool, and it is probable that only the last two of the above four periods of folding affected the area. Thus the lateritization of the siltstone (Tk) predates a folding which appears to have occurred during the latter part of period (3) above, namely between Pliocene and post-Pleistocene.

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LOCATION AND INVESTIGATION OF ZEBRA ROCK OCCURRENCES, EAST KIMBERLEY REGION

by P. M. Hancock

INTRODUCTION

Zebra rock from Argyle Downs Station provides the basis for a small but valuable souvenir and jewellery industry which is mainly centred at Kununurra. The striking, red and white banded rock presents interesting problems concerning its formation and distribution. It is currently believed that the known occurrences of zebra rock will be submerged beneath the full storage level of the Ord River dam. However, as shown on the accompanying plate, most of the occurrences will remain above water.

The Ranford Formation (Dunnet and Plumb, 1964), which contains the zebra rock, was traced along its strike for 35 miles in a south-easterly direction from Mount Brooking. The known occurrences 1, 2, and 5 (as marked on Plate 8) were located and examined, and two further occurrences, marked 3 and 4, were discovered.

During the dry season, localities 1 and 2 are accessible by graded track, and localities 3 and 4 can be reached by four-wheel-drive vehicle. Locality 5 is on a scarp slope alongside the Duncan Highway. Zebra rock may occur in the southern continuation of the Ranford Formation on to Lissadell station, an area normally accessible during the dry season from the Great Northern Highway. It is also likely that the Ranford Formation occurs north-northeastward from Mount Brooking on Newry Station in the Northern Territory.

PREVIOUS RECORDINGS AND INVESTIGATIONS

Specimens of zebra rock were described by Blatchford (1927), Larcombe, (1925 and 1927), and Hobson (1930). Blatchford thought that the banding could be explained by a leaching out of iron oxide to produce white bands from an originally all red rock, but Larcombe invoked a deposition of alternate layers of ferruginous and non ferruginous material. Hobson refuted Larcombe's explanation on the grounds that the heavy minerals present in the rock are not concentrated in the red bands. He gave a detailed petrological description of several selected specimens and chemical analyses illustrating the similar composition of red and white bands, apart from a 5:1 iron ratio in favour of the red bands.

Geidans (written communication) working mainly on specimens from the Geological Survey of Western Australia and on some held at the University of Western Australia, suggested that the banding was due to ripple marking, with iron-rich detrital particles accumulating in ripple mark troughs by gravitational separation. He explained the branching and break up of the red beds into rods and blebs by the irregular pattern made by troughs of ripple marks on a sea floor.

OBSERVATIONS ON THE FIELD OCCURRENCE AND DISTRIBUTION OF ZEBRA ROCK

Attempts to explain the formation of banding features in zebra rock appear to have been based on the examination of selected hand specimens. The investigation of the rock 'in situ', and its field relationships, produces evidence which renders previous explanations largely untenable.

Zebra rock occurs as sparsely distributed elongate lenses in the upper part of the Ranford Formation, which consists of thinly bedded to finely laminated ferruginous siltstone and fine-grained ferruginous sandstone. The extremely fine bedding is even and continuous, and no ripple marks were found. The lenses are up to 2 feet thick and 10 to 20 feet long, and taper laterally into dark red-brown to purple-brown siltstone or sandstone. Bedding planes are continuous laterally from the zebra rock lenses into the surrounding rock. The iron-rich bands are mainly parallel or subparallel to bedding, but occasionally the banding is broken into rods, blebs, and short bands almost perpendicular to the main banding. It is significant that these deviations away from the main banding occur in the vicinity of joint planes and are aligned parallel or subparallel to those joint planes. It is apparent from field evidence that the disposition of the bands has been controlled by bedding and joint planes, which are the only major physical anisotropic features in this rock.

The red and white banding can be seen to merge laterally and vertically into red-brown or purple-brown rock, uniform apart from small pallid lenses up to an inch long, and significantly not the same colour as the red bands. It is thus unlikely that the red and white bands are representative of the original colouring or composition of the rock, and it is suggested that there has been a post-depositional mobilisation and concentration of iron by rhythmic precipitation from a pervasive aqueous-colloidal pore solution, controlled by bedding and joint planes.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1968

by P. E. Playford and G. H. Low

INTRODUCTION

The principal events in oil exploration in Western Australia during 1968 were the discovery of gas at Mondarra in the Perth Basin and of oil in Legendre No. 1, the first offshore well in Western Australian waters, on the Northwest Shelf. The Mondarra gas field may have commercial prospects, but it seems that at present Legendre is non-commercial.

The amount of exploratory drilling during 1968 increased as compared with the previous year, though the number of wells completed was less. A total of 10 test wells and 14 stratigraphic wells were completed in 1968 and 4 test wells were drilling on December 31. The total footage amounted to 164,637 feet. This compares with 17 test wells and 11 stratigraphic wells completed, and a total footage of 115,970 feet in 1967.

Geophysical exploration during the year was at a lower level than in 1967. Seismic operations amounted to 19.62 party months (land) and 17.65 party months (marine) during 1968 compared with 53.4 party months (land) and 15.0 party months (marine) the previous year. During 1968, 4.42 party months of gravity surveys were conducted compared with 14.25 party months in 1967. No aero-magnetic surveys were carried out, but 3.69 party months of magneto-telluric surveys were conducted, compared with 6,478 line miles of aero-magnetic surveys and no magneto-telluric surveys in 1967. Field geological surveys increased from 22.5 geologist-months in 1967 to 30.0 in 1968.

OIL HOLDINGS

The positions of offshore exploration permits at the end of 1968 are shown on Plate 10. Details of these concessions are as follows:

Exploration Permits

Number	No. of graticular sections*	Expiry date of current term	Registered holder or applicant
WA–1–P	364	14/11/74	Woodside (Lakes Entrance) Oil Co. N.L., Shell Development Australia Pty Ltd, B.O.C. of Australia Ltd
WA–2–P	381	14/11/74	West Australian Petroleum Pty Ltd
WA–7–P	135	pending	do. do. do.
WA–8–P	18	pending	Coastal Petroleum N.L.
WA–9–P	56	pending	do. do.
WA–10–P	36	pending	do. do.
WA–12–P	5	pending	Associated Australian Oilfields N.L.
WA–13–P	387	29/8/74	West Australian Petroleum Pty Ltd
WA–14–P	396	29/8/74	do. do. do.
WA–15–P	352	pending	Australian Aquitaine Petroleum Pty, Arco Limited
WA–16–P	354	pending	do. do. do.
WA–17–P	379	pending	do. do. do.
WA–18–P	322	pending	do. do. do.
WA–19–P	142	pending	Alliance Oil Development Australia N.L.
WA–20–P	34	10/10/74	West Australian Petroleum Pty Ltd
WA–21–P	239	14/11/74	do. do. do.
WA–22–P	81	3/10/74	do. do. do.
WA–23–P	398	3/10/74	do. do. do.
WA–24–P	208	17/10/74	do. do. do.
WA–25–P	256	16/10/74	do. do. do.
WA–26–P	400	22/12/74	Canadian Superior Oil (Aust.) Pty Ltd, Australian Superior Oil Company Ltd, Phillips Australian Oil Company, Sunray D.X. Oil Company
WA–27–P	294	pending	do. do. do.
WA–28–P	375	pending	Woodside (Lakes Entrance) Oil Company No Liability, Shell Development (Australia) Proprietary Ltd, B.O.C. of Australia Ltd
WA–29–P	400	pending	do. do. do.
WA–30–P	400	pending	do. do. do.
WA–31–P	400	pending	do. do. do.
WA–32–P	395	pending	do. do. do.
WA–33–P	389	pending	do. do. do.
WA–34–P	397	pending	do. do. do.
WA–35–P	400	pending	do. do. do.
WA–36–P	57	pending	do. do. do.
WA–37–P	118	pending	do. do. do.
WA–39–P	104	pending	BP Petroleum Development Australia Pty Ltd, Abrolhos Oil N.L.
WA–40–P	102	pending	BP Petroleum Development Aust. Pty Ltd, Hawkstone Minerals Ltd
WA–41–P	33	pending	Coastal Petroleum N.L.

* A 'Graticular Section' is a rectangular area of 5 minutes latitude by 5 minutes longitude and of approximately 25 square miles extent.

Permits to Explore

Number	Area (square miles)	Expiry date of current term	Registered holder or applicant
27H	12,900	31/12/68	West Australian Petroleum Pty Ltd
28H	15,100	31/12/68	do. do. do.
30H	82,500	31/12/68	do. do. do.
106H	11,800	28/9/69	Westralian Sands Limited
127H	7,250	28/3/69	Alliance Oil Development Australia N.L.
151H	10,710	7/2/69	Beach-General Exploration Pty Ltd
152H	8,720	7/2/69	do. do. do.
153H	9,770	7/2/69	do. do. do.
172H	6,150	30/3/69	Coastal Petroleum N.L.
173H	12,250	30/3/69	do. do.
174H	6,100	30/3/69	do. do.
175H	4,100	30/3/69	do. do.
177H	6,050	30/3/69	do. do.
193H	2,750	5/2/69	Hawkstone Minerals Ltd, BP Petroleum Development Australia Pty Ltd
205H	16,700	17/9/69	Alliance Petroleum Australia N.L.
213H	10	20/6/69	Woodside (Lakes Entrance) Oil Co. N.L., B.O.C. of Aust. Ltd, Shell Development (Aust.) Pty Ltd
217H	3,350	30/5/68	West Australian Petroleum Pty Ltd
221H	950	28/7/68	Australian Aquitaine Petroleum Pty Limited, Arco Ltd
226H	31,900	6/4/68	West Australian Petroleum Pty Ltd
227H	11,400	6/4/68	do. do. do.
228H	2,200	13/5/68	do. do. do.
235H	19,850	21/1/69	Canadian Superior Oil (Aust.) Pty Ltd
236H	2,600	3/2/69	Abrolhos Oil No Liability, BP Petroleum Development Aust. Pty Ltd
238H	1,190	9/1/69	B.O.C. of Australia Ltd, Shell Development (Aust.) Pty Ltd, Woodside (Lakes Entrance) Oil Co. N.L.
240H	3,050	14/6/69	Coastal Petroleum N.L.
251H	4,228	28/6/69	West Australian Petroleum Pty Ltd
253H	5,200	28/12/68	Westralian Sands Limited
259H	12,930	1/2/69	West Australian Petroleum Pty Ltd
260H	5,860	19/4/69	do. do. do.
261H	3,000	19/4/69	do. do. do.
263H	30	11/6/70	Associated Aust. Oilfields N.L.

Licenses to Prospect.

108H	200·000 (excluding Lyndon Loc. 42)	17/1/69	West Australian Petroleum Pty Ltd
111H	150·000	4/6/69	do. do. do.
115H	200·000	5/11/68	do. do. do.
119H	109·032	12/1/69	do. do. do.
121H	120·000	11/7/69	do. do. do.
122H	113·418	11/7/69	do. do. do.
123H	113·232	11/7/69	do. do. do.
124H	112·528	20/4/69	do. do. do.
125H	112·477	20/4/69	do. do. do.
126H	200·000	8/2/69	do. do. do.
130H	189·929	8/3/69	do. do. do.
132H	200·001	13/5/69	do. do. do.
133H	200·001	13/5/69	do. do. do.
140H	198·750	17/5/69	do. do. do.
145H	187·411	17/5/69	do. do. do.
146H	187·032	17/5/69	do. do. do.
147H*	135·500	17/5/69	do. do. do.
149H	200·000	14/7/69	do. do. do.
150H	200·000	18/10/69	do. do. do.
151H	194·367	5/7/69	do. do. do.
154H	160·200	13/12/68	Beach-General Exploration Pty Ltd
158H*	0·960	20/3/69	West Australian Petroleum Pty Ltd
159H*	1·440	20/3/69	do. do. do.
160H*	0·400	20/3/69	do. do. do.
161H*	8·960	20/3/69	do. do. do.
162H*	0·480	20/3/69	do. do. do.
163H*	0·320	20/3/69	do. do. do.
164H*	2·500	20/3/69	do. do. do.
165H*	1·920	20/3/69	do. do. do.
169H*	0·320	20/3/69	do. do. do.
171H	190·000	14/4/69	do. do. do.
172H	199·697	21/6/69	do. do. do.
173H*	2·200	9/8/68	do. do. do.
174H	190·000	28/7/69	do. do. do.
175H	200·000	10/8/69	do. do. do.
177H	200·000	20/12/69	do. do. do.
184H	200·000	4/4/69	do. do. do.
185H*	5·600	26/7/69	do. do. do.
186H*	7·040	14/8/69	do. do. do.
187H	193·440	13/8/69	do. do. do.
190H	100·000	2/10/69	do. do. do.
191H*	0·800	16/10/69	do. do. do.
192H	130·000	28/2/70	do. do. do.
195H*	6·560	16/1/70	do. do. do.
196H	150·640	11/3/70	do. do. do.
198H	197·980	27/2/70	do. do. do.
199H	200·000	8/8/70	Beach-General Exploration Pty Ltd

Licenses to Prospect—continued

Number	Area (square miles)	Expiry date of current term	Registered holder or applicant
200H	197·000	27/3/70	West Australian Petroleum Pty Ltd
202H*	0·320	27/3/70	do. do. do.
203H*	1·600	27/3/70	do. do. do.
204H*	6·880	27/3/70	do. do. do.
213H	196·418	27/3/70	do. do. do.
215H	199·961	7/10/70	do. do. do.
216H	198·372	7/10/70	do. do. do.

* Only the onshore area has been given for these Licenses to Prospect which are affected by Exploration Permits.

Petroleum Leases

Number	Area (square miles)	Expiry date of current term	Holder
1H	100	2/2/88	West Australian Petroleum Pty Ltd
2H	100	2/2/88	do. do. do.

DRILLING

The positions of wells drilled for petroleum exploration in Western Australia to the end of 1968 are shown on Plates 9, 11. Drilling was carried out during the year on the following permits:

EXPLORATION PERMIT WA-1-P

Exploration Permit WA-1-P (offshore) is held by Woodside (Lakes Entrance) Oil Co. N.L., Shell Development Australia Pty. Ltd., and B.O.C. of Australia Ltd., B.O.C. being the operating company. The permit covers the northernmost part of the Carnarvon Basin, on the Northwest Shelf. The first offshore well in Western Australian waters, Legendre No. 1, was drilled on this concession during the year. Oil flowed at a maximum rate of 1,014 bbl/day with 0.11 mmcf/day of gas on a drill-stem test of the interval 6,211-6,227 feet in Lower Cretaceous rocks of the "Barrow Group". However, the producing sand is thin and it is unlikely that the field can be developed commercially at this time. Details of the well are as follows:

Lengendre No. 1

Type: Test well.

Latitude and Longitude: 19° 40′ 16″S, 116° 43′ 57″E.

Elevation: W. D. — 170 feet, R. T. + 30 feet.

Commenced: 7th June, 1968.

Completed: 17th November, 1968.

Total depth: 11,393 feet.

Bottomed in: Jurassic.

Status: Non-commercial oil well, plugged and abandoned. A drill stem test of the interval 6,211 to 6,227 feet flowed oil at 1,014 bbl/day and gas at 0.11 mmcf/day through a 24/64-inch choke.

EXPLORATION PERMIT WA-13-P

Exploration Permit WA-13-P is held by West Australian Petroleum Pty. Ltd., and covers part of the offshore Perth Basin. The company commenced drilling an offshore well, Gage Roads No. 1, on this concession during 1968. Details are as follows:

Gage Roads No. 1

Type: Test well.

Latitude and Longitude: 31° 57′ 20″S, 115° 22′ 33″E.

Elevation: W. D. — 191 feet, R. T. + 70 feet.

Commencement: 27th December, 1968.

Status: Drilling at 6,976 feet on 31st December.

EXPLORATION PERMIT WA-14-P

Exploration Permit WA-14-P is held by West Australian Petroleum Pty Ltd and covers part of the offshore Perth Basin. The company drilled its first offshore well, Quinn's Rock No. 1, on this concession during 1968. It was dry and was plugged and abandoned. Details are as follows:

Quinn's Rock No. 1

Type: Test well.

Latitude and Longitude: 31° 48′ 01″S, 115° 30′ 52″E.

Elevation: W. D. — 133 feet, R. T. + 79 feet.

Commenced: 10th October, 1968.

Completed: 11th December, 1968.

Total depth: 7,248 feet.

Bottomed in: Lower Cretaceous or Upper Jurassic.

Status: Dry, plugged and abandoned.

EXPLORATION PERMIT WA-28-P

Exploration Permit WA-28-P is held by Woodside (Lakes Entrance) Oil Co. N. L., Shell Development Australia Pty Ltd., and B. O. C. of Australia Ltd., B. O. C. being the operating company. The permit covers part of the Northwest Shelf and includes parts of the offshore Carnarvon and Canning Basins. The company commenced drilling an offshore well, Dampier No. 1, on this concession during the year. Details are as follows:

Dampier No. 1

Type: Test well.

Latitude and Longitude: 19° 52′ 42″S, 166° 00′ 45″E.

Elevation: W. D. — 250 feet, R. T. + 30 feet.

Commenced: 23rd November, 1968.

Status: Drilling at 8,611 feet on 31st December.

PERMIT TO EXPLORE 27H

Permit to Explore 27H is held by West Australian Petroleum Pty Ltd., and covers part of the Perth Basin. The company drilled two test wells, Dongara No. 7 and Mondarra No. 1, and commenced a third, Mondarra No. 2 during the year. Dongara No. 7 was dry, and Mondarra No. 1 was completed as a gas well in the 'Lower Triassic Sand'. Strong hopes are held that Mondarra will be developed as a commercial field, and the results of the second well are awaited with interest. Details of the wells are as follows:

Dongara No. 7

Type: Test well.

License to Prospect: 171H.

Latitude and Longitude: 29° 18′ 36″S, 115° 01′ 38″E.

Elevation: G. L. 141 feet, R. T. 154 feet.

Commenced: 24th July, 1968.

Completed: 21st August, 1968.

Total depth: 7,100 feet.

Bottomed in: Lower Permian.

Status: Dry, plugged and abandoned.

Mondarra No. 1

Type: Test well.

License to Prospect: 171H.

Latitude and Longitude: 29° 18′ 51″S, 115° 06′ 55″E.

Elevation: G. L. 259 feet, D. F. 273 feet.

Commenced: 9th October, 1968.

Completed: 25th November, 1968.

Total depth: 10,049 feet.

Bottomed in: Lower Permian.

Status: Gas well. A drill stem test of the interval 8,822-8,860 feet flowed gas at 10mmcf/day on ⅜-inch choke.

Mondarra No. 2

Type: Test well.

License to Prospect: 171H.

Latitude and Longitude: 29° 21′ 07″S, 115° 06′ 05″E.

Elevation: G. L. 87 feet, R. T. 101 feet.

Commenced: 20th December, 1968.

Status: Drilling at 6,783 feet on 31st December, 1968.

PERMIT TO EXPLORE 28H

Permit to Explore 28H is held by West Australian Petroleum Pty Ltd., and covers part of the Carnarvon Basin. The company drilled two test wells and three stratigraphic wells in the permit area during 1968. All were dry and were plugged and abandoned, although a minor amount of oil was obtained in Thevenard No. 1. Details of these wells are as follows:

Hope Island No. 1

Type: Stratigraphic Well.

License to Prospect: 196H.

Latitude and Longitude: 22° 09′ 34″S, 114° 28′ 35″E.

Elevation: G. L. 16 feet, R. T. 30 feet.

Commenced: 26th February, 1968.

Completed: 13 March, 1968.

Total depth: 4,680 feet.

Bottomed in: Lower Permian.

Status: Dry, plugged and abandoned.

Observation No. 1

Type: Stratigraphic well.

License to Prospect: 195H.

Latitude and Longitude: 21° 44′ 28″S, 114° 32′ 12″E.

Elevation: G. L. 16 feet, R. T. 30 feet.

Commenced: 31st December, 1967.

Completed: 14th February, 1968.

Total depth: 7,510 feet.

Bottomed in: Middle Triassic.

Status: Dry, plugged and abandoned.

Sandy Point No. 1

Type: Test well.

License to Prospect: 192H.

Latitude and Longitude: 22° 25′ 50″S, 113° 47′ 46″E.

Elevation: G. L. 366 feet, R. T. 378 feet.

Commenced: 30th November, 1967.

Completed: 31st January, 1968.

Total depth: 9,992 feet.

Bottomed in: Lower Jurassic.

Status: Dry, plugged and abandoned.

Thevenard No. 1

Type: Test well.

License to Prospect: 164H.

Latitude and Longitude: 21° 27′ 45″S, 115° 01′ 05″E.

Elevation: G. L. 16 feet, R. T. 30 feet.

Commenced: 28th March, 1968.

Completed: 28th April, 1968.

Total depth: 6,810 feet.

Bottomed in: Upper to Middle Jurassic.

Status: Minor oil and gas shows, plugged and abandoned. A drill stem test of the interval 5,101-5121 feet recovered approximately half a gallon of oil.

Urala No. 1

Type: Stratigraphic well.

License to Prospect: 187H.

Latitude and Longitude: 21° 49′ 06″S, 114° 43′ 22″E.

Elevation: G. L. 7 feet, R. T. 12 feet.

Commenced: 15th September, 1968.

Completed: 7th October, 1968.

Total depth: 2,500 feet.

Bottomed in: Upper Triassic.

Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 30H

Permit to Explore 30H is held by West Australian Petroleum Pty Ltd and covers part of the Canning Basin. The company drilled one test well and two stratigraphic wells in this permit during 1968. All were dry and were plugged and abandoned. Details are as follows:

Chirup No. 1

Type: Stratigraphic well.
License to Prospect: 212H.
Latitude and Longitude: 19° 15′ 00″S, 120° 26′ 00″E.
Elevation: G. L. 10 feet, R. T. 15 feet.
Commenced: 26th August, 1968.
Completed: 7th September, 1968.
Total depth: 2,502 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged and abandoned.

Doran No. 1

Type: Stratigraphic well.
License to Prospect: 210H.
Latitude and Longitude: 18° 10′ 56″S, 123° 29′ 06″E.
Elevation: G. L. 209 feet, R. T. 214 feet.
Commenced: 22nd July, 1968.
Completed: 5th August, 1968.
Total depth: 2,504 feet.
Bottomed in: Upper Devonian.
Status: Dry, completed as a water well.

Willara Hill No. 1

Type: Test well.
License to Prospect: 211H.
Latitude and Longitude: 19° 03′ 31″S, 121° 52′ 45″E.
Elevation: G. L. 247 feet, R. T. 252 feet.
Commenced: 10th August, 1968.
Completed: 22nd August, 1968.
Total depth: 2,814 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 152H

Permit to Explore 152H is held by Beach-General Exploration Pty Ltd and is farmed out to Australian Aquitaine Petroleum Pty Ltd. The company drilled one dry test well on the consession during 1968. Details are as follows:

Wilson Cliffs No. 1

Type: Test well.
License to Prospect: 199H.
Latitude and Longitude: 22° 16′ 39″S, 126° 46′ 55″E.
Elevation: G.L. 1,444 feet, K.B. 1,460 feet.
Commenced: 8th June, 1968.
Completed: 28th November, 1968.
Total depth: 12,212 feet.
Bottomed in: Proterozoic.
Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 193H

Permit to Explore 193H is held by Hawkstone Minerals Ltd and B.P. Petroleum Development Australia Pty Ltd. B.P. drilled a stratigraphic well on the concession during 1968. Details are as follows:

Gun Island No. 1

Type: Stratigraphic well.
License to Prospect: 205H.
Latitude and Longitude: 28° 53′ 30″S, 113° 51′ 27″E.
Elevation: G. L. 10 feet, K. B. 24 feet.
Commenced: 26th June, 1968.
Completed: 12th November, 1968.
Total depth: 12,220 feet.
Bottomed in: Lower Jurassic.
Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 217H

Permit to Explore 217H is held by West Australian Petroleum Pty Ltd and covers part of the Carnarvon Basin. The company drilled six stratigraphic wells on the concession during 1968, four of them on islands. Details are as follows:

Direction Island No. 1

Type: Stratigraphic well.
License to Prospect: 204H.
Latitude and Longitude: 21° 32′ 03″S, 115° 07′ 42″E.
Elevation: G. L. 15 feet, R. T. 20 feet.
Commenced: 26th April, 1968.
Completed: 7th May, 1968.
Total depth: 2,207 feet.
Bottomed in: Lower Permian.
Status: Dry, plugged and abandoned.

Mangrove Island No. 1.

Type: Stratigraphic well.
License to Prospect: 162H.
Latitude and Longitude: 21° 14′ 22″S, 115° 46′ 04″E.
Elevation: G.L. 15 feet, R.T. 20 feet.
Commenced: 6th June, 1968.
Completed: 14th June, 1968.
Total depth: 938 feet.
Bottomed in: ?Lower Permian.
Status: Minor gas show, plugged and abandoned.

Mary Anne No. 1

Type: Stratigraphic well.
License to Prospect: 202H.
Latitude and Longitude: 21° 17′ 55″S, 115° 30′ 04″E.
Elevation: G.L. 15 feet, R.T. 20 feet.
Commenced: 12th May, 1968.
Completed: 21st May, 1968.
Total depth: 1,750 feet.
Bottomed in: Middle to Lower Triassic.
Status: Dry, plugged and abandoned.

Mulyery No. 1

Type: Stratigraphic well.
License to Prospect: 186H.
Latitude and Longitude: 21° 18′ 26″S, 115° 47′ 48″E.
Elevation: G.L. 15 feet, R.T. 20 feet.
Commenced: 22nd January, 1968.
Completed: 23rd January, 1968.
Total depth: 458 feet.
Bottomed in: Upper Jurassic.
Status: Gas show, plugged and abandoned. Flow test through perforations over interval 406-420 feet flowed gas at 0.04 mmcf/day.

North Sandy Island No. 1

Type: Stratigraphic well.
License to Prospect: 162H.
Latitude and Longitude: 21° 06′ 25″S, 115° 38′ 56″E.
Elevation: G.L. 15 feet, R.T. 20 feet.
Commenced: 23rd May, 1968.
Completed: 3rd June, 1968.
Total depth: 2,000 feet.
Bottomed in: Middle to Lower Triassic.
Status: Minor gas show, plugged and abandoned.

Peedamullah No. 1

Type: Stratigraphic well.
Latitude and Longitude: 21° 24′ 26″S, 115° 37′ 50″E.
Elevation: G.L. 18 feet, R.T. 23 feet.
Commenced: 24th December, 1967.
Completed: 7th January, 1968.
Total depth: 1,077 feet.
Bottomed in: Devonian.
Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 259H

Permit to Explore 259H is held by West Australian Petroleum Pty Ltd., and is farmed out to Total Exploration Australia Pty Ltd. This company drilled a test well and two stratigraphic wells on this permit during 1968. All were dry and were plugged and abandoned. Details are as follows:

Edgar Range No. 1

Type: Stratigraphic well.
License to Prospect: 213H.
Latitude and Longitude: 18° 45′ 26″S, 123° 35′ 33″E.
Elevation: G.L. 434 feet, K.B. 447 feet.
Commenced: 10th August, 1968.
Completed: 14th September, 1968.
Total depth: 6,457 feet.
Bottomed in: Precambrian.
Status: Dry, plugged and abandoned.

Kemp Field No. 1

Type: Stratigraphic well.
License to Prospect: 216H.
Latitude and Longitude: 20° 19′ 10″S, 123° 27′ 58″E.
Elevation: G.L. 768 feet, K.B. 782 feet.
Commenced: 28th September, 1968.
Completed: 13th October, 1968.
Total depth: 3,875 feet.
Bottomed in: Devonian.
Status: Dry: plugged and abandoned.

McLarty No. 1

Type: Test well.
License to Prospect: 200H.
Latitude and Longitude: 19° 23′45″S, 123° 39′30″E.
Elevation: G.L. 558 feet, K.B. 572 feet.
Commenced: 14th May, 1968.
Completed: 30th July, 1968.
Total depth: 8,500 feet.
Bottomed in: Ordovician.
Status: Dry, plugged and abandoned.

PERMIT TO EXPLORE 260H

Permit to Explore 260H is held by West Australian Petroleum Pty. Ltd. and is farmed out to Marathon Petroleum Australia Ltd. This company commenced one test well on the permit during 1968. Details are as follows:

Remarkable Hill No. 1

Type: Test well.
License to Prospect: 215H.
Latitude and Longitude: 22° 57′ 20″S, 114° 09′ 20″E.
Elevation: G.L. 350 feet, K.B. 364 feet.
Commenced: 15th October, 1968.
Status: Drilling at 7,959 feet on 31st December.

PERMIT TO EXPLORE 261H

Permit to Explore 261H is held by West Australian Petroleum Pty. Ltd. and is farmed out to Union Oil Development Corp. That company drilled one test well, Whicher Range No. 1 on the permit during 1968. Moderate flows of gas were obtained from the Permian sequence, but the well was abandoned as being non-commercial. Details are as follows:

Whicher Range No.1

Type: Test well.
License to Prospect: 198H.
Latitude and Longitude: 30° 50′ 21″S, 115° 22′ 12″E.
Elevation: G.L. 485 feet, K.B. 501 feet.
Commenced: 19th March, 1968.
Completed: 28th August, 1968.
Total depth: 15,226 feet.
Bottomed in: Upper Permian.
Status: Non-commercial gas well, plugged and abandoned. A drill stem test of the interval 13,662½-13,694 feet flowed gas 1.93 mmcf/day on ½-inch choke. Other intervals between 12,958½ and 13,794½ feet flowed gas at lesser rates.

GEOPHYSICAL OPERATIONS

Seismic

During 1968 seismic surveys were conducted in the Perth, Carnarvon, Canning, Bonaparte Gulf, and Eucla Basins. This work was distributed as follows:

Company	Permit	Basin	Party months
Westralian Sands Limited	106H and 253H	Canning	0·8 (land)
West Australian Petroleum Pty Ltd	27H	Perth	1·5 (land)
Do. do. do.	27H and WA–14–P	Perth	3·0 (marine)
Do. do. do.	28H	Carnarvon	1·5 (land)
Do. do. do.	28H and WA–24–P	Carnarvon	3·1 (marine)
Do. do. do.	30H	Canning	2·4 (land)
Do. do. do.	30H	Canning	2 days (marine)
Do. do. do.	217H and WA–23–P	Carnarvon	3·2 (marine)
Do. do. do.	225H and WA–13–P	Perth	1·6 (marine)
Do. do. do.	233H and WA–25–P	Carnarvon	1·1 (marine)
Total Exploration Australia Pty Ltd	WA–20–P	Perth	0·15 (marine)
Australian Aquitaine Pty Ltd	205H	Canning	2·0 (land)
Do. do. do.	152H	Canning	0·66 (land)
Do. do. do.	151H	Canning	1·26 (land)
B.O.C. of Australia Ltd	213H	Canning	3·0 (marine)
Arco Limited	221H	Bonaparte	2·5 (marine)
Union Oil Development Corporation	261H	Perth	4·5 (land)
Canadian Superior Oil (Aust.) Pty Ltd	235H	Carnarvon	½ day (marine)
Marathon Petroleum Australia Ltd	260H	Carnarvon	5·0 (land)

Gravity

Gravity surveys were carried out during the year in the Canning Basin. Details are as follows:

Company	Permit	Basin	Party months
West Australian Petroleum Pty Ltd	30H	Canning	0·5
Australian Aquitaine Petroleum Pty Ltd	205H	Canning	2·0
Do. do. do.	152H	Canning	0·66
Do. do. do.	151H	Canning	1·26

Magneto-Telluric Surveys

A magneto-telluric survey was carried out during the year in the Canning Basin. Details are as follows:

Company	Permit	Basin	Party months
Australian Aquitaine Petroleum Pty Ltd	205H	Canning	1·46
Do. do. do.	152H	Canning	1·3
Do. do. do.	151H	Canning	0·93

GEOLOGICAL OPERATIONS

Field geological studies were carried out by oil exploration companies in the Perth, Canning, and Carnarvon Basins. Details are as follows:

Company	Permit	Basin	Geologist months
West Australian Petroleum Pty Ltd	27H	Perth	0·5
Do. do. do.	30H	Canning	4·0
Australian Aquitaine Petroleum Pty Ltd	205, 152, and 151H	Canning	1·5
B.O.C. of Australia Limited	213H	Canning	21·0
Marathon Petroleum Australia Pty Ltd	260H	Carnarvon	3·0

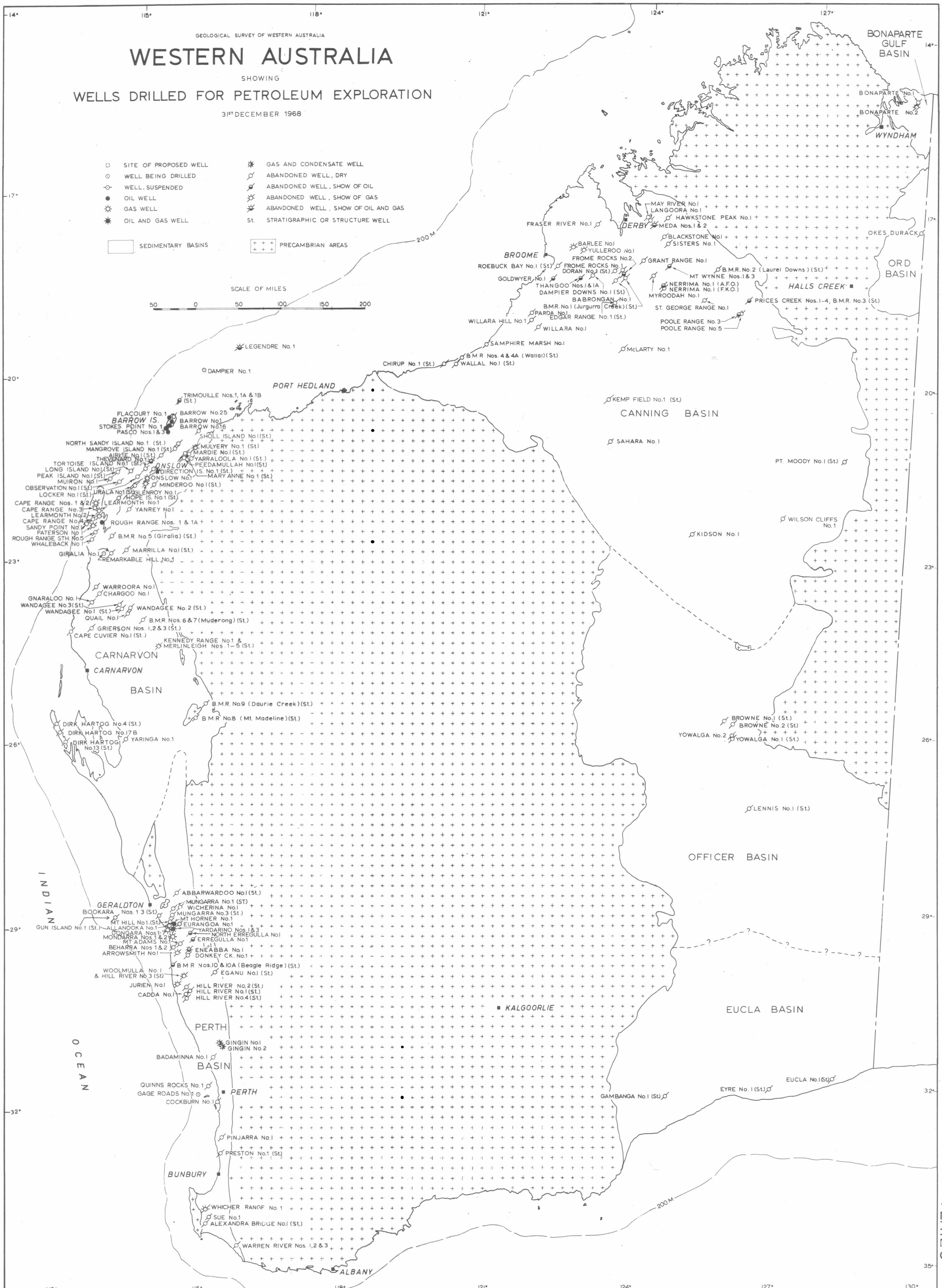

PLATE 9

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PLATE 10

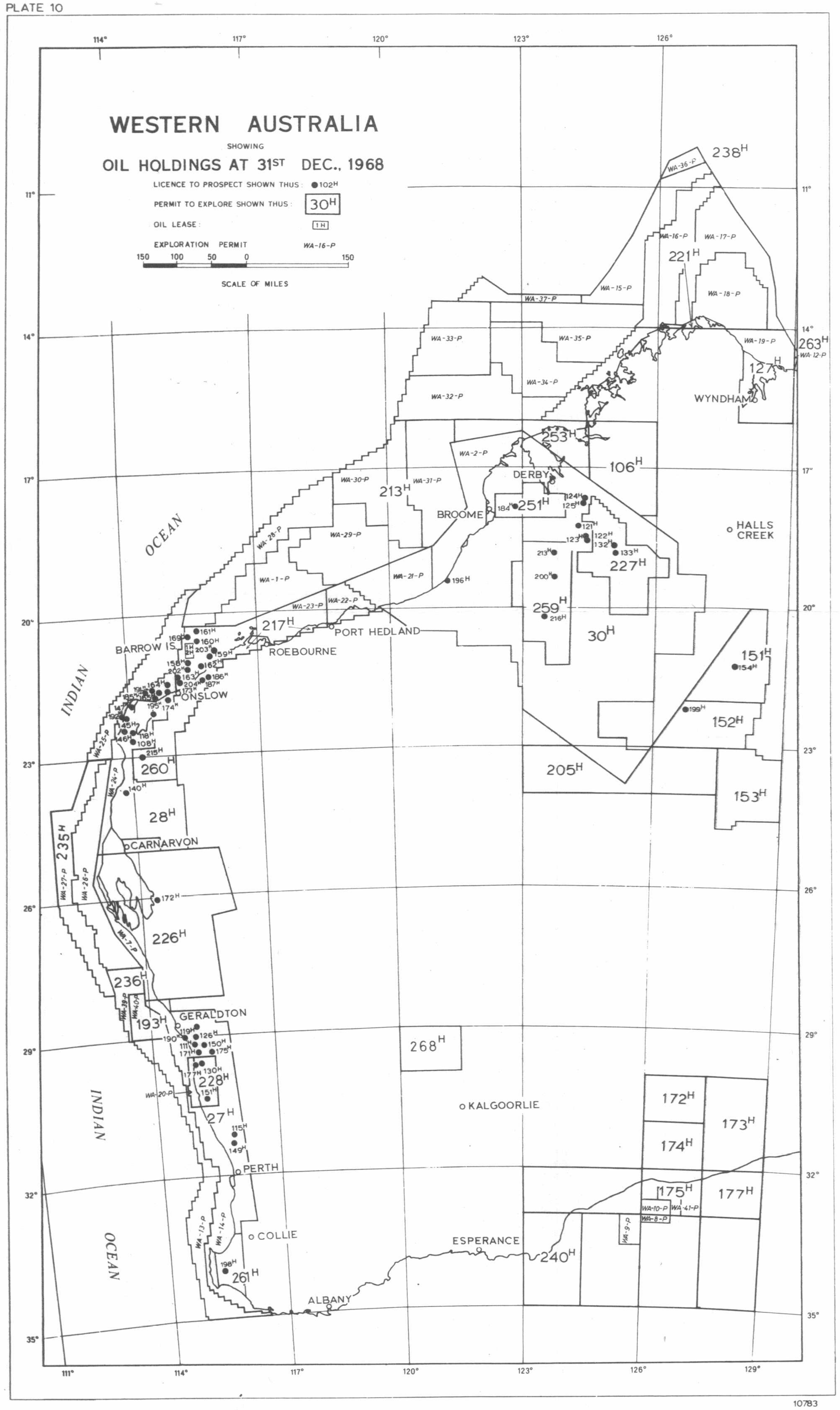
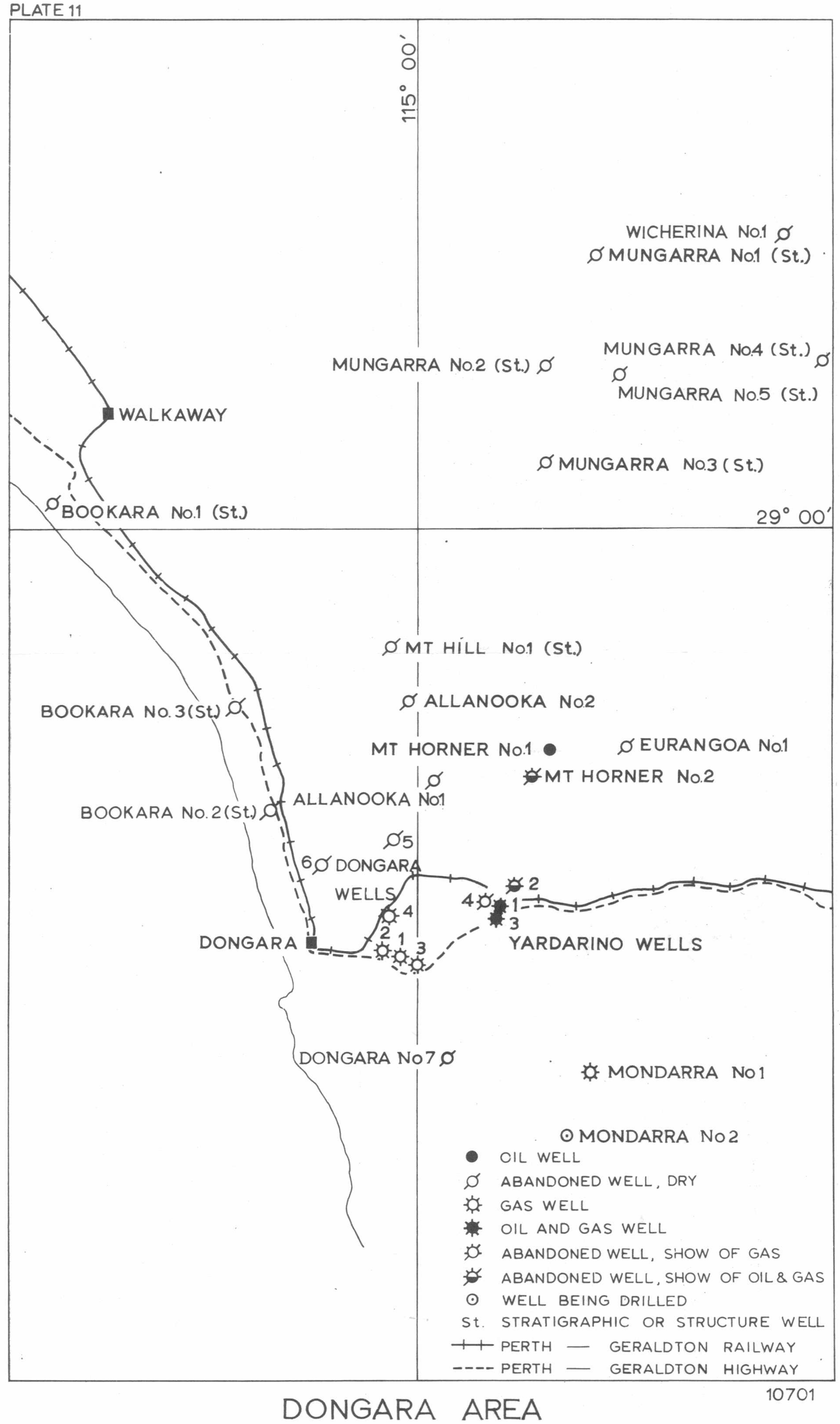


PLATE 11



DONGARA AREA
SHOWING WELLS DRILLED FOR PETROLEUM

0 4 8
SCALE OF MILES

PETROLEUM PRODUCTION IN WESTERN AUSTRALIA IN 1968

by A. H. Pippet

Barrow Island is the only producing field in the State at present, although the Dongara and Mondarra fields show promise for eventual economic development.

Development of the Barrow Island Field continued during the year with the drilling of a further 52 producing wells mainly on the primary 80-acre-spacing scheme. The positions of all wells drilled to the end of 1968 are shown on Plate 12.

The pilot water-injection tests initiated in 1967 indicated that favourable injection rates could be obtained in the Windalia reservoir; as a result the company announced that it was proceeding with a field-wide water-flood project which was expected to increase the recoverable reserves to approximately 200 million barrels of oil. By the end of the year 45 water-injection and 5 water source wells had been drilled. In addition to the development wells two 'new-pool wildcats' (Stokes Point No. 1 and Flacourt No. 1) and one 'outpost' (C-52) were drilled with some degree of success. Stokes Point No. 1 (Loc. C-65) was drilled on a possible structure southeast of the main Barrow Island fault. The Jurassic proved non-productive and the well was completed in the Windalia reservoir as an oil and gas well. An 'outpost' well C-52, drilled in a downdip position as a follow-up to Stokes Point No. 1 proved to be water productive and was abandoned. However, on the northeast flank Flacourt No. 1 (Loc. S-27) was completed as a small oil producer and indicated that where trapping conditions are favourable, small accumulations of oil are present in the Windalia beneath the level of the oil-water contact in the main pool.

In addition, sands in the Muderong Formation have been found to be oil productive in the 'F' area, where this reservoir is now being developed.

Oil production rose from 28,700 barrels per day in December 1967 to 30,000 barrels per day in May 1968, at which level production was maintained throughout the remainder of the year. It is anticipated that by the end of 1969 the field production will be of the order of 45,000 barrels per day.

The total footage of holes drilled on Barrow Island during the year amounted to 270,951 feet.

Production statistics for the year are summarized in the following tables.

OIL AND GAS PRODUCTION 1968

Reservoir	Production for year 1968			Cumulative production		
	Oil (bbls)	Water (bbls)	Gas (Mcf)	Oil (bbls)	Water (bbls)	Gas (Mcf)
Windalia	10,479,076	170,969	8,000,976	15,122,857	186,691	10,976,718
Muderong	20,811	204	9,325	20,811	204	9,325
Jurassic 6200'	529	690	12,851	9,423	4,770	65,177
Jurassic 6600'	45,933	43,352	167,228	106,098	47,620	341,488
Jurassic 6700'	236,332	20,817	466,424	439,763	39,647	715,083
Total field	10,782,681	236,032	8,656,804	15,698,952	278,932	12,107,791
Windalia	Water injected, 1,975,967 bbls			Cumulative water injected, 2,044,319 bbls		

OIL AND GAS DISPOSAL 1968

	Oil (bbls)	Gas (Mcf)
Total production	10,782,681	8,656,804
Used in drilling	463	....
Field fuel	4,695	92,922
Gas flared	....	8,563,882
Percentage field utilization	·0043	1·07
Percentage gas flared	....	98·93
Oil shipments	10,641,703	....

The following table summarizes the wells drilled on Barrow Island (Petroleum Lease 1H) during 1968.

WELLS DRILLED ON BARROW ISLAND DURING 1968

Well	Elevation		Total depth (feet)	Commenced	Completed	Objective*
	Rotary table (feet)	First flange (feet)				
A 17	108	98	2580	15/5/68	20/5/68	WI
A 27	86	75	2550	14/6/68	18/6/68	P
A 28	88	77	2540	5/5/68	8/5/68	WI
A 38	154	144	2517 (577)	30/12/67	2/1/68	P
A 47	45	35	2540	2/6/68	7/6/68	WI
B 11	73	62	2487	1/4/68	5/4/68	WI
B 13	79	69	2370	27/4/68	29/4/68	WI
B 22	52	42	2457	5/4/68	10/4/68	WI
B 24	54	43	2320	29/4/68	4/5/68	WI
B 31	48	38	2457	14/4/68	19/4/68	WI
B 33	49	39	2336	20/4/68	23/4/68	WI
B 36	52	41	3613	5/1/68	11/1/68	P
B 41	47	37	2456	23/3/68	27/3/68	P
B 43	46	35	3488	2/2/68	9/2/68	P (Abx)
E 25	85	74	2564	11/1/68	16/1/68	P
F 11	163	153	2380	23/12/68	27/12/68	WI
F 15	192	182	2343	27/12/68	30/12/68	WI
F 17	159	148	482	31/12/68	Drilling	WI
F 22	134	123	2972	11/12/68	17/12/68	P (M)
F 31	173	162	2356	30/7/68	1/8/68	WI
F 33	135	125	2269	26/7/68	29/7/68	WI
F 35	114	103	148	31/12/68	Drilling	WI
F 37	114	104	2284	28/12/68	30/12/68	WI
F 42	127	116	2970	14/11/68	22/11/68	P (M)
F 51	146	135	2915	{11/5/68 29/6/68	16/5/68 10/7/68	} WI
F 53	116	106	2268	22/7/68	26/7/68	WI
F 62	113	103	2246	17/8/68	23/8/68	P (M)
G 11	87	77	2461	3/12/68	5/12/68	WI
G 13	140	130	2461	11/12/68	14/12/68	WI
G 15	147	137	2447	30/11/68	3/12/68	WI
G 17	185	175	2447	20/11/68	24/11/68	WI
G 31	124	113	2510	8/5/68	11/5/68	WI
G 33	154	143	2480	25/6/68	28/6/68	WI
G 35	123	113	2389	16/7/68	18/7/68	WI
G 37	177	167	2364	14/8/68	17/8/68	WI
G 51	131	121	2490	14/11/68	18/11/68	WI
G 53	157	147	2449	10/7/68	13/7/68	WI
G 55	149	139	2358	13/7/68	15/7/68	WI
G 71	109	99	2517	23/4/68	26/4/68	WI
G 73	113	103	2401	20/4/68	24/4/68	WI
G 75	118	107	2401	17/4/68	20/4/68	WI
G 77	104	94	2312	13/4/68	17/4/68	WI
G 82	98	88	2461	25/4/68	27/4/68	WI
G 86	93	83	2311	10/4/68	13/4/68	WI
H 17	92	81	2610	26/11/68	30/11/68	WI
H 37	135	125	2610	23/11/68	26/11/68	WI
H 57	89	78	2550	19/11/68	22/11/68	WI
H 77	101	91	2610	3/5/68	9/5/68	P
H 87	122	111	2600	20/6/68	25/6/68	WI
H 88	124	113	2580	27/4/68	3/5/68	WI
K 12	151	141	2576	23/2/68	28/2/68	P
K 14	192	182	2547	16/2/68	22/2/68	P
K 16	179	168	2547	28/1/68	1/2/68	P
K 21	114	103	2547	22/3/68	25/3/68	P
K 23	152	141	2515	4/2/68	12/2/68	P
K 32	172	162	2576	28/2/68	2/3/68	P
K 34	164	153	2518	15/3/68	18/3/68	P
K 36	192	181	2517	5/3/68	8/3/68	P
K 41	160	149	2547	11/3/68	14/3/68	P
K 43	183	173	2547	8/3/68	11/3/68	P
K 54	137	126	2487	13/2/68	16/2/68	P
K 56	142	131	2457 325)	30/12/67	4/1/68	P

Well	Elevation		Total depth (feet)	Com-menced	Com-pleted	Ob-jective*
	Rotary table (feet)	First flange (feet)				
K 58	170	159	2456	9/3/68	12/3/68	P
K 61	104	93	2576	2/3/68	6/3/68	P
K 63	145	134	2488	22/1/68	26/1/68	P
K 65	167	156	2456	15/3/68	18/3/68	P
K 67	187	176	2456	12/3/68	15/3/68	P
K 71	122	112	2551	30/11/68	3/12/68	WI
K 73	165	155	2461	6/12/68	8/12/68	WI
K 75	141	130	2431	8/12/68	11/12/68	WI
K 77	196	186	2448	25/11/68	28/11/68	WI
L 12	208	197	2518	19/1/68	22/1/68	P
L 21	199	188	2517	3/1/68	5/1/68	P
L 23	198	188	2517	20/2/68	23/2/68	P
L 32	198	188	2436	28/3/68	2/4/68	P
L 36	206	196	2456	9/2/68	13/2/68	P
L 38	158	148	2487	16/1/68	19/1/68	P
L 41	182	171	2480	19/1/68	27/1/68	P
L 43	210	200	2487	31/1/68	4/2/68	P
L 53	194	184	2407	14/12/68	17/12/68	WI
L 71	170	160	2370	17/12/68	20/12/68	WI
L 73	169	152	2350	20/12/68	23/12/68	WI
M 27	128	118	2569	16/5/68	19/5/68	P
M 47	105	95	2537	18/3/68	23/3/68	P
P 81	180	169	2547	13/1/68	16/1/68	P
P 87	123	113	2547	25/3/68	31/3/68	P
Q 14	193	183	2570	18/7/68	21/7/68	P
Q 32	116	105	2547	28/3/68	31/3/68	P
Q 41	180	169	2576	18/3/68	21/3/68	P
Q 61	120	110	2518	7/1/68	10/1/68	P
Q 74	166	155	2487	16/1/68	18/1/68	P
Q 78	169	159	2516	13/2/68	16/2/68	P
Q 83	173	163	2517	16/2/68	20/2/68	P
R 47	92	81	2491	12/5/68	15/5/68	P
R 58	186	175	2547	29/2/68	4/3/68	P
R 67	118	108	2491	9/5/68	12/5/68	P
R 85	147	137	2518	4/1/68	7/1/68	P
T 87	159	149	2576	10/1/68	13/1/68	P
WSW 1 A, B 13	93	83	3675	19/5/68	25/5/68	WSW
WSW 1 B, G 74	102	91	3700	26/5/68	2/6/68	WSW
WSW 2 A, G33	114	103	3600	2/8/68	9/8/68	WSW
WSW 3 A, F 15	165	155	3539	4/12/68	11/12/68	WSW
WSW 4 A M 54	144	134	4029	18/12/68	26/12/68	WSW

Total development drilling, 1968 : 257,181 feet.

Datum adopted for Barrow Island wells is 18·54 feet above mean sea level or 23·44 feet above Indian spring low water mark.

* P = Windalia producer.
P (M) = Muderong producer.
WI = Windalia water injector.
WSW = water source well.
(Abx) = Abandoned.

NEW POOL WILDCAT WELLS (2)

Stokes Point No. 1 (Location C-65)

Latitude and longitude: 20° 52′ 55″S, 115° 22′ 55″E.

Elevation: G.L. 59 feet, R.T. 73 feet.

Commenced: 9th May, 1968.

Completed: 16th June 1968.

Total depth: 8,150 feet.

Bottomed in: Upper Jurassic.

Status: Oil and gas well. Completed in zones between 2,602 to 2,630 feet.

Flacourt No. 1 (Location S-27)

Latitude and longitude: 20° 44′ 44″S, 115° 22′ 40″E.

Elevation: F.F. 165 feet, R.T. 175 feet.

Commenced: 8th June, 1968.

Completed: 13th June, 1968.

Total depth: 2,680 feet.

Bottomed in: Lower Cretaceous.

Status: Oil well, completed in zones between 2,396 to 2,425 feet.

OUTPOST WELLS (1)

Location C-52

Elevation: F.F. 43 feet, R.T. 54 feet.

Commenced: 9th August, 1968.

Completed: 14th August, 1968.

Total depth: 2,940 feet.

Bottomed in: Lower Cretaceous.

Status: Plugged and abandoned.

THE ORIGIN OF SMALL CAVITIES IN THE LIMESTONE OF THE BUNDA PLATEAU, EUCLA BASIN

by D. C. Lowry

ABSTRACT

The limestone of the Bunda Plateau contains several varieties of small cavities between the surface and the water table some 200 to 400 feet below. Some near-surface cavities have previously been attributed to phreatic solution below a late Cainozoic water table which stood within a few feet of the present surface, but this article shows that some of the cavities were formed by tree roots and others by surface weathering. Cavities of undoubted phreatic or epi-phreatic origin are recognized only up to about 250 feet above the present water table, and a late Cainozoic elevation of sea level by that amount is inferred.

INTRODUCTION

The Bunda Plateau covers some 50,000 square miles of Western Australia. Its southern part is underlain by Miocene limestones of the Eucla Group, and the plateau slopes southwards from an altitude of 500 to 650 feet near the Trans Australian Railway to about 200 to 350 feet at the scarp that forms its southern boundary (Figure 7). The low rainfall (7 to 12 inchest annually) and the generally high permeability of the limestone means that most of the plateau is underlain by a water table of low relief. Large caves are relatively rare, but in most areas the limestone is riddled with small cavities at various levels above the water table. Jennings (1958, 1961) referred to some of the cavities as 'solution tubes' and interpreted them as having formed below a water table which stood within a few feet of the present surface of the plateau. Although I formerly agreed with this suggestion (Lowry, 1964), I have since examined most quarries and large caves in the Western Australian part of the plateau, and now believe that Jennings has misinterpreted the origin of some of the cavities.

In the last 25 years, much of the speleological literature on the origin and development of limestone caves has been devoted to distinguishing between cave formation in the vadose, epi-phreatic. and phreatic zones (above the water table, just below the water table, and far below it.) The distinction has usually been made by identifying the diagnostic morphological features described in the classic paper by Bretz (1942). This article shows that such identification is not always easy.

VARIETIES OF CAVITIES

There is a great diversity of small cavities in the limestone, and the following classification is a tentative one. There appear to be gradations between the various types of cavity and detailed study would probably result in an even more complex classification.

Anastomosing tubes developed on fracture surfaces

The tubes are mostly developed along fractures in near-surface limestone, and are exposed as half-tubes by collapse of walls of dolines, cliffs and quarries (see Plate 13A, and Jennings 1967a Figure 2-9). The tubes anastomose freely in all directions and occasionally penetrate the limestone between fracture surfaces. The diameter

PLATE 12

BARROW ISLAND AREA
WINDALIA RESERVOIR

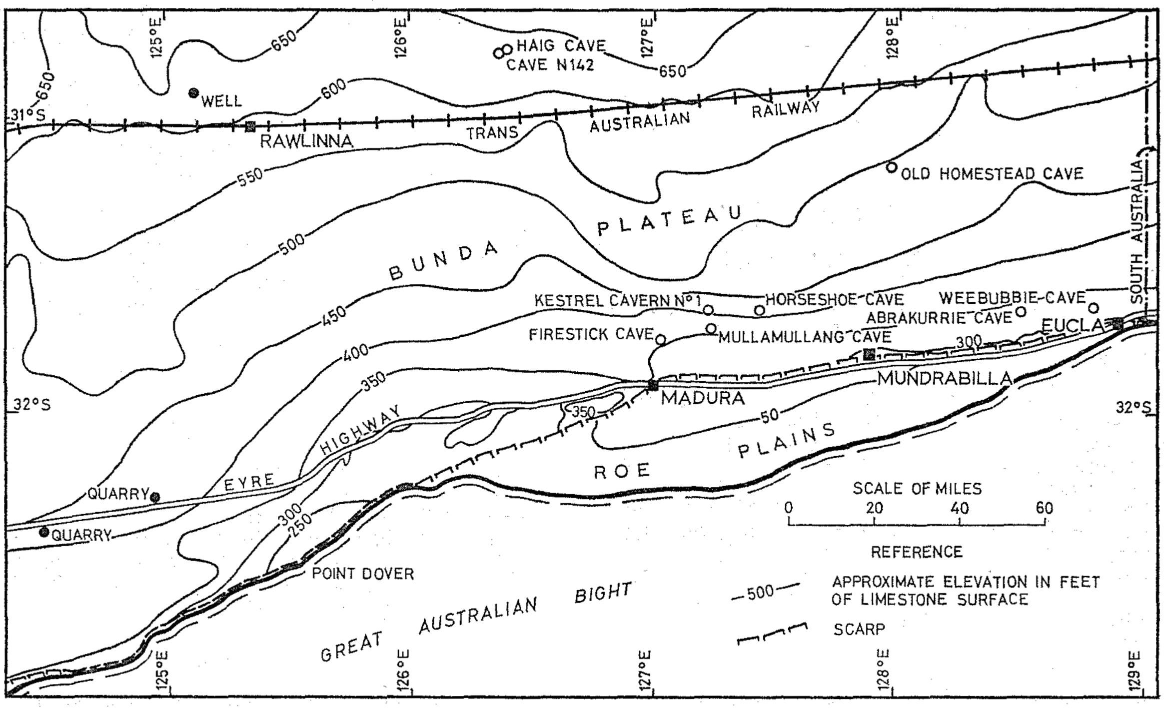


Figure 7. Sketch plan of part of the Eucla Basin. Contours show elevation of surface of Tertiary limestone; coastal dunes are omitted.

ranges from about 10 centimeters down to a few milimeters, and each tube has a remarkably constant diameter. They are commonest in the interval from 5 to 50 feet below the surface. Jennings (1963 p. 50) described them as "anastomosing networks of small half-tubes exposed on bedding and joint-planes" and favoured a phreatic origin because of their apparent similarity to phreatic features described by Bretz (1942) and Glennie (1954). Jennings presumably intended a comparison with Bretz's "bedding-plane anastomosis" and "joint-plane anastomosis." However, they differ in the following ways:

(1) Although the tubes are concentrated along fracture planes, they also penetrate the solid limestone between fractures, whereas tubes of a bedding-plane anastomosis are restricted to the particular bedding plane.

(2) They are remarkably circular in cross section whereas tubes of bedding-plane anastomoses are bulbous (Bretz, 1942) or trapezoidal (Ewers, 1966).

(3) When the tubes along fractures developed, they widened symmetrically on both sides of the fracture, whereas the tubes of bedding-plane anastomoses only enlarged upwards into the overlying bed.

(4) Tubes exposed on any particular surface of Eucla Group limestone have a great range in size, whereas bedding-plane anastomoses have tubes of about equal size (Ewers, 1966).

Although Bretz (1942) introduced the term "joint-plane anastomosis", he found the feature to be so rare that he did not describe it in sufficent detail to allow determination of the extent of its similarity to the tubes on fractures in Eucla Group limestone. Jennings (1967b) also referred to "spongework", but Bretz (1942) described spongework as having "amazingly intricate perforated partitions and remnants of partitions" and as ranging in size up to cave passages. The spongework of Bretz therefore has a much higher proportion of cavity to limestone that the tubes described here, although the comparison might be valid for features described later under 'Irregular cavities'. There are sufficient differences therefore between tubes in the limestones of the Eucla Group and the phreatic features of Bretz (1942) to suggest that they have different origins.

The anastomoses in the fractures of the Eucla Group limestones are most likely to have been caused by tree roots. Evidence for this is as follows:

(1) Tree roots or bundles of roots can occasionally be seen occupying tubes; for example at quarries on the Eyre Highway near the 173 and 206 mile pegs east of Norseman, and in road cuttings at Madura, Mundrabilla, and Eucla (Plate 13A).

(2) In some places close to the surface of the plateau, tubes following vertical fractures tend to be vertical (see Plate 13B).

(3) The tubes are similar to other tubes believed to have been formed by tree roots. Jennings's (1967a) Figure 2-9 strongly resembles Plate 4 of Wall and Wilford (1966).

(4) Illustrations of bedding-plane anastomoses show that the tubes branch in a series of 'Y' junctions, whereas tubes in Eucla Group limestones sometimes cross over each other in an 'X' junction.

(5) Many tubes are filled with clay, and others with clay that has partly or completely lithified.

The range in degree of lithification suggests a range of ages, and therefore is more in keeping with the tree-root hypothesis.

(6) Tree roots are capable of penetrating considerable depths below the plateau. Quarries and road cuttings show they penetrate at least 10 feet, but the most striking example is Mullamullang Cave, where rotted wood in the cave is thought to have come from the roots of *Acacia* sp. growing more than 150 feet above (Hamilton-Smith *in* Hill 1966).

Where a root or bundle of roots is observed occupying a tube freshly exposed by quarrying, they do not fill the tube, but are surrounded by clay. The tubes probably form by corrosion by root exudates (Wall and Wilford, 1966) and vadose water seeping through the clay. If the seepage is by capillarity, the tubes could develop features which are usually associated with phreatic flow such as anastomoses and irregular gradients.

Surface pitting

The exposed limestone surface in many dolines shows an abundance of circular openings about 1 to 6 inches across. The openings give the impression of being part of a maze of tubes penetrating the limestone, but in fact they are blind and do not penetrate more than a few inches. Plate 13c shows roof surface which developed pitting and then partly collapsed. The fresh surfaces on the right of the photograph do not show the holes that would be expected if the openings on the left of the photograph represented the ends of a maze of tubes. Figure 2-10 of Jennings (1967a) possibly illustrates pits of this type rather than solution tubes. The origin of the pits is uncertain, but the fact that they seem concentrated on overhanging and other dry surfaces, and have an apparent association with films of halite, suggests that some sort of exudation mechanism may be in operation. In any case, the pits are younger than the doline walls, and a phreatic origin is improbable.

Irregular cavities with smoothly curving walls

These cavities, which are usually filled with red clay, are distinguished from the root tubes by having smoothly curving walls with little constancy of diameter. They are also somewhat larger, ranging up to 20 inches in diameter, and seem to have a greater proportion of cavity to limestone. The tubes are not concentrated on fracture planes, although they do seem to be concentrated at disconformities. The zone in which they develop varies. In Haig Cave they extend from 25 to 140 feet below the surface and are particularly concentrated at the disconformity between the Nullarbor Limestone and the Wilson Bluff Limestone 94 feet below the surface. In Old Homestead Cave there are irregular clay-filled cavities at about 50 feet below the surface and in Abrakurrie Cave there is a zone at about 90 feet. In a few instances the tubes lie quite close to the surface; in an old well (lat. 30° 56'S, long. 125° 04'E) there is abundance of irregular clay-filled tubes from 20 to 110 feet below the surface, while in cave N142, they occur only 10 feet below the surface. The clay fillings show no signs of bedding.

The cavities are possibly the type that Jennings (1967b) referred to as spongework, and it is possible that they formed by phreatic solution. However, a vadose origin is also conceivable. Water seeping through clay-filled tubes could perhaps enlarge them into a three-dimensional maze that would resemble the work of slowly moving phreatic water.

Horizontal flat-bottomed cavities

These cavities range from a few inches to about 2 feet in width, and are up to about 1 foot high. They have flat bottoms and irregular tops, and are usually filled with horizontally-layered calcite. Usually they occur in a flat zone some distance below the surface of the plateau. At Mullamullang Cave, for example, there is a zone of these cavities about 60 feet below the surface (about 330 feet above the water table), but on the cliffs near Point Dover, there is a zone only 8 feet below the surface (about 200 to 250 feet above sea level). The horizontality of the cavities suggests that their formation was controlled either by a water table, or by horizontal bedding. Even if the cavities do represent former water table levels, it was possibly only a local effect. Small perched bodies of water occur beneath 'dongas' (solution dolines) in the Rawlinna area at the present time and since the flat-bottomed cavities occur mainly in indurated limestone of low permeability, it is conceivable that perched bodies of water could have developed in other parts of the plateau in the past.

Horizontal rectilinear cave passages

Several of the deeper caves of the Bunda Plateau intersect horizontal rectilinear cave passages 2 to 10 feet in diameter. The passages have smoothly curved walls and approximately circular cross sections. Their direction is controlled by jointing; in places they form networks in a horizontal plane and in others they form at different levels on the same joint. In Mullamullang Cave (Hill, 1960) the Ezam Extension has two levels 290 and 300 feet below the plateau (100 and 90 feet respectively above the present water table), while the Easter Extension has three levels about 20, 40, and 60 feet above the water table. Firestick Cave and Old Homestead Cave have passages 220 feet below the plateau, and Kestrel Cavern No. 1 has what is possibly the shallowest set of passages 160 feet below the plateau (about 250 feet above the present water table). Several of the passages are partly filled with well-bedded red clay.

The networks and approximately circular cross sections indicate a phreatic or epi-phreatic origin (Bretz, 1942), and the horizontality indicates control either by bedding or by the water table. The Abrakurrie Limestone in which most of the passages are developed is porous and weakly bedded, so the cave passages probably mark the approximate levels of former water tables.

DISCUSSION

The only cavities that can confidently be attributed to phreatic solution are the joint-controlled passages described above. These imply that the water table stood at various levels from 10 to about 250 feet above its present level. This elevation could have been caused either by an increase in intake of vadose water (because of a colder or wetter climate), or an elevation in sea level. Hill (1966) calculated that the water table at Mullamullang Cave is 20 feet above sea level, but my measurements indicate it is even lower, probably less than 5 feet. The cave lies 42 miles from the sea, and this exceptionally low water table gradient is probably due to the very high permeability of the limestone. Even if the climate changed sufficiently to double the intake of vadose water and so approximately doubled the water table gradient, the water table would still be only about 10 feet above sea level at Mullamullang Cave and the adjacent Kestrel Cavern No. 1. Thus any major change in the water table level in the vicinity of these caves was probably due to changes in sea level, and the passages in Kestrel Cavern No. 1 therefore indicate that the sea once stood about 250 feet above its present level for a period long enough for the cave passages to develop.

The high sea level occurred at some time between emergence of the plateau in the Miocene, and deposition of Pleistocene marine shell beds 100 feet above sea level on the Roe Plains. The sea level possibly marks the early Pleistocene 'Sicilian' high sea level recognized by some writers, but it could also have occurred at some time in the Pliocene or even Miocene.

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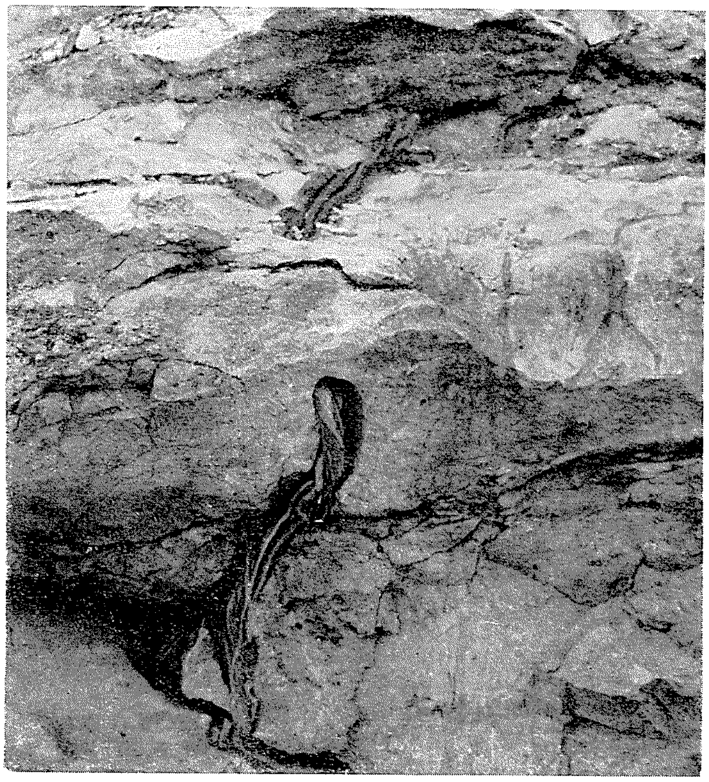
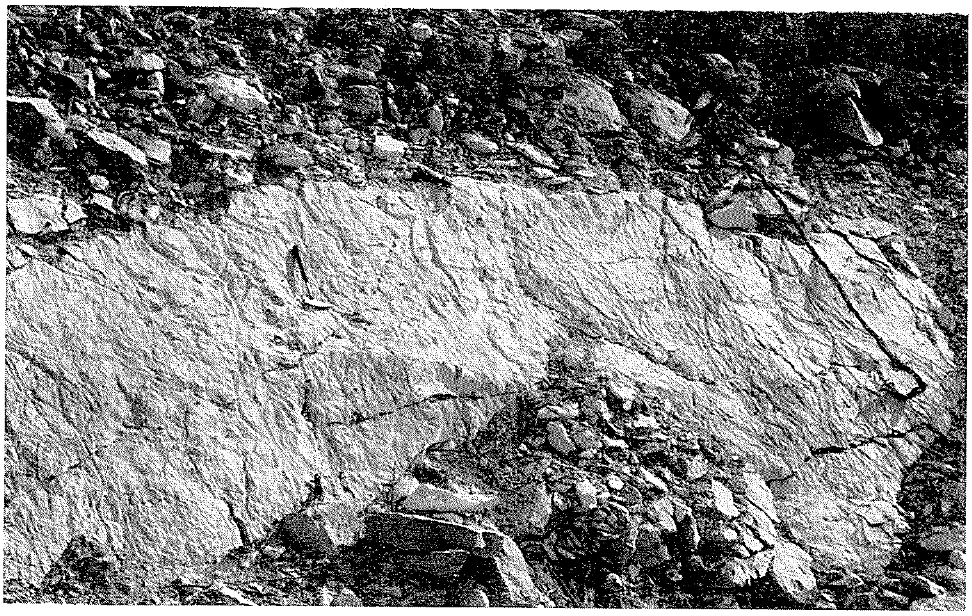


A.—Tube occupied by a bundle of tree roots, Eucla Pass. Note the anastomosis of fine tubes on the left.
FN 1362.



B.—Half tubes exposed at Kuthala Pass, 40 miles west of Eucla. Most of the tubes follow the direction of greatest slope of the fracture surface.
FN 1363.

C.—Pitted roof of Horseshoe Cave doline. The absence of cavities in the freshly exposed limestone surface on the left indicates that the cavities on the right are due to pitting and are not the ends of anastomosing tubes.
FN 1364.

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PRECAMBRIAN TECTONIC UNITS OF WESTERN AUSTRALIA

by J. L. Daniels and R. C. Horwitz

ABSTRACT

A map is presented depicting the localities and names of broad tectonic units of the Precambrian of Western Australia.

The geology of Western Australia is conveniently divisible into a number of regional units and, for ease of reference, these should be consistently named. The names chosen should be geographical and pertaining to a tectonic unit, but not so rigid as to preclude any further subdivision. This is largely established for the Phanerozoic sedimentary basins, as outlined on a map by Playford and Low (1968). In the Precambrian however, there is less consistency in the nomenclature of the tectonic units.

This paper and the map (Plate 14) present broad tectonic units with names for the Precambrian of Western Australia. For a number of these units several names have been published and it is thought necessary to tabulate these for clarification with some references. The names that we have chosen are, in most cases, selected from literature; for a few units, a new name is introduced. The boundaries on the map are as compiled by Horwitz (1966). A review of all the geochronology of the Precambrian upon which some of these boundaries are based is given in Compston and Arriens (1968): a map with a generalization of these results appeared in Peers and Trendall (1968).

It is not our intention to define the real, as distinct from the erosional limit of each unit as, in some cases, data is inadequate and not likely to be available for some time.

The Precambrian of Western Australia is subdivided into the major units listed in the accompanying table.

Name	Other names, approximate analogies, comments	Age of predominant rocks	Approximate size in sq. miles
Yilgarn Block (Prider, 1965)	Yilgarn Nucleus (Hills, 1965)	Archaean	240,000
Pilbara Block (Prider, 1965)	Pilbara Nucleus (Hills, 1965)	Archaean	20,000
Albany - Fraser Province	Albany-Esperance Block (Prider, 1965) Frazer Range (Compston and Arriens, 1968) is part of this belt	Archaean rocks. Middle Proterozoic granites and metamorphism	25,000
Gascoyne Block	....	Archaean and Lower Proterozoic rocks and Proterozoic metamorphism	25,000
Paterson Province	....	Of unknown age	12,000
Northampton Block	Northampton District (Clarke, 1931) Greenough Block (Fairbridge, 1951) Northampton Block (Hills, 1965)	Proterozoic metamorphism	14,000
Naturaliste Block	Leeuwin Block (Prider, 1965) Leeuwin - Naturaliste Block (Peers and Trendall, 1968)	Upper Proterozoic metamorphism	600
Hamersley Basin (Trendall and Blockley, in press)	Mt. Bruce Supergroup (Peers and Trendall, 1968) Part of Median Belt (of Prider, 1965, and Hills, 1965) Nullagine Basin (Daniels, 1966)	Lower Proterozoic sedimentary rocks	50,000
Bangemall Basin	Part of Median Belt (of Prider, 1965, and Hills, 1965)	Lower Proterozoic	50,000
Musgrave Block (Wilson, 1953)	Pitjentara Shield (Chewings, 1935) Pitjandjara Archaean Block (Johnson, 1963) Musgrave - Warburton Block (Wilson, 1954) Musgrave Mann Complex (Brown, Campbell and Crook, 1968)	Middle Proterozoic	18,000
Arunta Block (Chewings, 1935)	Arunta Complex (Mawson and Madigan, 1930)	Includes Proterozoic	In Western Australia 4,000
Halls Creek Province	Includes Halls Creek, Mobile Zone (Harms, 1965), and	Archaean Rocks and Lower Proterozoic igneous rocks	12,000
	King Leopold Mobile Zone (Harms, 1965)	Of unknown age	4,000
Kimberley Basin	Kimberley Block (Noakes, 1953)	Lower Proterozoic	56,000
Lake Mackay Basin	....	Middle and Upper Proterozoic	11,000
Victoria River Basin	Extension in Western Australia of the Victoria River Basin (of Aust. B.M.R., 1962)	Middle and Upper Proterozoic	In Western Australia 5,800
Rawlinson Basin	Extension into Western Australian Precambrian margin of Amadeus Trough (Amadeus Sunkland, Chewings, 1935)	Middle and Upper Proterozoic	6,000

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SAND RIDGE DISTRIBUTION IN THE GIBSON AND GREAT VICTORIA DESERTS OF WESTERN AUSTRALIA

by J. L. Daniels

ABSTRACT

The sand ridge pattern at the junction of the Gibson and Great Victorian Deserts results from a number of factors including: interference of the different wind patterns in the two deserts in a zone straddling the 26° parallel; modification by hills and ranges; and a temporary shift to the north or south of the whole wind pattern.

Sand ridges approximately 10 feet to 60 feet high and up to several tens of miles long are the main character of the Gibson and Great Victoria Deserts of Western Australia. Their general distribution and the causal wind system in both of these deserts has been studied by King (1960). A more detailed study of the orientation and frequency of the sand ridges in the Gibson Desert was undertaken by Veevers and Wells (1961).

King (1960) showed that in the Great Victoria Desert an easterly trend exists. This trend persists into South Australia where it gradually swings to the north and thence into a west-northwesterly or northwesterly trend across the Gibson Desert. The two different main trends of sand ridges in the Gibson and Great Victoria Deserts are therefore related by their physical continuation through South Australia and Northern Territory.

It is the purpose of this contribution mainly to present a more detailed plan of the sand ridge pattern in parts of the Gibson and Great Victoria Deserts and to record and interpret the pattern in the east-west zone straddling the 26° parallel at the junction of the two deserts (Plate 15).

This east-west zone is characterised by a complex pattern which is interpreted as having arisen in a number of ways:

(a) By the production of a number of large eddies in the contact zone of the two wind directions.

(b) By modification of the causal wind direction by hills and ranges. This is especially noticeable between Warburton Mission and the Western Australian border.

(c) By slight north or south shift of the whole wind pattern which apparently allowed some dunes to come under the influence, at different times, of winds from approximately opposing directions. This appears to have produced small areas of crossing dunes and also dunes with conflicting 'Y' intersections.

A minor feature of the dune pattern, indicated on the summarized diagram (Fig. 8) is a number of northeast and northwest-trending narrow zones. Some may extend for a minimum of 400 miles and cross both the Gibson and Great Victoria Deserts. They lie at approximately 45° to the causal wind direction for the regional sand ridge pattern. The writer cannot at present suggest any satisfactory explanation for these features.

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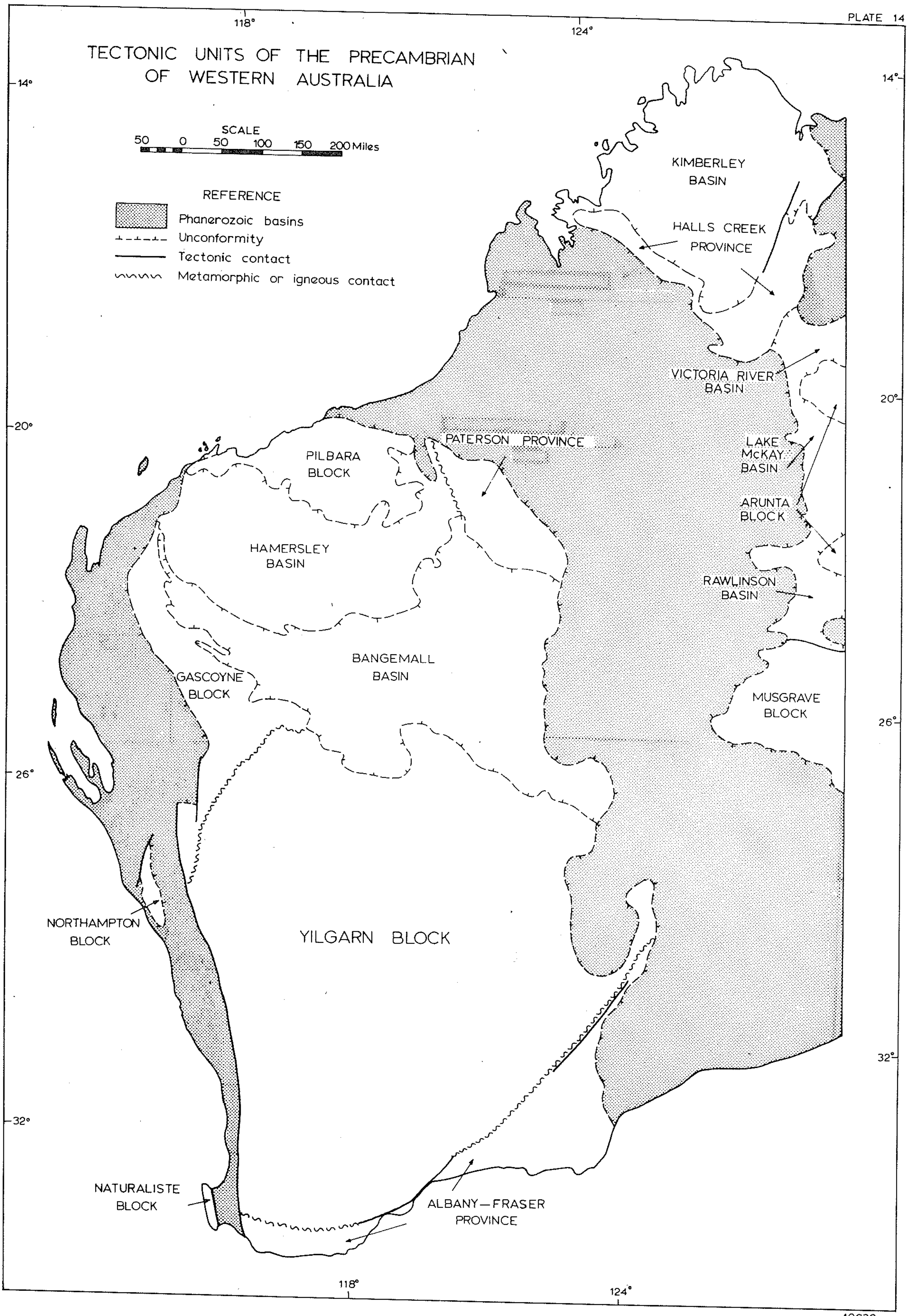
118°
124°
TECTONIC UNITS OF THE PRECAMBRIAN OF WESTERN AUSTRALIA
14°
SCALE
50 0 50 100 150 200 Miles
REFERENCE
Phanerozoic basins
Unconformity
Tectonic contact
Metamorphic or igneous contact
KIMBERLEY BASIN
HALLS CREEK PROVINCE
VICTORIA RIVER BASIN
20°
PATERSON PROVINCE
PILBARA BLOCK
LAKE McKAY BASIN
ARUNTA BLOCK
HAMERSLEY BASIN
RAWLINSON BASIN
BANGEMALL BASIN
GASCOYNE BLOCK
MUSGRAVE BLOCK
26°
NORTHAMPTON BLOCK
YILGARN BLOCK
32°
NATURALISTE BLOCK
ALBANY—FRASER PROVINCE

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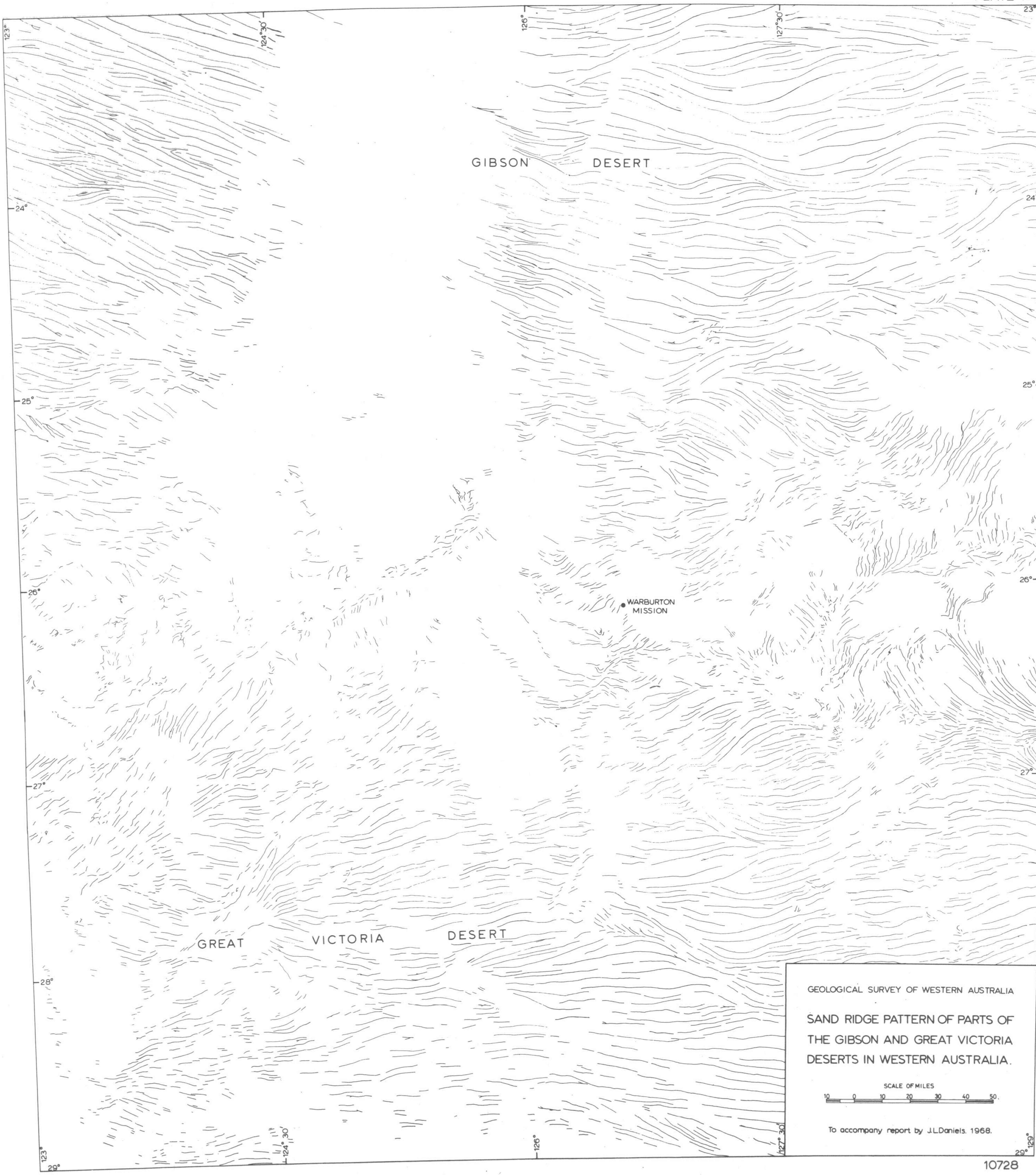

123°
124°30'
126°
127°30'
129°
23°
24°
25°
26°
27°
28°
29°
GIBSON DESERT
WARBURTON MISSION
GREAT VICTORIA DESERT
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
SAND RIDGE PATTERN OF PARTS OF THE GIBSON AND GREAT VICTORIA DESERTS IN WESTERN AUSTRALIA.
SCALE OF MILES
10 0 10 20 30 40 50
To accompany report by J.L.Daniels. 1968.

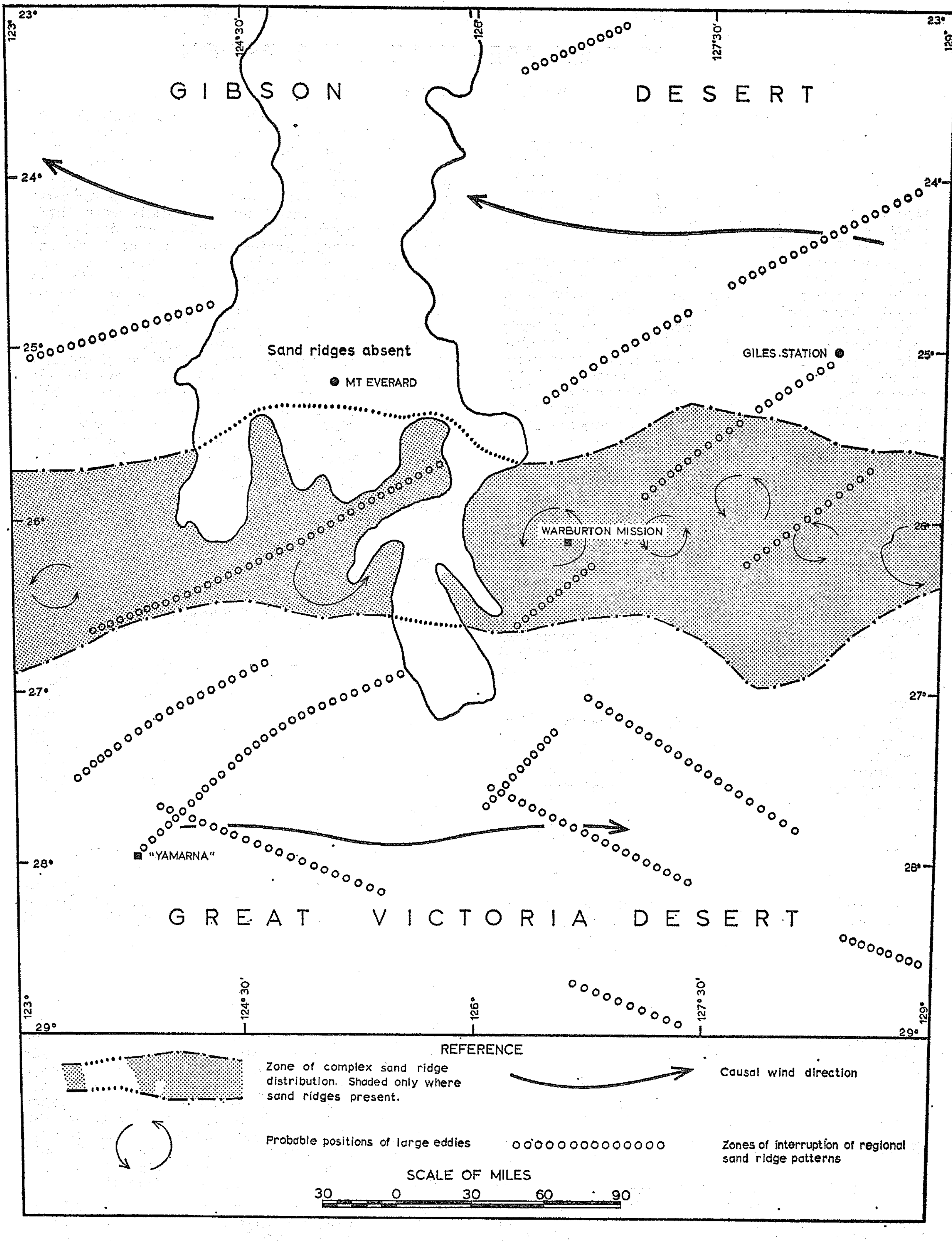


Figure 8. Summary of broad features of sand ridge distribution in the Gibson and Great Victoria Deserts.

STRUCTURAL LAYERING IN THE ARCHAEAN OF THE KURNALPI 1:250,000 SHEET AREA KALGOORLIE REGION

by I. R. Williams

SUMMARY

Regional mapping in the area east and north-east of Kalgoorlie, on the Kurnalpi 1:250,000 Sheet, has led to the setting up of a stratigraphic succession for the Archaean layered rocks. The succession consists of three basic volcanic rock associations which alternate with two associations of mixed acid volcanic and clastic rocks.

The primary control for the lithological associations is considered to be a repetitive igneous cycle. It commences with widespread extrusion of largely basic rocks interbedded with fine-grained clastic rocks and concomitantly intruded by basic and ultramafic rocks. This is followed and gradually replaced by acid effusion and intrusion in more restricted areas and by the deposition of thick clastic sequences marginal to, interlayered with, and overlaying, the acid volcanic rocks. Prominent beds of chert and banded iron formation are commonly present between the acid volcanic clastic association and the overlying basic volcanic association, and these are interpreted as representing a period of quiescence between succeeding volcanic cycles.

INTRODUCTION

The complexity of Archaean stratigraphy is well illustrated in the layered succession of the Kurnalpi 1:250,000 sheet area. The typical lenticular form of the bedding together with facies change and dissimilarity of lithology across simple structures make it difficult to present type and measured sections. A detailed description of the lithological units and type areas will be presented in the explanatory notes of the Kurnalpi 1:250,000 sheet area.

The complex stratigraphy is more easily understood if demonstrably related rocks are grouped together to form lithological associations. The resultant continuity of the associations in turn facilitates interpretation of the regional structure. The layered succession in this form can be divided into five structurally identifiable associations; basic volcanic associations (greenstone) numbered I, III, V, alternating with acid volcanic—clastic associations (whitestone) numbered II and IV (see Plate 16).

The marginal zones between the five associations were studied in some detail and genetic relationships were established between associations I and II and similarly between III and IV. These relationships are thought to represent volcanic cycles and are numbered 1 to 3 on Plate 16.

The regional extent of these associations outside of the Kurnalpi Sheet is unknown at this stage but a similar relationship is thought to exist throughout the layered rocks of the Kalgoorlie region.

STRATIGRAPHY

The regional distribution of the association is set out in plate 16 together with a generalized description of the main lithology of each association.

The basic volcanic associations I, III, and V are made up of basic to intermediate lavas interbedded with fine-grained pelitic sediments. The ratio of volcanic rocks to sedimentary interbeds varies for any given section but in most cases the volcanic material is the main constituent. Concurrent with deposition, the associations have been intruded by sills and dykes of basic and ultramafic rocks. Minor acid intrusions are present in associations I and III. The basal units of associations III and V (the base of unit I is unknown on the Kurnalpi Sheet) commonly include thick beds of ferruginous chert, jaspilite, and banded iron formation, together with some minor coarse-grained fragmental rocks. Each basic association is estimated to be between 5,000 and 15,000 feet thick.

The acid volcanic—clastic associations II and IV are both divided into two facies which are contemporaneous but spatially separate. One facies consists of acid volcanic complexes that are made up of intermediate and acid lavas, breccias, agglomerates, and large quantities of pyroclastic material. The complexes are locally very thick but are restricted in area. They are flanked by oligomictic conglomerates (clasts are acid volcanic material) which appear to be derived from the complexes by contemporaneous erosion (Horwitz and others, 1967). Thick clastic deposits make up the second part of each association. These deposits consist of greywacke, interbedded shales, siltstone, and sandstone and include thick lenses of polymictic conglomerate. The conglomerates contain a wide variety of rock types that include clasts of acid volcanic and intrusive rock, sediment, chert, jaspilite, and basic volcanic and intrusive rocks. Local disconformities are common within this type of association. Because of the mixed nature of the acid—clastic associations, the total thickness varies considerably but is thought to reach a maximum of about 30,000 feet in each case.

DISCUSSION

The alternate basic or acid—clastic layers show many lithological similarities. This broad similarity is interpreted as a repetition in conditions of sedimentation and volcanicity which can be extended to include the complete volcanic cycle (see Plate 16).

There are several small features that help to distinguish one sequence from another. Basic associations I and III contain sills and dykes of acid porphyry rocks; these are lacking in association V. This observation is also recorded by Horwitz and Sofoulis (1965) who describe a suite of basic rocks that truncate acid porphyry rocks. Basic association III contains a higher percentage of fine-grained sediments than I or V. The sediments include minor occurrences of fuchsitic schist.

Acid volcanic complexes are more numerous in association II and hence there is a higher proportion of derived and primary volcanic material in II than in association IV. Conversely there is a greater proportion of foreign clastic material in association IV than in II. Thick lenses of polymictic conglomerate are a prominent feature of association IV, whereas these are absent or only poorly developed in association II.

The broad structural trends are shown on Plate 16. A difference in fold styles between the associations suggest that unconformities probably lie between succeeding volcanic cycles, for example between cycles 1 and 2. Additional evidence gathered from a study of the marginal areas between the volcanic cycles shows that convergence and disappearance of units are present in this region. Local unconformities are also present within a cycle and may reach major proportions as in the area north of Bulong where association IV rests on eroded rock of association II.

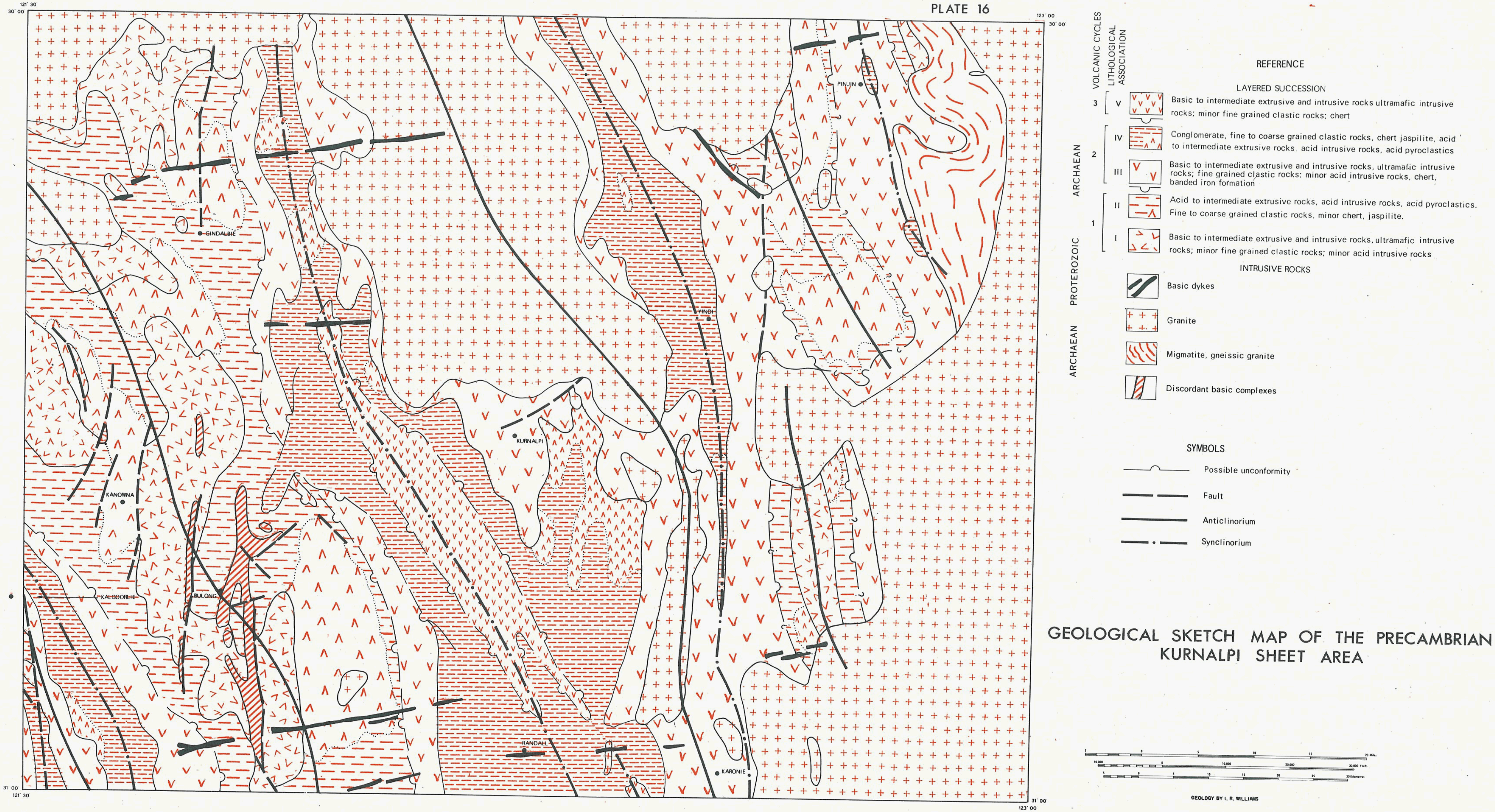
The recognition of unconformities is difficult and it is suspected that they are not continuous for long distances. They appear to be more obvious in the western half of the Kurnalpi Sheet.

CONCLUSION

The recognition of lithological association has led to a clearer understanding of the geological enrivonment and the Archaean palaeogeography in the region. A possible analogous situation may be present in some recent island arc environments, particularly where volcanic centres show rhythmic changes in composition from basic to acid lavas.

Two major points have been established from the field mapping.

PLATE 16



GEOLOGICAL SKETCH MAP OF THE PRECAMBRIAN KURNALPI SHEET AREA

(1) the grouping of rocks into lithological associations has enabled the setting up of a stratigraphic succession;

(2) the establishment of repetition in the Archaean environment has led to the recognition of volcanic cycles.

The validity of lithological associations as a workable concept has still to be fully examined.

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THE PRECAMBRIAN GEOLOGY BETWEEN ZANTHUS AND ISRAELITE BAY, WESTERN AUSTRALIA

by J. J. G. Doepel

ABSTRACT

Granites and metamorphic rocks, between Zanthus and Israelite Bay, in the southeast corner of the Precambrian Shield of Western Australia, are in a layered sequence folded into a large anticline in the core of which the lowest exposed unit is composed of the metamorphic rocks of the Fraser Range. Higher units include Proterozoic granites and metamorphosed sediments. The highest outcropping unit, exposed at the south coast, is a gneissic complex containing rocks believed to be Archaean.

INTRODUCTION

Regional mapping between Zanthus, a siding on the Trans-Australian Railway about 130 miles east of Kalgoorlie, and Israelite Bay, about 180 miles to the south and on the south coast, has shown that the Precambrian of the area can be broadly subdivided into a number of structural layers or units, as shown in Plate 17. The units trend southwest with a general steep dip to the southeast, and are covered to the northeast by the Tertiary sediments of the Eucla Basin. The region is at the eastern end of exposure of the Albany—Fraser Range Province.

SEQUENCE

Progressing across the layering, from the southeast to the northwest, the units are, in order:

(1) A strongly folded and metamorphosed complex in which at least two generations of granitic material cut remnants of quartzites and schists and are cut by basic dykes. Pegmatites cut the basic dykes.

(2) An augen gneiss; a metamorphosed biotite-rich lath granite which is thought to represent a metamorphosed margin to unit 3. It was cut before metamorphism by aplites, pegmatites and occasional basic dykes.

(3) A granite, often with feldspar phenocrysts, which in places has an imposed metamorphic foliation marked by biotite alignment and deformation of the feldspar phenocrysts.

(4) Steeply dipping quartzites and quartz-mica schists which occur in what are interpreted as two separate synclines. Only one closure, at the north end of the southern structure, is, however, exposed and no contact with granite is seen. Quartz veins are the only rocks observed cutting these metamorphosed sediments and it is unknown whether they are unconformable on the granites or folded rafts in the granites.

(5) Mixed granites. Fine and medium-grained metamorphosed granitic rocks are cut by lath granites of units 3 and 6 and both of these by leucocratic granite of unit 7.

(6) A granite, often with feldspar phenocrysts similar to that of unit 3.

(7) Equigranular leucocratic granite of varying grain size and degree of foliation. It contains many thin rafts of biotite-rich granular rock. It is younger than the lath granite which it invades with numerous dykes that trend north and northeast. Many aplites and microgranites cutting the gneissic granites and the granulites of the Fraser Range are thought to be related to this granite. These aplites and microgranites have themselves undergone some metamorphism.

(8) A garnet-biotite-quartz-feldspar gneiss in which feldspar augen are presumably after original feldspar laths in a lath granite. It intrudes basic rock near Newman Rock and is intruded by leucocratic granite. It is cut by northeast-striking bands of mylonite.

(9) The metamorphic complex of the Fraser Range contains basic granulites, cut, before or during metamorphism, by acid veins and dykes, some of which have a rapakivi texture. Later aplites cut these rocks parallel to the metamorphic foliation. The granulites contain pods of metamorphosed norite which are either less affected residuals or intrusions emplaced during metamorphism. A zone of amphibolite grade metamorphism is present along the western side of the complex. The acid dykes and the aplites have undergone cataclasis of varying degree and several bands of mylonite are present at the western margin of the complex. The other margins are nowhere exposed but may well also be zones of shear or of faulting.

Compston and Arriens (1968) report that "The granulite facies rocks . . . give an isochron of 1330 $\pm$ 15 m.y., with initial $^{87}Sr/^{86}Sr$ of 0.705 $\pm$ .001". They also report that, "studies now in progress suggest that the flanking augen gneisses that lie on either side of the granulite-facies rocks . . . have ages several hundred million years older than the granulites, whereas the granitic rocks further east at Balladonia could be younger". It is likely that both the lath granite of unit 6 and the leucocratic granite of unit 7 were included in this last younger group.

(10) Mixed granites. At least three ages of granites are present.

(11) About 6 miles south of Coonana the granites are cut by strong north-northeast shearing, and a sheared serpentinite, possibly intrusive, is present in this zone.

(12) About 30 miles north of Israelite Bay a thin unmetamorphosed feldspar-phyric

dolerite dyke, trending 056°, intrudes metamorphosed granites.

No basic dykes have been observed cutting the lath granites of units 3 and 6, the leucocratic granite of unit 7, or the gneissic granite of unit 8.

STRUCTURE.

Morgan, Horwitz and Sanders (1968), describing the structural layering of the Precambrian rocks of the Archipelago of the Recherche, found that mixed gneisses, believed to be Archaean, which may be correlated with unit 1 of this paper, were the highest exposed rocks of a broad southwest plunging anticlinorium. A lath granite, unit 6 of this paper, was the deepest rock exposed in the area described by them. It is here suggested that units 7, 8 and 9 are successively still lower layers; unit 9, the metamorphics of the Fraser Range, being the core of the anticlinorium. It is not suggested that the mixed granites of unit 10 are the direct equivalent of any one of the units to the southeast.

The presence of basic dykes in the gneisses and their absence in the lower units is continued to the west (Morgan, Horwitz and Sanders, 1968).

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INVESTIGATION OF MINISTERIAL RESERVE 4538H, LAKE YINDARLGOODA, BULONG DISTRICT, W.A.

by J. Sofoulis, X. K. Williams, and D. L. Rowston

ABSTRACT

The gossans on Ministerial Reserve 4538H are interpreted as visible geological indications of stratiform sulphide concentrations and are presumed to have been formed in place by the oxidation of disseminated or massive sulphides, probably pyrite.

Although the geological environment is favourable for base metal mineralization, an integrated geological, geochemical, and geophysical survey indicated no significant metal sulphide concentrations other than iron. However, some anomalous geochemical and geophysical results were obtained locally from the main gossan and from the adjacent lake floor area.

A diamond drilling programme to test some of these anomalies has been outlined.

INTRODUCTION

Ministerial Reserve 4538H was created with the intention that the Geological Survey of Western Australia carry out an integrated geological, geochemical and geophysical investigation on the limonitic gossans contained therein, to ascertain whether such gossans indicate the presence of base metal sulphides.

The Reserve lies within Hampton Hill Station owned and operated by C. B. Jones and Sons of Bulong (19 miles east of Kalgoorlie). The gossans occur near Rocky Dam, on the northwestern margin of Lake Yindarlgooda, approximately 19 miles northeast of the station. Access over the area is by graded station tracks as shown on the locality map (Plate 18).

Air photographs, at a scale of 1,000 feet to 1 inch, and photo enlargements, at a scale of 200 feet to 1 inch, were used for geological mapping of the Reserve area and for the more detailed investigation of the main gossan zone (outline dotted on the locality map). The initial phase of the programme was aimed at defining the geology and structure of the area (J. Sofoulis) with subsequent geochemical and geophysical work over selected parts of the main gossan zone (X. K. Williams and D. L. Rowston respectively). The field work was carried our during the period July to September, 1968.

A more detailed report on this Reserve is given by the same authors in G.S.W.A. Record 1968/17.

PHYSICAL FEATURES

The general area, with a rainfall 9 to 10 inches per annum, can be described as semi-arid and is characterized by salt lakes and remnant soil plains. Ferruginous gossans, associated with banded chert marginal to Lake Yindarlgooda dominate the topography as scrub-covered strike ridges extending discontinuously down the length of the Reserve. Topographic relief in these localities is up to 200 feet. There are other prominent chert bands and some smaller gossans in the northwestern part of the Reserve area, west of the main gossan line. An elevated plateau surface developed over conglomerate in the northern part of the Reserve is delimited by a prominent escarpment up to 100 feet high.

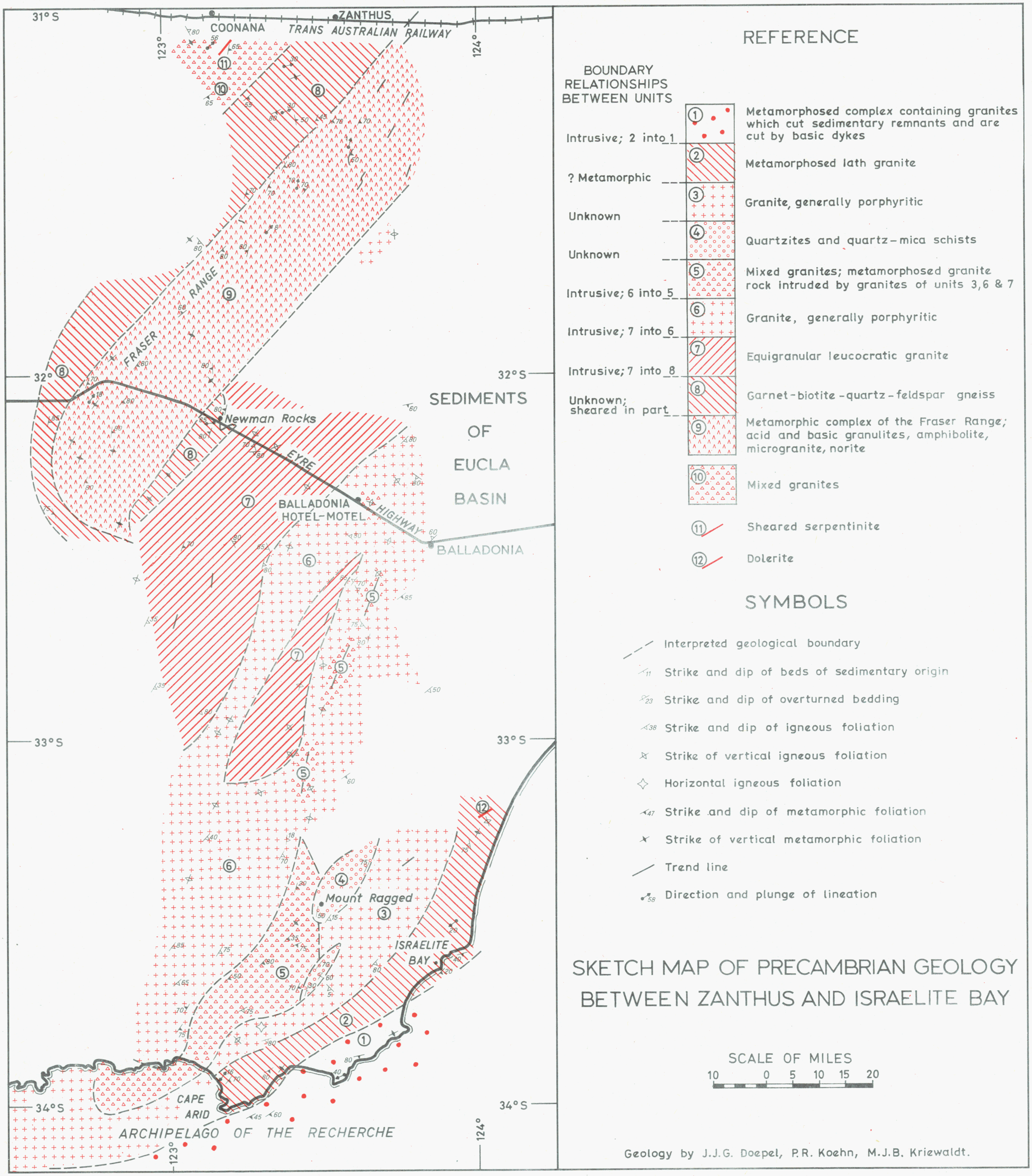
Elsewhere the Reserve area is of low relief, with small erosion escarpments (to 50 feet) in the dissected parts; intervening areas of soil-covered plains support eucalypt and acacia woodlands interspersed with salt bush and blue bush meadows. These areas contain scattered exposures of weathered bedrock and widespread veneers of quartz debris derived from the more resistant quartz dykes. The eastern and southern parts of the Reserve area are occupied by bare salt lake floors of Lake Yindarlgooda.

STRATIGRAPHY AND GEOLOGICAL SETTING

Three major Archaean units separated by probable unconformities have been recognized in the Reserve area. These units are equated with rock association units II, III, and IV as mapped on the Kurnalpi sheet by Williams (1969), (see Table 1). Their distribution over the Reserve area is shown on Plate 18.

TABLE 1. ROCK ASSOCIATION UNITS

Unit	Kurnalpi 1 : 250,000 Sheet Area (After Williams, 1969)	Ministerial Reserve 4538H Area
V	Basic to intermediate extrusive and intrusive rocks; ultrabasic intrusive rocks; minor fine-grained clastic rocks, chert	Unit not represented
IV	Conglomerate, fine to coarse-grained clastic rocks; chert, jaspilite, acid to intermediate extrusive rocks and acid intrusive rocks, acid pyroclastics	Conglomerate, fine to coarse-grained clastic rocks
III	Basic to intermediate extrusive and intrusive rocks, ultrabasic intrusive rocks, fine-grained clastic rocks; minor acid intrusives, chert, banded iron formation	Basic extrusive and intrusive rocks, dolomite, graphitic shales, siltstone, conglomerate ?tuffs, chert
II	Acid to intermediate extrusive rocks and acid intrusive rocks, fine to coarse-grained clastic rocks, minor chert, jaspilite	Acid to intermediate extrusive rocks, fine to coarse-grained clastic rocks
I	Basic to intermediate extrusive and intrusive rocks, ultrabasic intrusive rocks; minor fine-grained clastic rocks; minor acid intrusives	Unit not represented



SKETCH MAP OF PRECAMBRIAN GEOLOGY BETWEEN ZANTHUS AND ISRAELITE BAY

UNIT II

Acid volcanics are the oldest rocks exposed in the Reserve area. These are mainly sericitic, chloritic schist and phyllite, and are confined to to the area south and southeast of Rocky Dam, where they form a thick pile at the base of the unit. Intermediate volcanics in the middle and upper part of the sequence are separated by, or interfinger with, pyroclastics, tuffs, and fine and coarse-grained clastics. Closely interstratified tuffs are gradational with the clastics and are discontinuous laterally. Thicker beds of clastic rocks (e.g. west of main gossan line) include greywacke, sandstone, arkose, and conglomerate. Observations on grading and cross bedding confirm that the sediments are facing east and that they are right-way up.

UNIT III

Chert beds and their associated limonitic gossans are interbedded with pelitic schists and other recognizable clastic sediments in the lower part of this unit. The uppermost chert beds are commonly pyritic with variable concentrations of single, perfectly formed crystals, now replaced by limonite.

Broad belts of altered basic volcanic rocks (meta-basalt and gabbro) with interbeds or stratigraphic equivalents of siltstone, shale, greywacke, dolomitic limestone, graphitic beds, and conglomerate, are found in the upper part of this sequence.

An unconformable relationship between this unit and the underlying unit is inferred from the slight discordance in bedding and schistosity noted between rocks of Unit II and those of Unit III, and from the fact that the various volcanic and sedimentary phases of Unit II are progressively truncated by rocks of Unit III along the southeastern extension into Lake Yindarlgooda.

UNIT IV

Conglomerate with interbedded greywacke of turbidite affinities rests with structural discordance on the rocks of Units III and II in the northern and northwestern part of the Reserve area. The conglomerate consists of an assortment of closely packed, well-rounded pebbles, cobbles and boulders, which collectively comprise up to 30 per cent of the rock. The matrix is coarse, gritty greywacke to sub-greywacke which also forms thin and thick bands separating layers and lenses of conglomerates.

The contact between this Unit and the underlying Unit is concordant in the southeastern part of the Reserve area, but to the northwest the conglomerates and greywackes of Unit IV fill hollows or embayments in the old erosion surface formed on Units II and III.

STRUCTURE

Isoclinal fold structures are aligned north-northwesterly and correspond to the regional fold trends observed in the eastern goldfield areas. The strata dip moderately to steeply northeast, so it is probable that some of the folds, such as those in the western part of the Reserve area, are overturned to the northeast.

Lineations, as indicated by alignment of mineral grains, plunge 30 to 40 degrees in a north-northwesterly direction and correspond in amount and direction to minor drag folds observed. The folded chert beds with which the gossans are associated, lie on an eastern limb of a north-northwesterly plunging anticline, while the repeated chert beds further west constitute a complex synclinorial trough similarly plunging north-northwest.

Two major sets of steeply dipping faults at right angles to each other, have affected all units. These trend north-northeast and west-northwest and are oblique to the strike of bedding. The faults were probably formed at the same time by the same diastrophic compressional forces. An alternation between the two fault directions is noted along the major chert belts. Faults of north-northeast trend predominate where strata are convex to the southwest, whilst those of west-northwest trend predominate where strata are convex towards the northeast.

In these faults, the horizontal component of movement is small, but it seems probable that vertical movements were more severe, causing truncations or divergencies in the rock belts. Many of the faults are quartz-filled or have quartz lenses along their strike extensions.

Fault lineaments, such as those prominent on the lake floors, are often continuous with known fault lines, and are locally marked by discontinuous quartz lenses.

LIMONITIC GOSSANS

Limonitic gossans are associated with the pyritic schists and cherts of the lower part of Unit III. This geological environment has similar characteristics to other Shield areas in which base metal deposits have been found. These gossans are interpreted as visible geological indications of stratiform sulphide concentrations and have presumably formed in place by oxidation of disseminated or massive sulphides, probably pyrite. They are classified as indigenous in the sense of Hill (1962) since they simulate the shape and structure of ore bodies.

The indigenous gossans range in thickness from a few inches up to 20 feet or more and are discontinuous along strike, with separate lenses being from a few feet to more than a thousand feet long. Their size however may not necessarily be proportional to that of the source sulphide deposits. The most common variety of gossan is a lightweight, slaggy, and spongy limonite which is very tough and hard to break with a hammer. The colour of these gossons is mainly dark reddish-brown, usually with a black patina, and locally with limonitic orange coatings. Larger voids within the gossans are commonly lined with microbotryoidal structures and microscopic films of irridescent yellow, red, green and blue-black limonite. Minor box works are mainly of silica, deposited as a very fine vein filling of microcrystalline quartz and arranged in small radial or comb structures.

More exotic vuggy gossans have a high porosity and form a spongy type of gossan resembling brown and yellow pumice. These are interpreted as a superficial form of indigenous gossan. Discontinuous and narrow ferruginous gossans cutting across structure are migrative forms of gossan probably related to ferruginization or oxidation of concentrated sulphides along fault or shear lines. Other thin gossanous lines paralleling the bedding are associated with sulphide-bearing graphite schists and dolomite/graphite beds.

Prominent banding in the indigenous gossan is attributed to the original bedding planes of the host rock and in many instances the gossan may contain thin bands of pyritic jaspilite or chert, and narrow schist zones.

Isolated patches of limonitic gossan form strike extensions of the indigenous type or may appear as separate masses that are apparently in place and independent of the main gossan lines. Minor turquoise (a hydrous phosphate of aluminium and copper) was recorded below the main gossan in the northwestern part of the area. (Grid 1). The upper cherts and associated sediments commonly contain pyrite casts and limonite pseudomorphs after pyrite. These are mainly concentrated along the schist and chert foliae close to the developed gossan. However, no surface indications of copper or other metal sulphides other than iron were observed in the gossan.

GEOCHEMISTRY

SAMPLING

Two groups of samples were collected for geochemical analysis. Gossan samples were taken to obtain information about the gossan itself, and to locate possible indications of underlying economic base metal mineralization. Lake floor samples were collected from two grids (1 and 5) in which geophysical work had already been done and some significant electromagnetic anomalies found. Correlations between the geophysical and geochemical results were sought, also any interdependence of the gossan and lake floor results.

Representative samples were collected at intervals of 100 to 200 feet along the length of the main gossan, and from smaller gossans occurring close to, or as branches of, the main one. Other isolated gossans within the Reserve area were also sampled. The localities and results are shown on the geological map (plate 18).

The lake floor samples were collected at intervals of 25 feet from 18 lines in the two grids, mid-way between the geophysical centres to avoid the possibility of contamination. At each locality the surficial material was removed and the sample collected from the weathered sub-outcrop, usually at a depth of 3 to 12 inches. The samples were dried and sieved prior to analysis of the fine fraction.

RESULTS

All samples were submitted to the Government Chemical Laboratories for analysis by atomic absorption spectroscopy. The results from the gossan samples are shown on Plate 18, and anomalous samples from Grid 5 in Table 2.

The mean concentrations of copper, cobalt, nickel, and lead in the gossan are similar to or higher than those from the lake floor samples (Table 3). The concentration of zinc is higher in the lake floor samples suggesting possible accumulation by weathering, as zinc is the most mobile of the elements studied. Silver is relatively immobile, its mobility being reduced by co-precipitation with manganese, and thus occurs in greater concentration in the gossan.

The anomalous results from samples of the gossan fall into two groups, both of copper, cobalt, zinc, lead, and silver, no nickel (see Table 4). One group is in and north of Grid 1, and the other in and south of Grid 5. At the southern end of the gossan there are several copper anomalies. Another gossanous area, in the northwest of the temporary reserve, shows significant nickel, cobalt, and zinc concentrations.

Of the lake floor samples, the average and range of metal content of samples from Grid 5 is higher than for samples from Grid 1. Silver is the only element whose mean concentration is higher in Grid 1 than Grid 5. Lead, with which silver is often associated, is only slightly higher in Grid 5. The mean concentration of the other elements is between 2.4 and 3.2 times higher in Grid 5. The ranges of concentration of copper, cobalt, nickel, and zinc are greater in Grid 5, and of silver and lead in Grid 1.

There are very few anomalous results from Grid 1. Samples with anomalous lead and silver occur in lines 4N and 6S and follow the occurrence of gossanous rocks, which also contain high concentrations of lead and silver. Other anomalous samples, in lines 4N and O, are associated with gossanous outcrops and graphitic dolomite. There are a few scattered copper and zinc anomalies which are probably local variations and of little significance.

Grid 5 contains one major anomaly (Table 2) between and including lines 11S and 15S. The anomaly is essentially copper, cobalt, nickel, and zinc, with some lead. It extends from a width of 25 feet on line 10S to a maximum of 350 feet on line 15S, and continues on through line 17S. There are some scattered cobalt and nickel concentrations in line 19S which are possibly related to its proximity to the basalt. Of the gossan samples in and near Grid 5, the four collected between lines 10S and 17S have anomalous concentrations of lead, one has some copper, and the sample from line 19S has anomalous cobalt.

There are other isolated anomalies, on lines 3S, 5S, 7S, 8S, 9S, and 10S; these may be associated with the main anomaly, but are probably local variations and of minor significance.

The main anomaly may either be caused by the weathering processes that produced the gossan, or by the presence of anomalous underground concentrations of these elements. If the gossan at this point had high base metal concentrations initially the weathering effects of decomposition and erosion would have caused these elements to be removed from the acidic environment of the gossan and deposited on the lake floor. However, at this point the gossan forms a slight topographical arc and this could cause an accumulation of drainage material in the area; further dispersion would be limited by the higher pH on the lake floor, relative to the gossan. If this is the origin of the anomaly, no anomaly within the gossan is necessarily indicated. Possible subsurface sources of the anomaly are:

(a) leakage anomalies from underlying sulphides that give rise to the present gossan,

(b) the presence of underlying, near surface rocks with high base metal content, such as the graphitic shale and dolomite.

From the results obtained it is clear that the two grid areas are adjacent to gossans that are relatively rich in base metals. The concentrations obtained are low compared to others found in the Kalgoorlie District, but they were mainly from areas of basic and ultrabasic country rock, where base metal concentrations are normally high, even in background areas. On the other hand, acid rocks in the Reserve area have relatively low background levels of base metal content, so lower intensity anomalies may be correspondingly more significant. The very high cobalt concentrations are interesting, particularly as less work has been done on cobalt than on the other elements, in this district.

TABLE 2. ANOMOLOUS RESULTS ON LINES 11S AND 15S GRIDS

Sample Nos.	Concentrations in parts per million					
	Ni	Zn	Co	Pb	Ag	Cu
Line 11						
B 114	75	1000*	110*	80	x	300
115	75	990*	85	60	1	260
116	160*	1200*	280*	200*	1	400*
117	160*	875*	400*	120*	1	480*
118	140	580	70	90	1	450*
119	120	360	95	120*	x	460*
120	160*	1200*	270*	110	x	320*
121	80	250	65	90	2	270
122	175*	440	115*	100	1	190
123	175*	920*	125*	100	1	160
A' 124	200*	840*	185*	100	1	440*
Line 15						
B 133	50	260	30	120*	x	479*
134	100	150	50	90	x	205
135	360*	1900*	170*	100	1	625*
136	150	550	110*	80	1	490*
137	200*	420	55	70	1	180
138	400*	1550*	300*	40	1	630*
139	400*	1270*	480*	80	1	260
140	175*	770*	120*	80	x	320*
141	780*	2120*	1060*	60	x	510*
142	650*	820*	185*	70	1	275
143	650*	2100*	900*	50	x	1100*
144	180*	650	140*	40	x	270
145	480*	460	10	50	1	1100*
B' 146	80	130	55	120*	1	170

* = anomalous results.

TABLE 3. MEAN AND RANGE OF RESULTS

Metal	Gossan		Grid 1		Grid 5	
	Mean p.p.m.	Range p.p.m.	Mean p.p.m.	Range p.p.m.	Mean p.p.m.	Range p.p.m.
Cu	153	15–400	68	5–550	177	0–1100
Co	65	5–60	18	0–100	58	0–1060
Ni	68	20–280	34	0–180	81	0–780
Zn	152	5–850	117	5–800	291	0–2400
Pb	62	20–400	46	0–250	59	0–200
Ag	1·4	0–6	0·77	0–4	0·46	0–3

TABLE 4. THRESHOLD CONCENTRATIONS AND DISTRIBUTION OF RESULTS

Metal	Gossan		Lake Floor	
	Threshold p.p.m.	Anomalous results per cent.	Threshold p.p.m.	Anomalous Results per cent.
Cu	270	12·4	310	5·8
Co	30	11·5	100	5·9
Ni	140	6·2	130	7·6
Zn	300	10·6	700	4·0
Pb	130	8·0	110	4·3
Ag	3	8·0	2	4·3

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF
MINISTERIAL RESERVE 4538H
LAKE YINDARLGOODA
BULONG DISTRICT, W.A.

SCALE
FEET 0 400 800 1,200

Geology by John Sofoulis, Oct. 1968

10571

PLATE 19

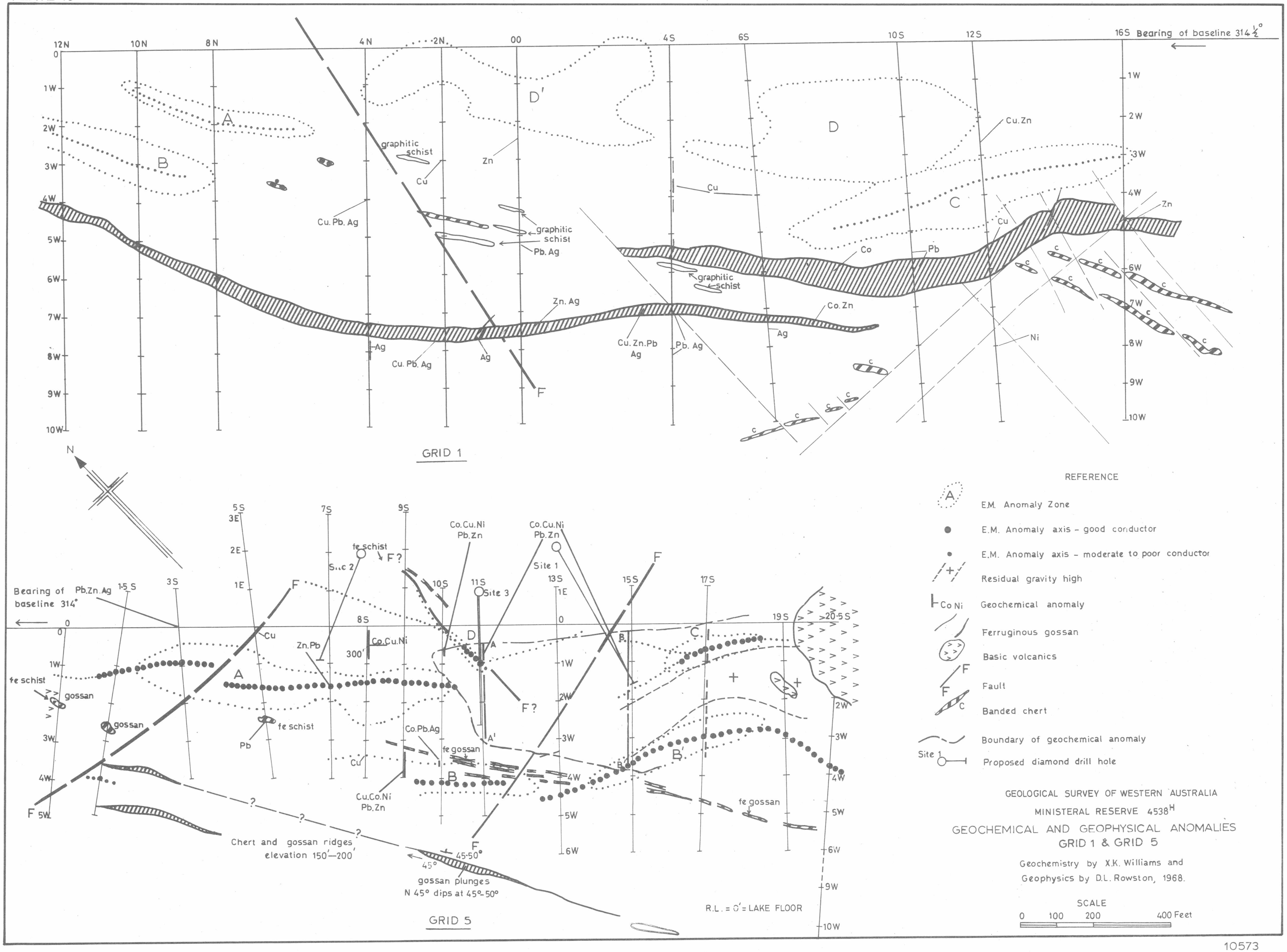


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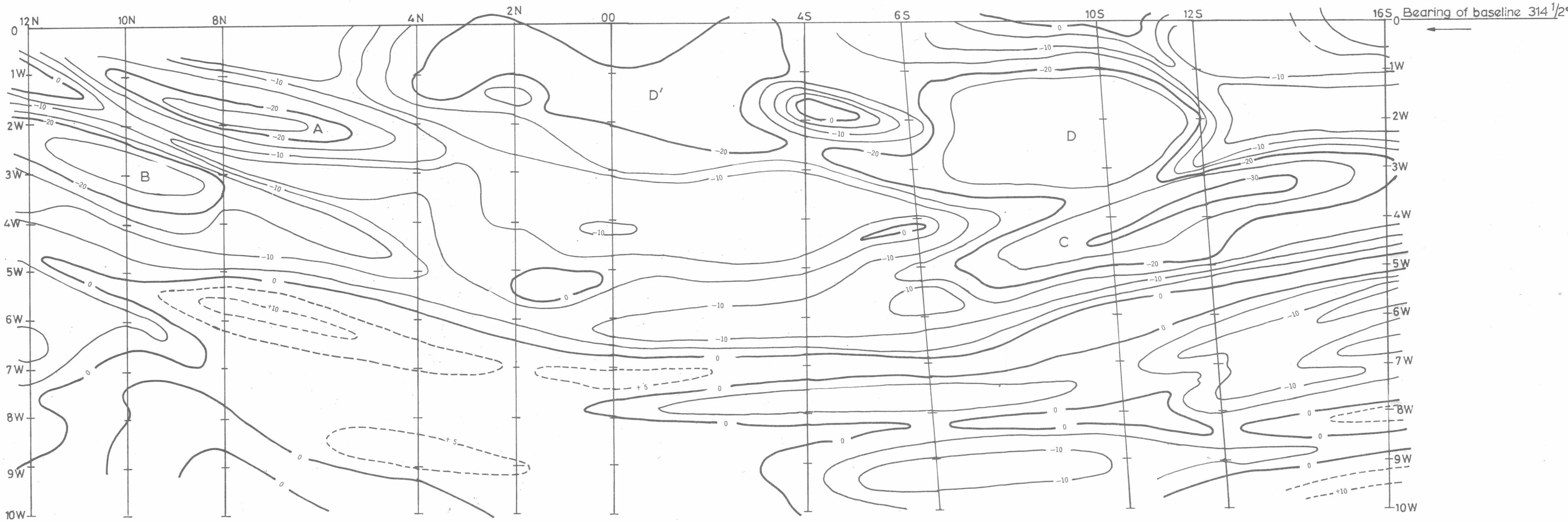
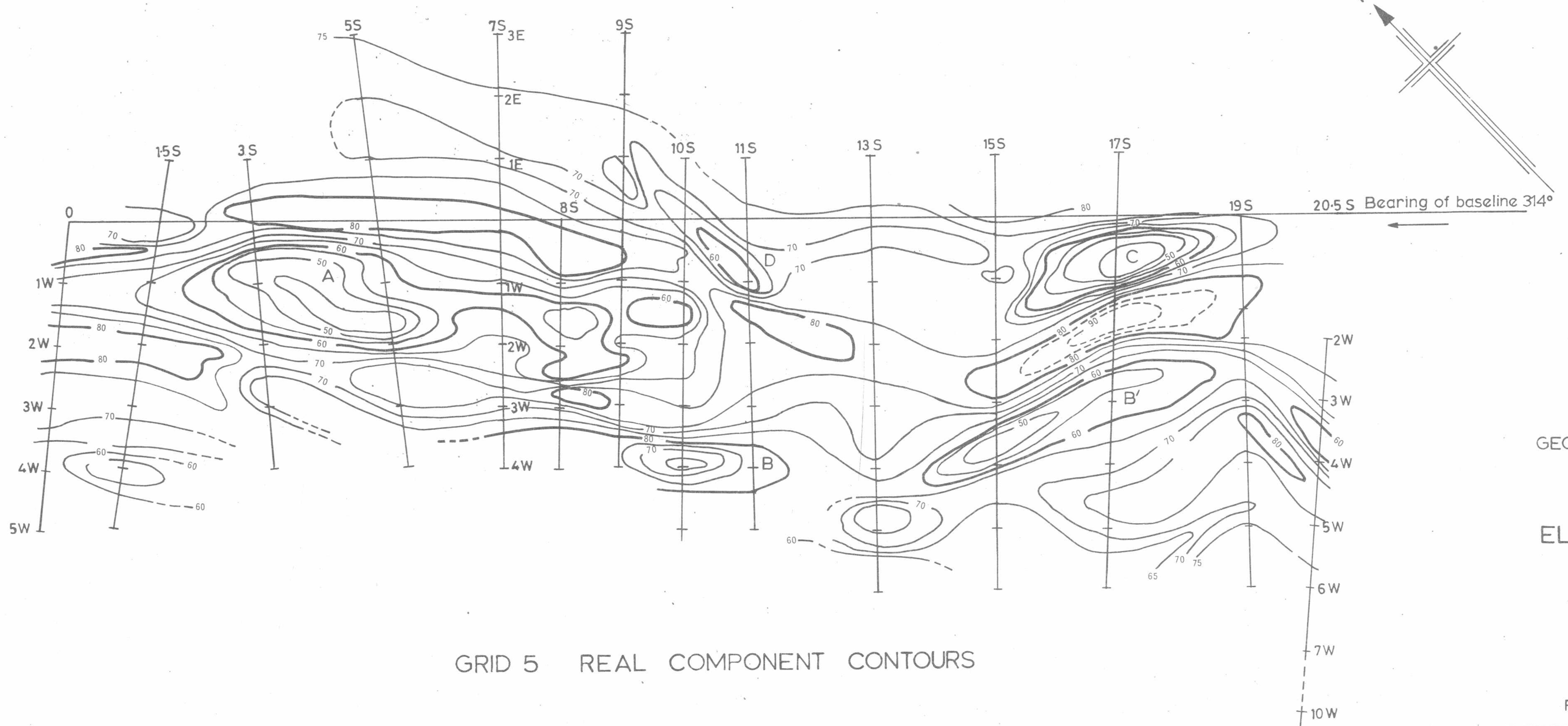
PLATE 20



GRID 1 IMAGINARY COMPONENT CONTOURS



GRID 5 REAL COMPONENT CONTOURS

NOTES

ABEM EM GUN EQUIPMENT
COIL SPACING 100 feet
FREQUENCY 440 cps
STATION INTERVAL 25 feet
CONTOUR INTERVAL R and I 5%
VERTICAL DIPOLE IN-LINE ARRAY

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINISTERIAL RESERVE 4538H

ELECTROMAGNETIC CONTOURS
GRID 1 and GRID 5

SCALE

0 100 200 400 FEET

Field work by D. L. Rowston, Sept. 1968.

10574

GEOPHYSICS

The geophysical phase of the investigations which included magnetic, electromagnetic self potential, and gravity methods, was restriced to several small grids over the more interesting outcrops of ferruginous gossan. The localities of Grids 1, 2, 3, 5, and 6 are shown on the geological map (Plate 18). Grid coordinates with respect to an arbitrary grid zero are given in units of 100 feet. For example coordinate 5/17S/6W denotes Grid 5, the traverse 1,700 feet south of the origin and the observation point 600 feet west of the baseline.

DISCUSSION OF RESULTS

Of the four geophysical methods used on Ministerial Reserve 4538H the electromagnetic proved to be the most effective, albeit with the reservation that to this time a metallic sulphide body has not been discovered. There were no obviously significant results from application of the potential and gravity methods and the ground magnetic survey confirmed the aeromagnetic indications that most of the localities were magnetically undisturbed.

The electromagnetic results varied considerably depending on the environment. Pronounced variations in conductivity were generally confined to the lake floor whereas there was little variation in conductivity on the more elevated areas, such as the ridge along which a large part of the main gossan is situated. The conductivity contrasts on the lake are probably enhanced by penetration of saline water into the more porous and deeply weathered rocks; the resistant rocks would thus appear as relatively poor conductors. Although this factor contributes toward the electromagnetic component configurations, the method can still detect other good conductors. For instance most of the graphitic schists in the area coincide with anomalies and there is no reason to believe that massive sulphides cannot be detected.

The most interesting geophysical indications were obtained in Grid 1 and Grid 5, and further discussion will be confined to these areas with reference mainly to the data shown on Plate 19. Plate 20 consists of contour plans of the EM work; the I component for Grid 1 and the R component for Grid 5. The latter are considered more diagnostic for Grid 5, whereas in Grid 1 spurious anomalies from topographic effects over the main gossan confuse the pattern. Conductor axes determined from vector diagrams, and conductive zones, arbitrarily the -20%I and 60%R contours, together with the essential geology and geochemical results are shown on Plate 20.

Grid 1

In general the EM contours exhibit the same linearity and trends as the mapped sediments and volcanic rocks. Practically all the geophysical anomalies are east of the main gossan and these have been designated A, B, C, D, and D', The western side of the layout is markedly free of indications except in the southwest corner, over kaolinitic tuffaceous sediments.

Anomaly C (Plate 20), which extends from about 7S to 16S, represents a narrow conductor dipping steeply to the east; the axis is displaced on the down dip side of the gossan as would be expected if the conductivity were caused by fresh sulphides at depth. A tabular sheet of graphitic slate or schist would produce an equivalent anomaly. As the geochemical assays from the gossan over this sector were not encouraging it is most likely that pyrite is the only sulphide present.

The only other anomalies that may be related to mineralization are A and B in the northern part of the grid. They are due to relatively good conductors but their small dimensions preclude serious consideration. Their alignment with the mapped dolomitic and graphitic beds to the south suggest that those beds may be the sources of the anomalies.

D and D' are broad features unsupported by a real component anomaly and are thus classified as poor conductors; they probably represent either more deeply weathered rocks or broad depressions in the lake, infilled with saline sediments. In view of the lack of supporting evidence from the geochemical survey, anomaly C, which is the only one of interesting proportions in this area, is not recommended as a drilling target.

Grid 5

Investigation of Grid 5 commenced with an examination of the two small limonitic gossans on traverses 00 and 1.5S (Plate 20). The northern extremity of anomaly A was detected, and the grid was then extended to cover the small embayment defined by basic volcanic outcrops at the ends of the baseline. Operations were confined to the lake bed although Line 20.5S was later taken to 10W to test the main gossan.

A thin veneer of sediment prevented effective mapping of the lake floor and, with the exception of several isolated features protruding above the surface, the geology is unknown.

An interesting electromagnetic contour pattern (Plate 19) was obtained over this layout and intensive geochemical sampling was carried out to assist the interpretation of the main anomalies. Contrary to Grid 1, the R component here showed much more detail than the I component which failed to emphasise some of the less prominent features such as the fault cutting anomaly A.

Four anomaly zones have been defined, A, B and B', C, and D.

A is the most outstanding geophysical indication observed to the present on the Reserve. It is attributed to a tabular conductor dipping steeply to the east and has a strike length of 1,000 feet. There are three possible sources for this anomaly, sulphide mineralization, graphitic beds, or saline clay. A projection of the main gossan to the base of weathering, with due allowance for dip and plunge, supports a sulphidic origin. In addition, saline clays should give a more regular pattern and not exhibit the minor flexure corresponding to the fault; anomalies associated with graphitic beds are usually narrow as typified by anomaly B which is attributed to this source.

Unfortunately the geochemical results show only spasmodic and minor base metal values in the vicinity of the zone, and it must be concluded that, like anomaly C in Grid 1, if sulphides do occur they are mainly pyrite.

Anomaly B and the southern continuation of B', are ascribed to a graphitic bed and appear unrelated to the stringers of gossan mapped along the lake margin. Although a southeast-trending fault intersects this anomaly at about 12S there is no marked disclocation of the geophysical zone at this point.

Anomaly C, whilst indicative of a good nearly vertical conductor of limited dimension, has not been assigned an origin. It is roughly parallel to anomaly B', and a weak gravity high indicates that the two are probably separated by basic volcanics.

Because of its transverse strike and the general lack of indications immediately south of Line 11S, anomaly D was originally interpreted as a fault responsible for the abrupt termination of anomaly A. However, with the exceptions of a tenuous relationship to an outcrop of a ferruginous schist and the fact that the northeast strike is common to other faults elsewhere along the gossan, the geological mapping has not supported this belief. The anomaly is minor by geophysical standards but the geochemical results have enhanced its importance.

CONCLUSIONS

The limonitic gossans of Ministerial Reserve 4538H lie in a geological environment which has similar characteristics to other shield areas in which base metal deposits have been found. The gossans are interpreted as visible geological indications of stratiform sulphide concentrations and are presumed to have been formed in place by the oxidation of the disseminated or massive sulphides, probably pyrite.

Although some minor turquoise was recorded stratigraphically below the main gossan (near Grid 1), no relic mineral or boxwork structures indicative of particular metal sulphides other than iron sulphide (pyrite) were detected in the gossans. However, some anomalous geochemical and geophysical results were obtained from the gossan and from the adjacent lake floor areas.

The more intense geophysical and geochemical anomalies are in the lake floor area of Grid 5. These anomalies may be related to the main gossan, or may be attributable to minor gossanous developments associated with sulphide deposits, or sulphide-bearing dolomite/graphite beds. It is noted however, that the higher geochemical values are not necessarily coincident with geophysical anomalies. It is also stressed that the maximum concentrations shown by the geochemical results are not high, and that the presence of economic mineralization, while not ruled out, has not been positively indicated.

A diamond drilling programme based on the geochemical and geophysical results is recommended to test the Grid 5 area. Three proposed holes (Plate 19) are designed to intersect geochemical and geophysical anomalies below the zone of oxidation as well as to test the main gossan in depth. The holes are, in order of preference, at the following sites:

Site 1: Grid 5/13S/2E, to test the geochemical anomaly B/B' and geophysical anomalies B' and C below the zone of oxidation. Hole to have azimuth 194°, depression 45°, and length approximately 600 feet.

Site 2: Grid 5/8S/2E, to test the geophysical anomaly A (probably due to the main gossan), below the zone of oxidation. Hole to have azimuth 245°, depression 45°, and length approximately 500 feet.

Site 3: Grid 5/11S/1E, to investigate the geochemical anomaly A/A' between 100 and 200 feet vertical depth, and possibly geophysical anomaly D and the main gossan zone at depth. Hole to have azimuth 224°, depression 45°, and length approximately 600 feet.

Should the drilling results prove significant, the nickel, cobalt, zinc anomaly detected in a gossanous zone in the northwestern part of the area could also be worth testing.

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THE STRATIGRAPHY OF THE MOUNT TOM PRICE ORE BODY AND ITS IMPLICATION IN THE GENESIS OF IRON ORE

by J. G. Blockley

INTRODUCTION

During a brief visit to Mount Tom Price in 1966, the writer was impressed by the similarity of the shale bands within the hematite ore body to the 'shale' bands in the Dales Gorge Member of the Brockman Iron Formation, and thought that if a correlation could be established, it could be of value in predicting the position of shale throughout the ore body. Later, when a greater thickness of the ore body had been revealed in the open cut, a further examination was made in the company of Dr. A. F. Trendall.

The resident Mine Geologist, Mr. D. McKenna, assisted the work greatly by providing a guide in the mining area, and by supplying a composite section of the ore body compiled from drill logs.

REGIONAL STRATIGRAPHY

Mapping by geologists of the Geological Survey of Western Australia and C.R.A. Exploration Pty. Ltd. has shown that the Mount Tom Price ore body lies in the lower part of the Brockman Iron Formation (MacLeod, 1966), and that the concentrations of iron ore are controlled by minor folds near the axis of the Turner syncline. The Brockman Iron Formation has been studied extensively during the investigation of the crocidolite deposits of the Hamersley Range area.

Ryan and Blockley (1965) divided it into five members, the lowermost of which was termed the Dales Gorge Member, consisting of 17 units (macrobands) of banded iron formation (BIF), alternating with 16 macrobands of 'shale' (mixed stilpnomelane, chert, chert-siderite, dolomite, and tuff. Trendall (1965) described the lithology of these rock types, and correlated the 'shales' within the drill core sections available at the Wittenoom Gorge crocidolite mine. He designated the lowest shale band No. 1 and continued the sequence upwards to No. 16. The intervening BIF macrobands were numbered similarly, but as the drill core sections did not penetrate below shale No. 1, the lowermost BIF within the member was not numbered. Ryan and Blockley referred to it as the 'O' BIF, or the Basal BIF.

The type section of the Dales Gorge Member as defined from drill core at Wittenoom Gorge is shown in Figure 9 Column C, and a photographic log of the section has been published by Trendall and Blockley (1968). It has now been established that not only can all 33 macrobands be recognized over the entire outcrop area of the member, but that much of the finer stratigraphic detail visible in the photographic log has the same wide persistence. Thickness variations of the member have also been established over the basin. All 33 macrobands can be counted on the north face of Mount Noname, a prominent bluff 2 miles north of Mount Tom Price, although in the section measured on its south face in 1965, there was a short exposure gap surrounding the 5th and 6th 'shale' units.

The contact between the typical iron formation of the Dales Gorge Member, and the typical shale of the Mount McRae Shale, is gradational, and its definition must therefore be arbitrary. The position chosen for convenience in field mapping is immediately beneath the prominent cliff-forming 'O' BIF. There are however several thinner bands of BIF immediately below this which are here included in the Mount McRae Shale but which some mining companies map as portion of the Brockman Iron Formation. The uppermost of these BIF bands is usually 3 to 4 feet thick and is bounded on both upper and lower sides by one-foot thick shale bands. Where fresh, it con-

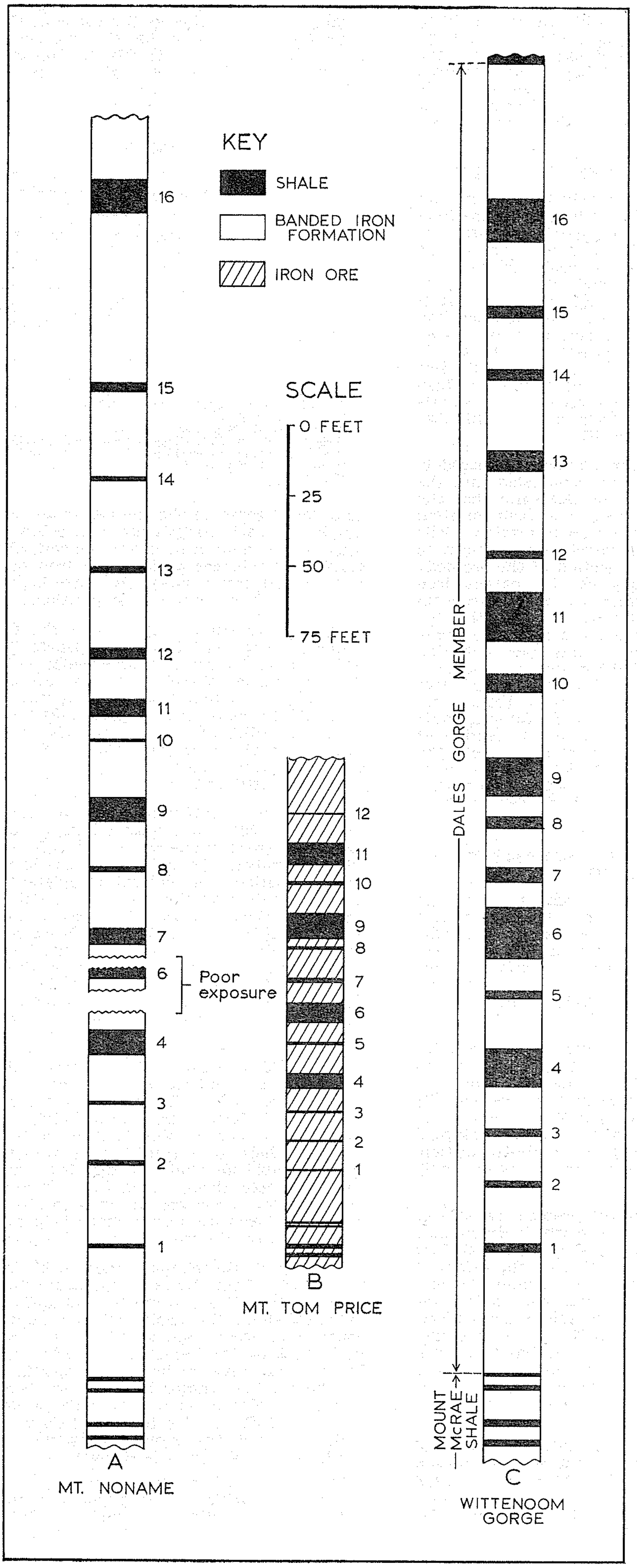

Figure 9. Stratigraphic columns showing relationship between shale bands within the Mt. Tom Price ore body and the shale beds within the upper part of the Mt. McRae Shale and the Dales Gorge Member of the Brockman Iron Formation.

A. Stratigraphic section at Mt. Noname, 2 miles north of Mt. Tom Price.

B. Section of the Mt. Tom Price ore body (from data supplied by Hamersley Iron Pty. Ltd).

C. Type section of Dales Gorge Member as established in diamond drill core at Wittenoom Gorge.

tains a central cherty bed with carbonate blebs which weather out on exposed surfaces to form rows of ovoid pits. The unit has been given the informal name of the 'bed of holes' and has been used as a stratigraphic marker throughout the Hamersley Range area. Another similar band, but without the distinctively pitted bed, occurs a few feet lower in the section.

STRATIGRAPHY OF THE ORE BODY

The Mount Tom Price ore body contains an alternation of bands of hematite, sometimes weathered to goethite, and 'shale', consisting of nondescript mixtures of clay and iron oxides. The shale bands lower the overall grade of the ore, and the thicker bands are mined selectively to prevent their being mixed with the hematite. It is therefore important when designing the position of the benches in the open cut, to know where these thicker bands can be expected. The distribution of shale bands within the ore body has been determined by geologists of Hamersley Iron Ltd from numerous drill core records. A stratigraphic section of the ore body showing this distribution is given in Figure 9B.

From a field study of the textures preserved in the hematite and shale, it was concluded that the hematite derived from original BIF, and that the shale bands in the ore body represent original shale macrobands within the iron formation. The most acceptable scheme of correlation is shown in Figure 9, which compares a section of the ore body (Column B) with sections of the parent iron formation at Mount Noname and Wittenoom Gorge (A & C). Correlative bands within the iron formation and ore body are given the same numbers. The lowermost shale bands have not been numbered, but the suggested correlation is obvious. The correlation is based mainly on the relative spacings and thicknesses of the shale bands, and is supported by other details. For example, shale 4 had a thin band of tuff in both the section at Mount Noname, and in its correlative within the ore body. Again, the 'bed of holes' seems to be reflected in the ore body by distinct pitting within the uppermost, thin hematite band near the base of the section.

APPLICATIONS OF THE SCHEME OF CORRELATION

This correlation between the shales in the ore body and those in the iron formation protore has a number of practical uses. For example, it indicates that the shale bands exposed in the open cut will persist throughout the ore body and are not merely local phenomena. It also suggests that the ratio of hematite to shale in the ore body will increase towards the stratigraphic top.

The most important application of this correlation would seem to be in the study of the origin of iron ore. Here, possibly for the first time, is a chance to compare a column of iron ore with its equivalent section of iron formation protore, and deduce the quantitative chemical and mineralogical changes which have taken place in the transition. To date, these changes seem to be known only qualitatively.

One important aspect of the problem capable of a quick solution is the degree to which the change takes place by replacement of silica in the BIF by iron oxide. Some authors writing on the origin of iron ore advocate a volume-for-volume replacement of the silica by iron oxides, while others incline to the idea that no replacement takes place, but that silica is leached, leaving the iron oxides to be compacted into iron ore. It has also been suggested that a combination of these two processes operated; that is, some leaching and compaction is accompanied by some replacement of silica by iron minerals.

A comparison of columns A and B in Figure 9, shows that approximately 235 feet of BIF between the base of the section and shale 11 are represented by about 118 feet of hematite within the Mount Tom Price ore body. Regional studies of the Dales Gorge Member are sufficiently detailed to rule out stratigraphic thinning as the cause of this change. Therefore, it is certain that the thinning took place during the conversion of BIF to iron ore. Table 1 below compares the chemical analyses of average BIF from the Dales Gorge Member with an average analysis of hematite from Mount Tom Price.

TABLE 1.

Material	Av. BIF[1]		Av. Hematite[2]		Difference (tons)
	Assay (%)	Wt.[3] (tons)	Assay (%)	Wt.[4] (tons)	
Fe	29·9	6·7	67·3	11·1	+4·4
O_2[5]	10·9	2·4	28·7	4·7	+2·3
SiO_2	47·7	10·6	1·6	0·26	—10·3
Al_2O_3	0·5	0·11	1·3	0·22	+ 0·1
Others[6]	11·0	2·5	1·1	0·18	— 2·3
		22·31		16·56	— 5·8

1. Average of 5 analyses of " typical BIF " by Govt Chem. Labs for Geol. Survey of W.A.
2. From MacLeod, 1966, p. 92.
3. Weight of column 235 feet high and one square foot in area.
4. Weight of column 118 feet high and one square foot in area.
5. O_2 contained in FeO and Fe_2O_3.
6. Mainly CO_2, CaO, MgO.

In order to compare the changes quantitatively, the weights of each component in a column one foot square, and equal in height to the equivalent stratigraphic thicknesses of BIF and iron ore (i.e. 235 feet and 118 feet respectively) have been tabulated alongside the percentage compositions.

The figures show that, despite the decrease in volume, the increase in the percentage of iron cannot be accounted for by simple removal of the other components; but there has in fact been an addition of iron to the system. It seems then that the change from BIF to hematite took place partly by leaching of original silica and carbonates with a consequent compaction of the residual iron oxides, and partly by volume for volume replacement of some of the primary constituents of the BIF.

It may be significant that the reduction in volume by 50% is almost exactly equal to the volume of chert bands within the BIF of the Dales Gorge Member. Possibly chert bands within the iron formation are leached completely, resulting in an overall reduction in volume, but silica and carbonate occurring in other bands (e.g. QIO of Trendall, 1965) have been replaced by iron without further reduction in volume. Almost certainly a detailed comparison of sections of the hematite ore with the equivalent stratigraphic sections of the protore BIF, could settle this point, and provide much more information on the genesis of iron ore.

Fresh BIF is available in the diamond drill core at Wittenoom, and the stratigraphic continuity of this over most of the Hamersley Basin has now been established. Good exposures of hematite are seen in the open cut at Mount Tom Price, and presumably there is a considerable amount of drill core available for study. A detailed comparison of the two could throw much light on the physical and chemical processes involved in the transition of BIF to hematite, and perhaps help focus future exploration on the most favourable areas.

A study of the changes that took place in the mineralogy of the shales may indicate the temperature at which the iron ore formed and could assist in establishing the geological environment. This could be of great importance now that palaeomagnetic work on the hematite has indicated a Middle Precambrian time for its origin (Porath, 1967) suggesting that the major hematite ore bodies in the Hamersley Range area may have a deep-seated origin, and not be due to the Tertiary weathering which formed the more widespread, but lower grade crust-ore hematite deposits.

It is hoped that some organization will take advantage of this unique opportunity to make a significant scientific, and possibly profitable, contribution to the study of the origin of iron ore.

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RANGE COPPER–LEAD DEPOSITS, ASHBURTON GOLDFIELD

by J. G. Blockley

INTRODUCTION

Since 1962, two small copper-lead mines have been discovered and worked in an area of metamorphic rocks 3 to 4 miles north of Range Station homestead in the western part of the Ashburton Goldfield. Known as the Turtle and the Range, the mines are about 20 miles distant from any previously recorded deposit of base metals, and thus may be considered to form a new locality.

Range Station is reached from the re-routed North-West Coastal Highway by a track branching westwards 18 miles north of Nanutarra, and is about 60 miles by road from the port of Onslow. The locality plan on Plate 21 shows the positions of the mines with respect to the homestead. At the time of inspection, neither mine was being worked, although the Range lead mine seemed only temporarily abandoned.

The Turtle mine was worked in 1962 by J. Heinsen, and produced a reported 45.14 tons of ore averaging 4.43% copper. Although lead was present in the ore, no assays for this metal were made at the time. Due to its low grade, the ore was not readily marketable, and production ceased. In 1964, Westfield Minerals N.L. obtained an option over the property and drilled 18 blast-holes to test the size and grade of the lode. The company relinquished the option when results proved disappointing.

The Range lead mine was pegged first in 1967 and worked during 1968 by K. Stubbs and party. To date no production figures have been lodged with the Department but at the time of inspection some 20 to 25 tons of high-grade ore were at grass.

PREVIOUS INVESTIGATONS

No published account of the geology of the two mines exists, but a private report for Westfield Minerals has been drawn upon for information concerning that company's drilling results. The broad geological features of the area of the deposits are shown on the State Geological Map and on Plate 2 of Condon (1965).

GEOLOGY

In the area around the mines, the bed-rock geology is largely obscured by sand. The few natural exposures present are quartz reefs on fault lines. The bed-rock exposed in pits and costeans is chloritic and micaceous schist, probably a metamorphosed equivalent of the Lower Proterozoic Wyloo Group. Granite stocks intrude the metamorphic rocks a few miles southwest, and also a mile north of the deposits. The lodes worked in the two mines are in quartz veins or stockworks striking at 060 to 070 degrees across the northwesterly trend of the metamorphic banding. The Turtle mine is close to a large north-northeasterly fault marked by a prominent quartz reef.

TURTLE MINE

The Turtle mine is on a low, elongated hummock rising 20 or 30 feet above the surrounding sandplain. Lead and copper minerals are disseminated through lodes of ferruginous quartz forming lenses within a silicious stock work made up of silicified schists and many closely spaced quartz veins. The stockwork extends over a length of 700 feet and has a maximum width of 100 feet. Most of the lenses of lode matter are at the northeastern end of the stockwork, although a few patches of ferruginous quartz with traces of lead and copper occur elsewhere. Plate 21 shows the distribution of the lodes within the stockwork. The lodes that have been tested dip steeply to the east.

The largest lode is 160 feet long and averages 12 feet in width. It contains lead and copper throughout, but is richest at its northern end where a section 8 to 10 feet wide was mined from an open cut 10 feet deep. Twenty feet east of this lode is another 1 to 3 feet wide and about 90 feet long. A shaft 27 feet deep was sunk near the northern end of this lode where it is widest and richest, but elsewhere it has been tested only by shallow pits. The other lodes are all small and appear to be low in grade. Ore minerals present are cerussite, cuprite, and malachite; and galena was reported from one of the drillholes.

Of the 18 holes drilled by Westfield Minerals N.L., only two intersected lodes of possible ore grade. Hole 15, drilled beneath the open cut, encountered 40 feet of lode (true width) averaging 4.6 per cent lead and 3.9 oz. of silver to the ton. A section in the middle of the lode contained 3.7 per cent copper over a true width of 8 feet. Hole 3, drilled from a position 50 feet southwest of the shaft, cut 10 feet of lode (true width) assaying 2.45 per cent lead. Two narrow sections within this each contained 11 per cent copper.

Of two samples taken by the writer, the first from the face of the open cut assayed 6.81 per cent lead, 0.02 per cent zinc, 3.39 per cent copper and 160 p.p.m. silver, and the second from the lode worked in the shaft, assayed 4.10 per cent lead, 0.70 per cent copper and 100 p.p.m. silver.

RANGE MINE

The lode worked in the Range mine follows a silicified shear-zone cropping out intermittently through a cover of sand and has been traced by costeaning over a distance of 1,300 feet. Mining has been restricted to a shoot about 250 feet long, some 300 feet from the eastern end of the line. The lode here is from 2 to 5 feet wide, dips 80°S, and consists of dense, greyish quartz carrying finely disseminated pyrite, chalcopyrite, and galena. Most of the ore mined has come from veins or lenses up to one foot wide, of massive, fine-grained galena situated on the hanging-wall side of the lode. Oxidation has affected the lode only near the surface where the economic minerals are malachite and cerussite.

At the time of inspection, workings comprised a number of pits and bulldozed costeans, a shallow open cut 75 feet long, and 4 shafts with depths ranging from 10 feet to 30 feet. In the deepest shaft, the lode was 3 ft 3 in. wide, including a vein of massive galena 11 inches wide at the hanging wall. Seventy feet further west in a shaft 25 feet deep, the lode widens to about 5 feet on a roll in the shear. Again it is richest on the hanging-wall side and a little gouging has been carried out from the shaft in this zone. The most recent work on the mine has been directed towards the sinking of a new shaft near the western end of the ore shoot, and at the time of inspection, this was 10 feet deep. The results of 3 samples taken from the lode are as follows:

No.	Position	Width	Pb per cent	Zn per cent	Ag p.p.m.
16358	Ore dump	....	35·5	0·09	130
16359	30 ft shaft	3'3"	32·5	0·03	130
16361	25 ft shaft	Abt 4 ft	15·5	0·33	100

CONCLUSIONS

Both the Range and Turtle mines are small deposits hindered from becoming profitable producers by their distance from ore treatment facilities and markets.

The lead content of the Turtle mine is too low to be worth extracting, but would probably prevent the ore being accepted as cupreous additive to fertilizer. One feasible method of winning the copper from the lodes is by leaching with sulphuric acid. The largest lode should be capable of yielding several thousand tons of ore by open-cut mining, and although some crushing might be required to render the copper accessible to the acid, the lode material should be free of acid-killing carbonates. Further testing would be needed before the economics of such a venture could be assessed.

At present, only the high-grade veins of massive galena within the lode of the Range mine can be exploited. In order to win all the lead in the lode, a small crushing and concentrating plant would be required. Ore in sight at present is insufficient to justify the cost of such a plant, but more thorough testing and development could change this situation.

The extensive sandplain surrounding the deposits may well conceal other lodes and further prospecting using the techniques of geophysics and geochemistry seems warranted.

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THE GEOLOGY OF THE GRANITIC ROCKS OF THE POONA–DALGARANGA AREA, MURCHISON AND YALGOO GOLDFIELDS

by P. C. Muhling

ABSTRACT

The Archaean granitic rocks of the Poona-Dalgaranga area have been divided into two groups. A border facies and an internal facies have been recognized, each containing several textural units. The border facies forms a closure of granitic rocks elongated parallel to the regional tectonic structure and encircling the internal facies. These granitic rocks are in a recess in the metamorphic rocks at the eastern margin of a batholith delineated by Johnson (1950).

There are two types of mineralization directly related to the granites. One comprises pegmatites with beryl, emeralds, cassiterite, tapiolite and tantalite; while wolframite and molybdenite deposits form the second type. Prospecting for these minerals should be concentrated in the metamorphic rocks at the edge of the granite. The probability of occurrence of alluvial tin deposits is not yet known.

INTRODUCTION

The Poona-Dalgaranga area is part of the western half of the Cue 1:250,000 sheet area (SG/50-15) and is enclosed between latitude 27°00′ to 28°00′S and longitude 117°00′ to 117°45′E. The locality is shown in Plate 22. Poona is in the north of the area, about 35 air miles northwest of Cue (about 42 miles by graded road). Dalgaranga homestead near the southern limit of the area is about 45 air miles north-northeast of Yalgoo.

In this report all granitoid rocks are referred to as 'granites' or granitic rocks. The ratio of plagioclase feldspar to K-feldspar has been determined in some rocks but not in all.

The first geologists in the area investigated the mining centres, but gave little attention to the granitic rocks. H. P. Woodward (1914) and L. de la Hunty (1962), have examined different aspects of the geology of this area.

In 1966, mapping of the Cue 1:250,000 sheet area was commenced as part of a regional mapping programme in the Murchison and Yalgoo Goldfields. Particular attention was given to the mineralized pegmatites of the Poona-Dalgaranga area. The different types of 'granites' near the mining centres were mapped and a study was made of igneous flow structures, and of the attitudes of pegmatites and joints, to determine the shape of the intrusions. Other information sought was the level of intrusion of the 'granites', the level within the 'granites' that erosion had reached, and the sequence of intrusion, metamorphism and folding. From the 'granite' study it was hoped to estimate the possibility of the occurrence of pegmatite minerals in primary and alluvial deposits. Another aim was to determine whether there was a pattern in the distribution of these deposits and a control for this pattern.

STRUCTURE

Three structural trends were recognized in the area:

(1) the Weld Range trends east-northeast.

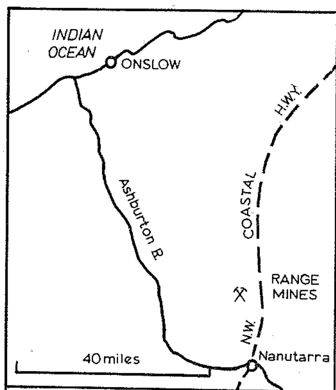
(2) From Poona around the eastern and south-end edge of the intrusion to Kylie, the country rocks are folded about axes trending north and northeast.

(3) The country rocks and 'granites' southeast of Dalgaranga homestead, and granites in the northwest part of the area, trend at 160°.

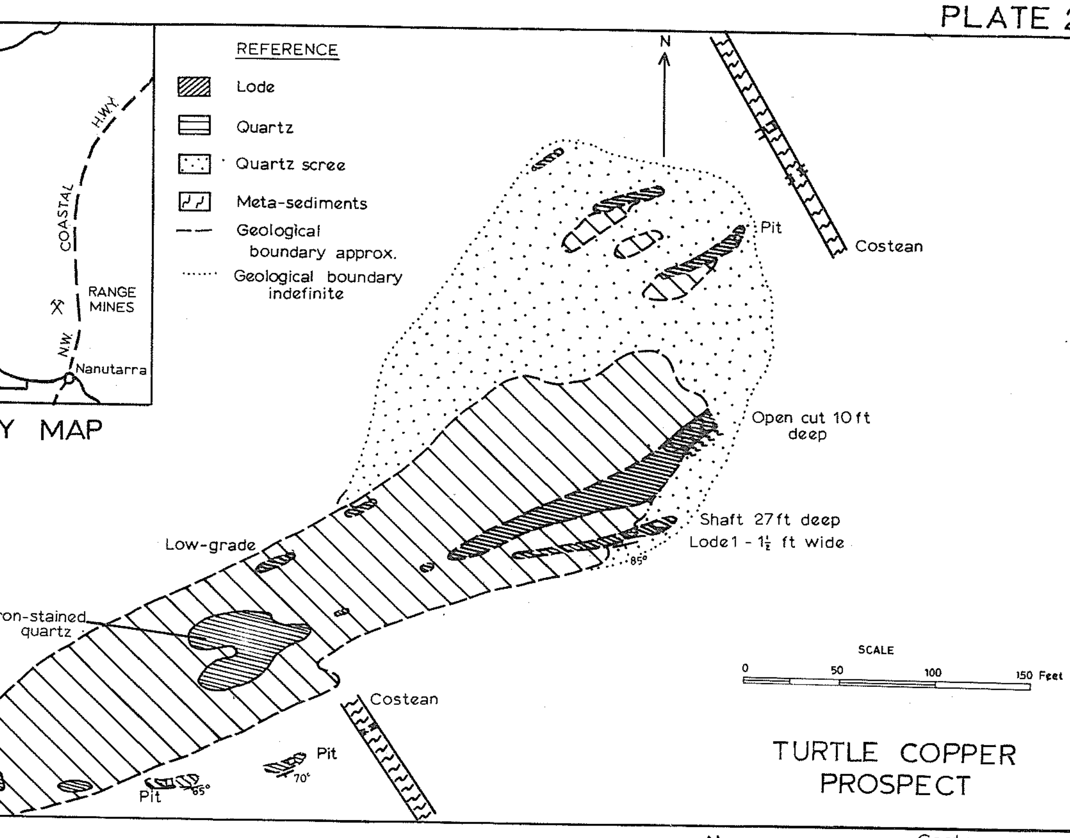
The types of foliations in 'granites' are represented on the map. One is a primary igneous foliation shown by aligned feldspar laths, small inclusions of country rock, and schlieren. The second foliation is of biotite grains and distorted quartz grains. Its origin is uncertain but it occurs in 'granites' next to country rock. This foliation was caused by shear in a solid crust of 'granite' near country rock during final stages of consolidation, or shear associated with folding; or possibly by primary igneous flow (partly protoclastic).

The primary foliations in the 'granites' appear to be controlled by the shape of individual intrusions which in turn form a pattern suggestive of an elliptical batholith. The long axis of the intrusion trends north-northeast, parallel to the regional

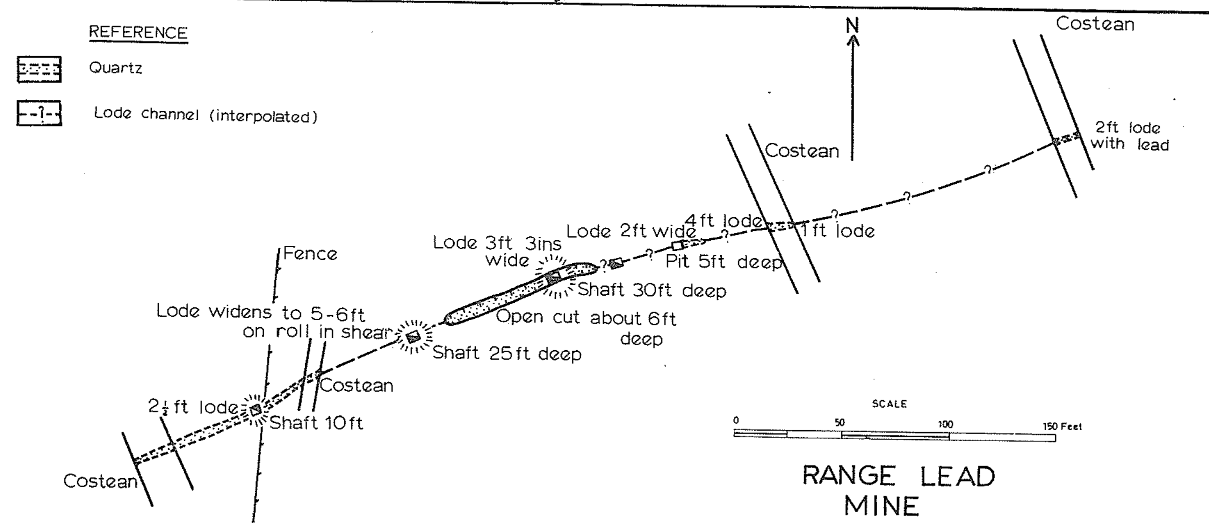
PLATE 21



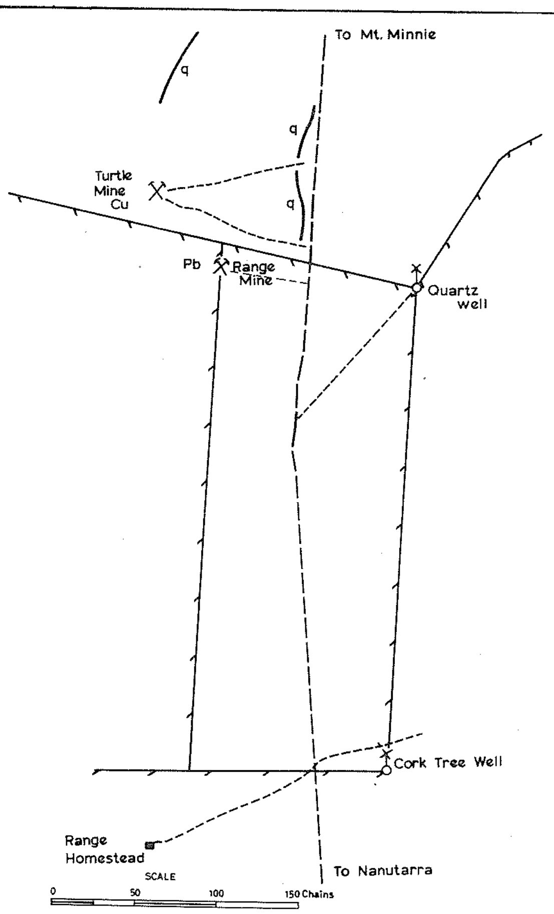
LOCALITY MAP



TURTLE COPPER PROSPECT



RANGE LEAD MINE



LOCALITY PLAN

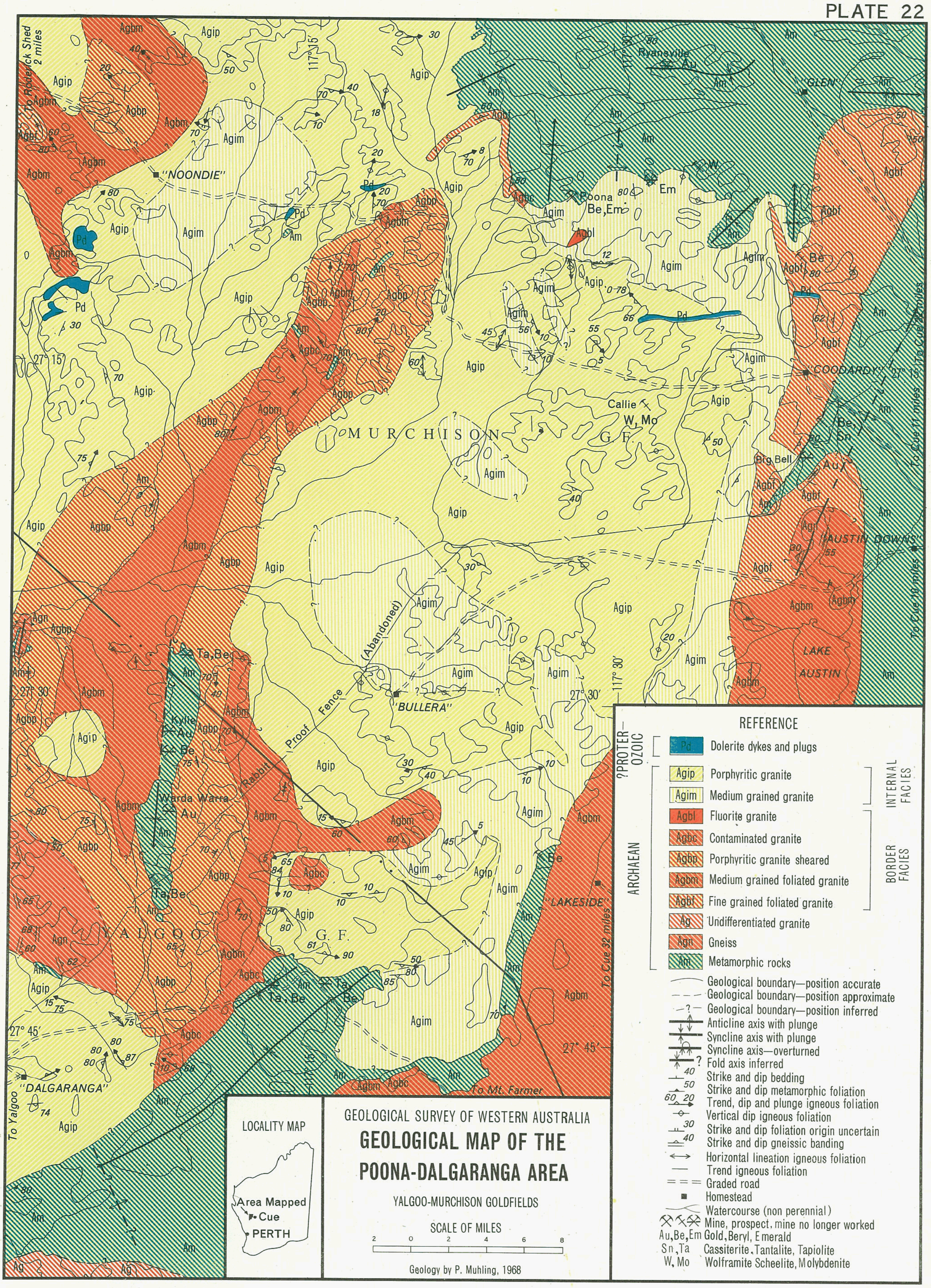
SURFACE PLANS OF RANGE AND TURTLE MINES

Ashburton Goldfield

Western Australia

To accompany report by J.G. Blockley 1968.

PLATE 22


GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP OF THE
POONA-DALGARANGA AREA
YALGOO-MURCHISON GOLDFIELDS
SCALE OF MILES
2 0 2 4 6 8
Geology by P. Muhling, 1968
LOCALITY MAP
Area Mapped
Cue
PERTH
REFERENCE
?PROTEROZOIC
Pd Dolerite dykes and plugs
ARCHAEAN
Agip Porphyritic granite
Agim Medium grained granite
INTERNAL FACIES
Agbl Fluorite granite
Agbc Contaminated granite
Agbp Porphyritic granite sheared
Agbm Medium grained foliated granite
Agbf Fine grained foliated granite
BORDER FACIES
Ag Undifferentiated granite
Agn Gneiss
Am Metamorphic rocks
Geological boundary—position accurate
Geological boundary—position approximate
Geological boundary—position inferred
Anticline axis with plunge
Syncline axis with plunge
Syncline axis—overturned
Fold axis inferred
Strike and dip bedding
Strike and dip metamorphic foliation
Trend, dip and plunge igneous foliation
Vertical dip igneous foliation
Strike and dip foliation origin uncertain
Strike and dip gneissic banding
Horizontal lineation igneous foliation
Trend igneous foliation
Graded road
Homestead
Watercourse (non perennial)
Mine, prospect, mine no longer worked
Au, Be, Em Gold, Beryl, Emerald
Sn, Ta Cassiterite, Tantalite, Tapiolite
W, Mo Wolframite Scheelite, Molybdenite
"NOONDIE"
Ryaneville
"GLEN"
Poona
Be, Em
MURCHISON G. F.
YALGOO G. F.
Callie
W, Mo
"COODARDY"
Big Bell
"AUSTIN DOWNS"
LAKE AUSTIN
"BULLERA"
Rabbit Proof Fence (Abandoned)
Kylie
Warda Warra
"LAKESIDE"
"DALGARANGA"
To Yalgoo
To Mt. Farmer
To Cue 32 miles
To Cue 16 miles
To Roderick Shed 2 miles
117° 15'
117° 30'
27° 15'
27° 30'
27° 45'

strike of metamorphic rocks in the Cue sheet area. Hence the shape and the intrusion of the 'granites' are closely linked with regional tectonic structure.

The sequence of events seems to have been:

(1) Folding and metamorphism of country rock. The relation between these two processes has not yet been determined.

(2) Intrusion of 'granite' synchonous with folding, though most granite was intruded after folding of the country rocks.

(3) metasomatism of country rocks at the contact with the 'granites', producing quartz-feldspar-biotite rocks.

DESCRIPTION OF 'GRANITE' UNITS

The 'granites' have been subdivided according to their textures and structures. There are gradations between different textural types and the distinction between units at some places is arbitrary. Some areas have more than one 'granite' and the mixture has been classified under the dominant type. Many boundaries between different 'granites' are mixed zones ranging in width from a few yards to about a mile.

All the 'granites' contain quartz, two feldspars (K-feldspar and a plagioclase feldspar) and biotite. There are small areas of muscovite 'granite' near Poona but the boundaries have not been mapped.

Preliminary work on thin-sections shows that the medium-grained granite, porphyritic granite, and sheared porphyritic granite all have less plagioclase than K-feldspar. These are true granites and the phenocrysts are microcline.

The 'granites' can be separated into two categories—a border facies and an internal facies.

BORDER FACIES

Fine-grained foliated 'granite' (Agbf)

The fine-grained foliated 'granite' is usually conformable with the country rock, though locally it has intruded the country rock. Most of the 'granite' is foliated, although there is some gradation into a massive type. The pattern of the foliation suggests they are primary. Numerous xenoliths of country rock are present.

Medium-grained foliated 'granite' (Agbm)

Rounded boulders, elongated parallel to the foliation are a common feature of the medium-grained foliated 'granite'. Its colour varies from light grey to white and there are some streaks of biotite.

Two, and occasionally three foliations can be detected in this 'granite'. No conclusions about the origin of these foliations can be presented until more work has been done.

This unit is intrusive into the contaminated 'granite'.

Contaminated 'granite' (tonalite) (Agbc)

There are two varieties of contaminated 'granite' but they are not distinguished from each other on the map.

The first variety crops out as rounded, grey tors and contains xenoliths of quartz and biotite lenses. This rock has not been examined in thin-section but it is probably a tonalite.

The other variety has numerous lenses and flakes of biotite set in a pale pink, medium-grained groundmass. There may be feldspar phenocrysts present. At most places this rock has two foliations defined by biotite flakes—one parallel, the other perpendicular to, the contact with the country rock. It is probably a border facies of the porphyritic granite.

Sheared porphyritic granite (Agbp)

The sheared porphyritic granite intrudes the country rock and the medium-grained foliated 'granite'. The foliation is shown by distorted feldspar phenocrysts (many have a square shape) and lenticles of quartz in the groundmass. The intensity of foliation varies.

This unit is generally mixed with the medium-grained foliated 'granite' and it is not known whether these two types can be separated into mappable units everywhere. Where the two types are mixed, their foliations are approximately parallel.

The boundary between this granite and the porphyritic granite is arbitrary (determined by the detection of signs of shear).

Fluorite 'granite' (Agbl)

The main exposure of fluorite 'granite' is about 3 miles south of Poona mine. It is medium-grained with scattered spots of fluorite and has a characteristic airphotograph pattern caused by closely-spaced joints.

INTERNAL FACIES

Medium-grained granite (Agim)

Medium-grained granite has intruded the fine-grained, foliated 'granite.' Some margins are porphyritic and grade into an even-grained rock. Part of the unit has a primary foliation of schlieren and feldspar crystals. The remainder of the granite is massive.

Porphyritic granite (Agip)

The porphyritic granite has a characteristic outcrop pattern of domes and rounded boulders.

It is a pale pink, medium to coarse-grained granite with phenocrysts ranging in length from ½ inch to 5 inches. The primary foliation is generally parallel to the contacts with other rock types. This granite appears to have intruded all other types though much of the evidence from contacts with medium-grained granites is inconclusive.

Gneiss (Agn)

Gneiss is a general term and is used only in a textural sense since it is uncertain whether these are metamorphic rocks.

Parallel lenses of metamorphosed country rock up to 3 feet wide are set in a medium-grained foliated granitic rock with discontinuous streaks of biotite less than an inch wide. This unit seems to be folded and has been intruded by medium-grained foliated 'granite'.

COUNTRY ROCKS

The layered succession has been metamorphosed. It consists dominantly of fine-grained, basic, igneous rocks with intrusive gabbros and pyroxenites (tremolite schist). Banded iron formation, fine-grained acid volcanic rocks with intrusive porphyries and minor fine-grained sediments, form the remainder of the country rocks.

ECONOMIC GEOLOGY

Mineralized pegmatites have been worked at Poona, near Big Bell, near Dalgaranga, west of Lakeside, and north and south of Kylie. The main minerals sought were beryl, emerald, tapiolite, tantalite, and cassiterite.

The pegmatites seem to be late stage differentiates of the 'granites'. All of the mineralized pegmatites are in the country rock adjacent to 'granite' but the 'granite' is different for each mining locality.

At Poona the pegmatities strike about 90° and dip 80° south; pegmatites near Big Bell are also oblique to the country rock and trend 70°; most of the pegmatities at other localities parallel the foliation of the host rock.

Other minerals associated with the 'granite', such as wolframite, scheelite and molybdenite, have been mined from quartz veins associated with late stage differentiates of granite near Callie Soak. It is significant that this occurrence is near the centre of a closure defined by flow structures in the porphyritic granite, and is comparatively close to the contact of the granite with the country rock. Wolframite has been mined from a quartz vein intrusive into metamorphosed fine-grained basic rocks, about 7 miles east from Poona.

CONCLUSIONS

The age of the 'granites' is unknown but is probably Archaean and possibly close to lower Proterozoic.

The association of a foliation which occurs in border facies 'granites' with a concentration of xenoliths suggest that the granitic rocks between Kylie and a point about 8 miles west of Poona could be regarded as the western boundary of all 'granites' further east. This indicates that an area of 'granites' forms a structural unit within the batholith defined by Johnson (1950). These 'granites' are probably of the same age as the batholith. The large area of 'granites' belonging to the border facies compared with those of the internal facies suggests the level of erosion is not far below the original roof of the intrusion. On a regional scale the granitic rocks of the Poona-Dalgaranga area can be regarded as an intrusion near the edge of the batholith.

Any mineralized zones in the top of the 'granite' have probably been eroded, though there are remnants of high temperature mineralization near Callie Soak. Because of the removal of the roof of country rock from the intrusion, and the distribution of mineralization, future prospecting for primary deposits should be concentrated in the metamorphic rocks around the edges of the 'granite'.

The presence of primary mineralization indicates that alluvial deposits may have formed, but more work is necessary in the Quaternary and Tertiary sequences before the degree of probability of their formation can be assessed.

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DASYCLADACEAN ALGAE FROM THE WERILLUP FORMATION, ESPERANCE

by A. E. Cockbain

ABSTRACT

The dasycladacean algae *Neomeris* and *Larvaria* are recorded from Australia, for the first time, in the Upper Eocene Werillup Formation. Present day *Neomeris* is a tropical (minimum temperature 20°C) and shallow water (less than 10m depth) genus and this suggests similar conditions existed in the Esperance area during the Upper Eocene. A tentative position for the Upper Eocene 20°C isocryme in the Australian region is plotted on a map.

INTRODUCTION

In the area east of Esperance, the Werillup Formation of the Plantagenet Group does not crop out and is known only from several boreholes drilled for water. Two boreholes in particular, Neridup 20 on Neridup Location 169 and Brookman 1 on Neridup Location 118 (see Figure 10) have yielded interesting fossil assemblages from this formation. In Neridup 20, yellow silty sandstone overlies dark-grey siltstone and sandstone. From the dark-coloured sandstones Cockbain (1967) recorded the larger foraminifer *Asterocyclina* together with an Upper Eocene fauna of smaller foraminifers. Brookman 1 borehole passed through a similar stratigraphical section. A sample from 85 to 94 feet (G.S.W.A Palaeontology Collection F7784) contains an abundant fauna of foraminifers, ostracods, molluscs, and bryozoans. The foraminifers include *Maslinella chapmani*, *Bolivinella* sp., *Notorotalia crassimura*, *Operculina* sp., and *Elphidium* sp. and suggest an Upper Eocene age. Figure 11 shows the correlation between this borehole and Neridup 20. In addition the dasycladacean algae mentioned below are also present in sample F7784.

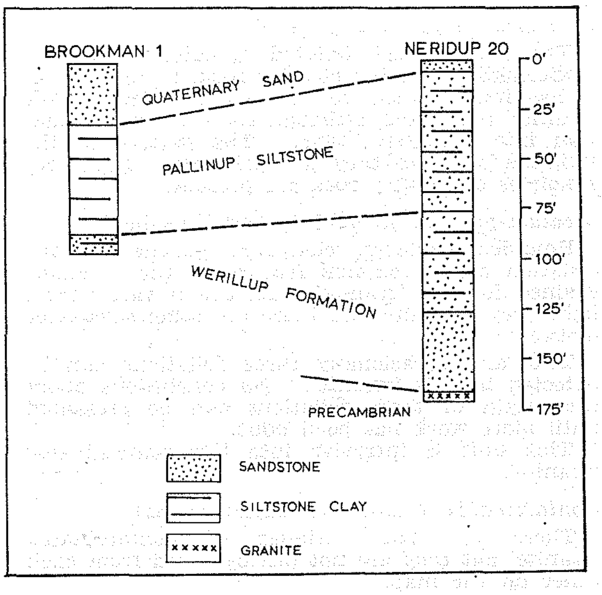


Figure 11. Correlation of Brookman 1 and Neridup 20 boreholes.

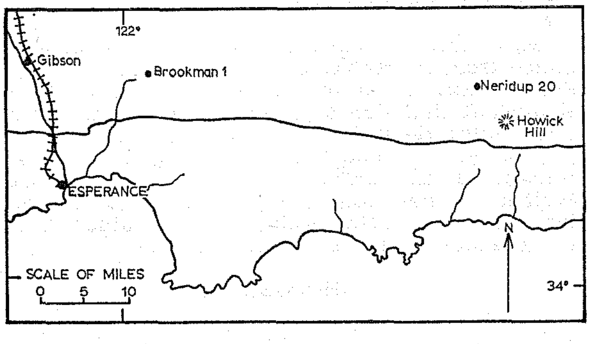
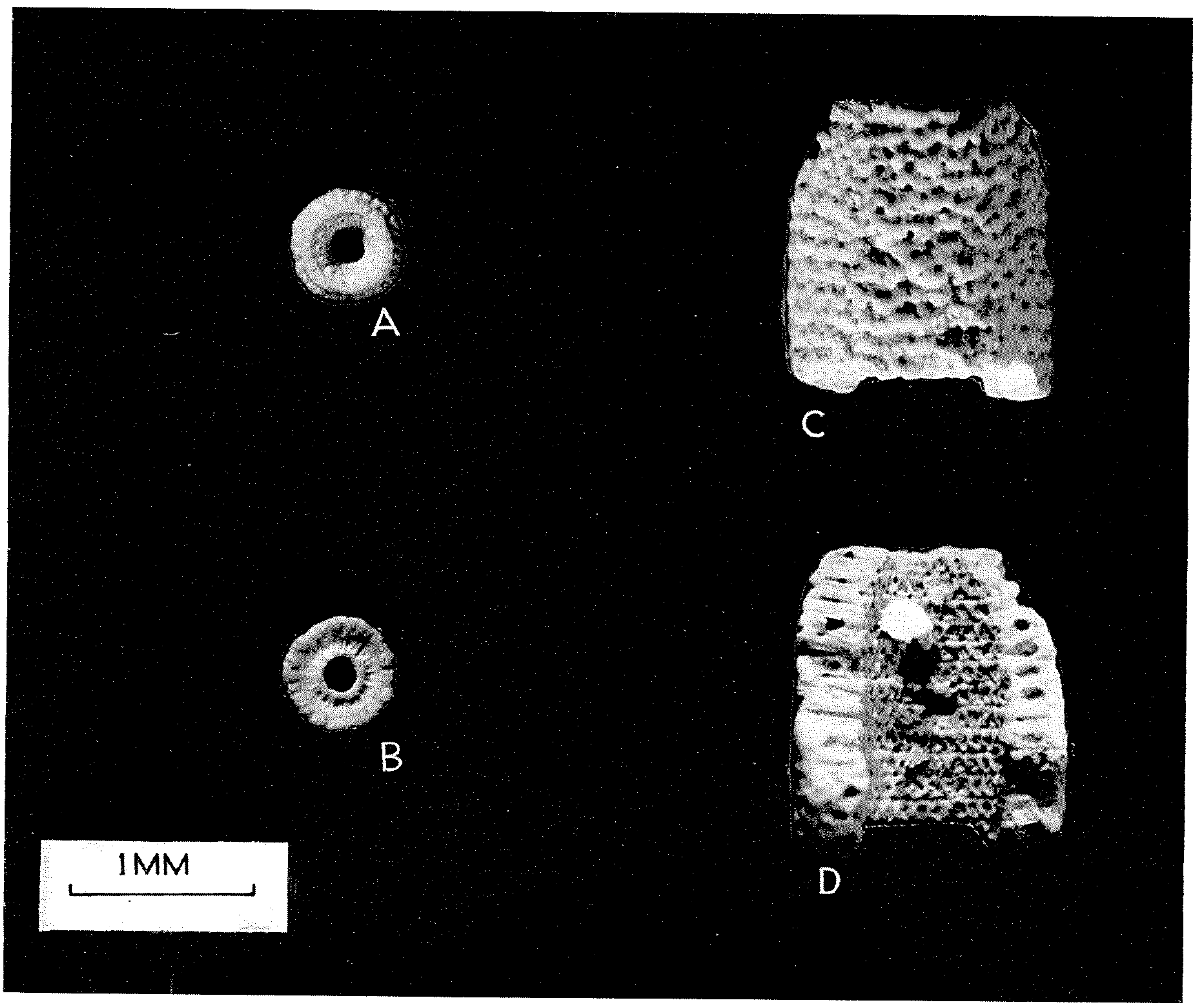


Figure 10. Map showing location of Brookman 1 and Neridup 20 boreholes.

SYSTEMATIC PALAEONTOLOGY

Dasycladacean algae have not been recorded previously from the Australian Tertiary. Like all fossil dasycladaceans the material is preserved as calcareous external moulds of the branches around the central stem of the original thallus. The fossils can be easily extracted from the rock matrix

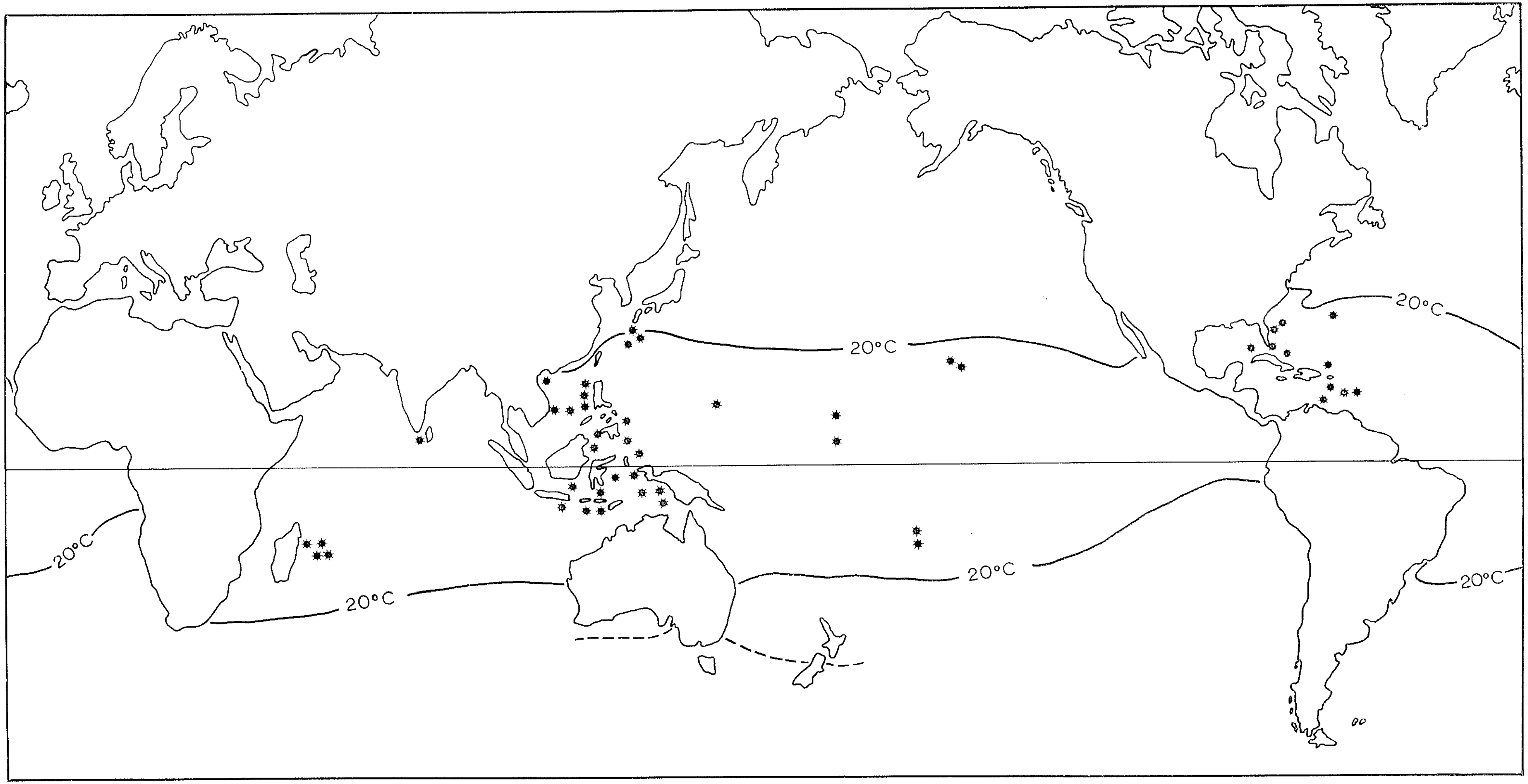
PLATE 23



Larvaria sp. (A) upper and (B) lower views of one segment of cylindrical external mould of thallus (G.S.W.A. F7784.1).

Neomeris sp. (C) external (D) internal views of broken portion of cylindrical external mould of thallus (G.S.W.A. F7784.2).

PLATE 24



Distribution of recent species of *Neomeris* (✲) in relationship to 20°C isocryme (after Konishi and Epis, 1962) and tentative position of Upper Eocene 20°C isocryme.

and may be examined whole. Two genera are present; no attempt is made to describe the fossils in this report.

Phylum	CHLOROPHYTA
Class	CHLOROPHYCEAE
Order	DASYCLADALES
Family	DASYCLADACEAE
Tribe	NEOMEREAE

Neomeris sp.

Plate 23, C, D

Remarks: Johnson (1961) gives the stratigraphic range of the genus as Cretaceous to Recent, with a world-wide distribution.

Larvaria sp.

Plate 23, A, B

Remarks: Cretaceous to Oligocene, with greatest development in Middle Eocene. The genus has been recorded previously in Europe and North America (Johnson, 1961).

DISCUSSION

The genus *Neomeris* is still living and Konishi and Epis (1962) have summarised data on the geographical distribution and depth range of recent species.

The accompanying map (Plate 24) shows the distribution of Recent *Neomeris*. The genus is tropical and occurs in both the Caribbean and the Indo-Pacific regions. At the present time it does not live where the mean temperature of the coldest month falls below 20°C. Assuming that Eocene species were similar in their temperature tolerance, this suggests that the sea in the Esperance region was tropical in Upper Eocene times. A similar conclusion was drawn on the evidence of *Asterocyclina* in the nearby Neridup 20 borehole (Cockbain, 1967). The additional algal evidence permits a refinement in that there was probably a southern shift of the 20°C isocryme of at least 600 miles in the Upper Eocene.

Devereaux (1967, fig. 1) has shown, from isotope work, that the Upper Eocene temperature at the latitude of Wellington was just over 20°C and he comments that the surface water temperature may have been one or two degrees higher. Whilst the Western Australian and New Zealand figures are not strictly comparable, they do suggest that in the Upper Eocene, the 20°C isocryme lay well to the south of its present position. On the other hand, palaeotemperature data from Victoria (see Dorman, 1968, for references) indicate no warming of the sea in the Eocene; in fact the Upper Eocene temperature there was about 15°C according to Dorman (1968, fig. 5). Bearing these facts in mind a tentative position for the Upper Eocene 20°C isocryme is shown on the map (Plate 24). At present no reason can be given for the northward swing of this isotherm in eastern Australia.

By contrast, Darlington (1965) believes that the climate in southern Australia and New Zealand was never fully tropical at any time during the Tertiary. In part this conclusion is based on the diversity of *Nothofagus* in southern Australia (see Darlington, 1965, p.96). However *Nothofagus* of the *N. brassi* group is known from lignites in the Werrillup Formation near Albany (B. S. Ingram, personal communication Nov. 1968). The *N. brassi* group is found nowadays only on mountains in New Guinea and New Caledonia. In New Guinea the trees are associated with " . . . a rich fauna of Carabidea (beetles) . . . almost all of them . . . derived from the surrounding tropical lowlands" (Darlington, 1965, p 31). Hence this particular group of *Nothofagus* seems to be capable of living, under suitable conditions, in a tropical climate.

Konishi and Epis' (1962) data on the depth range of *Neomeris* show that the genus presently lives between 0 and 10 metres. Johnson (1961) states that the Family Dasycladaceae as a whole normally occurs between low tide mark and 10 or 12 metres, with the greatest development near low tide level. Hence the Werillup Formation in Brookman 1 borehole was probably laid down in very shallow water, with the maximum depth around 10 metres. This is borne out by the presence in the formation of strongly ornamented, robust species of foraminifers and by the occurrence of numerous shell fragments.

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THE JOFFRE MEMBER IN THE GORGES SOUTH OF WITTENOOM

by A. F. Trendall

ABSTRACT

The Brockman Iron Formation is one of eight constituent formations of the Precambrian (2,000 m.y. old) Hamersley Group, of the Hamersley Range area in the northwestern part of Western Australia. Its members, from the base upwards, are: Dales Gorge Member (iron formation), Whale back Shale Member, Joffre Member (iron formation), and Yandicoogina Shale Member. The Joffre Member, at about 1,200 feet, is the thickest of these, but has received less attention than the Dales Gorge Member because of its relatively uniform lithology and low economic interest. In an area about 10 miles south-southwest of Wittenoom (lat. 22° 15′ S, long. 118° 20′ E), Joffre Creek flows for three miles through deeply incised gorges in which the gently dipping Joffre Member is spectacularly exposed. Measurement of the lower 900 feet provides a section on which the positions of 75 minor stratigraphic breaks (69 stilpnomelane-rich shales, 5 porcelanites and a limestone) appear. All these are thin and few conspicuous, but gross variations in the stratification, and the grouping of the four lower porcelanites, may have practical use in lithostratigraphic correlation. The position of the base of the Joffre Member is shown, locations within it of previously published data are given, and advice on access is given, so that the paper can be used as a practical field guide.

INTRODUCTION

The Precambrian (about 2,000 m.y.) Hamersley Group was first defined in the Hamersley Range area of Western Australia by MacLeod and others (1963), with a thickness of about 8,000 feet. Among its eight constituent formations, which they also defined, was the Brockman Iron Formation, about 2,200 feet thick. It is one of the best preserved and most extensive Precambrian iron formations now in existence. Ryan and Blockley (1965) divided this formation into five members, but Trendall and Blockley (in press) discarded the uppermost of these. Of the four members currently recognized the lowermost, the Dales Gorge Member, is distinguished by 33 easily recognizable subdivisions (macrobands) which make it the most suitable for detailed stratigraphic study; by a fortunate coincidence it is also the principal host rock for both crocidolite and iron ore in the Hamersley Range area. Trendall and Blockley (1968) published a complete photographic record of the 466.25-foot type section of the Dales Gorge Member which they redefined in drill core from the Wittenoom—Yampire area. Trendall (1966) had already given a detailed description of some features of the lower part of the member in a paper which serves as a field guide to the outstanding exposures at Dales Gorge itself.

The Dales Gorge Member is succeeded upwards by the Whaleback Shale Member, about 200 feet thick. Above this lies the Joffre Member (originally called the Mindy Mindy Member by Ryan and Blockley, 1965), of which a type section measured at Yandicoogina Creek has a thickness of 1,145 feet; the uppermost of the four members, the Yandicoogina Shale Member, immediately overlies the Joffre Member. In contrast with the Dales Gorge Member, with its strong economic interest and easy stratigraphic subdivisibility, there is little evident lithological variation within the iron formation of the Joffre Member, and only recently has it been discovered to be associated with saleable iron ore. Trendall and Blockley (in press) in a full report on several years of work on all the iron formations of the Hamersley Group, fully described the distinctive lithological and other features of the Joffre Member from observations over a wide area, including the gorges downstream from Joffre Falls, south of Wittenoom. In these gorges, for just over 3 miles between Joffre Falls and the head of Wittenoom Gorge, Joffre Creek flows, largely by way of a sequence of permanent pools, between steep joint-controlled cliffs of the Joffre Member, to give much spectacular exposure of high quality. However, the main stratigraphic concern of Trendall and Blockley (in press) was with the Dales Gorge Member, and they did not systematically measure the section exposed there to determine the exact stratigraphic levels of their observations.

This measurement was carried out in August 1968. The main purposes of this paper are to record the minor lithological variations present in this measured section, to compare the reported discontinuities with those of the type section measured at Yandicoogina Creek, to indicate the positions within the Joffre Member of data already published or in press, and to record the exact equivalence between the base of the member exposed in the gorge and the correlative drill core in the collection of the Geological Survey of Western Australia from Hole 47A, which is the upward continuation of the designated type section of the Dales Gorge Member (Trendall and Blockley, 1968). Sufficient details of access and structure are included for this paper to be used as a practical field guide for independent inspection of the Joffre Member in these gorges.

LOCATION, ACCESS, MORPHOLOGY, AND NOMENCLATURE OF THE GORGES

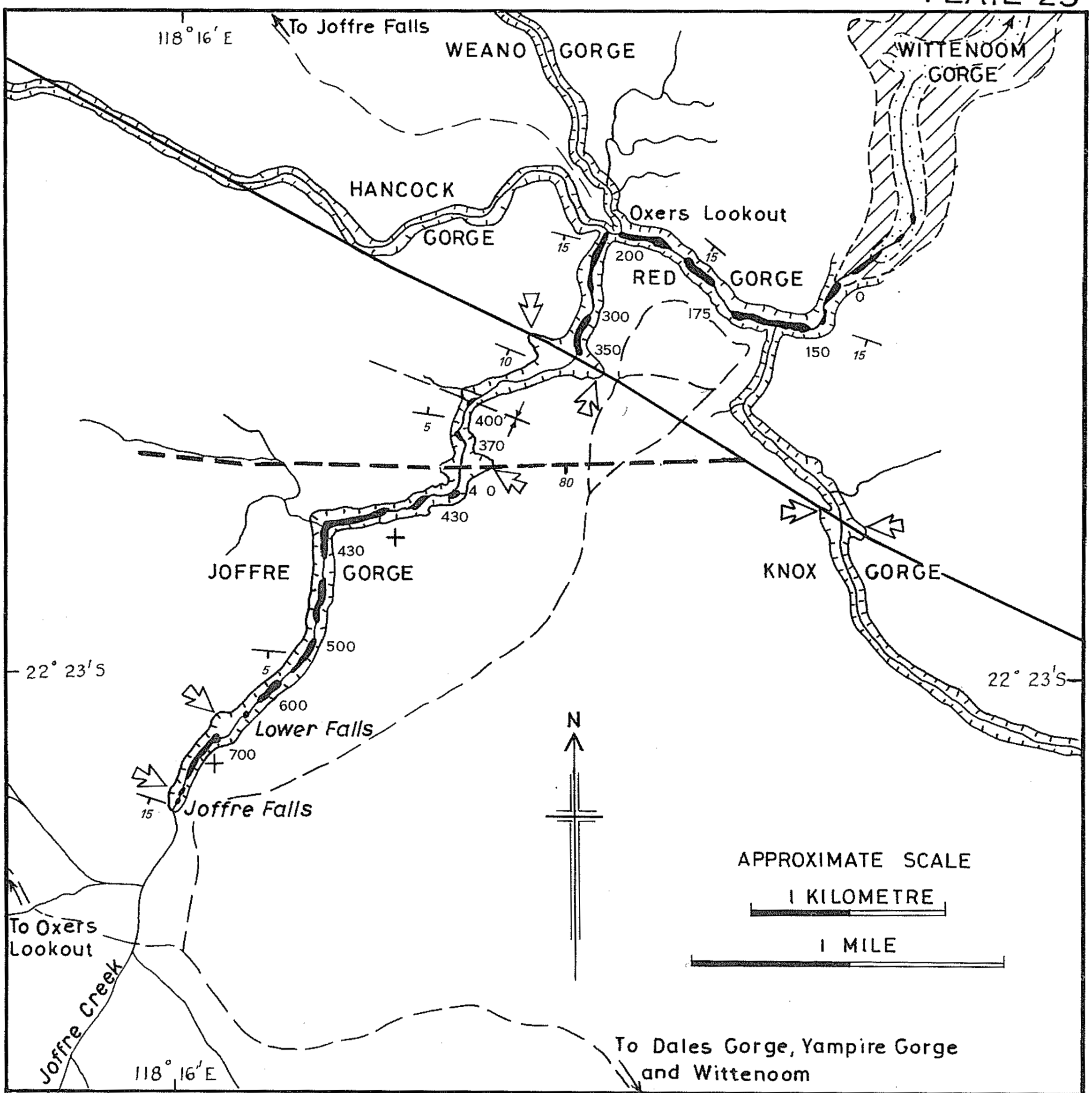
The gorges with which this paper is concerned occupy an area centred about 10 miles south-southwest of Wittenoom township (lat. 22° 15′ S, long. 118° 20′ E) in the northwestern part of Western Australia. Plate 25 is a map of this area; its location may be identified on the 1 : 250,000 scale map of de la Hunty (1965). The mouth of Wittenoom Gorge lies just south of the township and a sealed road follows the broad floor of the gorge southwards for about 5 miles to the old Wittenoom and Colonial crocidolite mines and their associated service buildings. The road follows Joffre Creek closely; the creek flows only after rain, but there are many permanent pools along its bed.

A rough drillers' track, closed to public access, continues southward for a further 3 miles up Wittenoom Gorge past the old Wittenoom mine, during which the cliffs of the Dales Gorge Member on either side become steeper and closer together. The track terminates just below a long pool which marks the southernmost outcrop of the Dales Gorge Member in the gorge (Plate 25). Farther upstream the first cliffs of the Joffre Member present an even more formidable obstacle than those of the Dales Gorge Member; half a mile south of the end of the track (at the figure '150' on Plate 25) Joffre Creek makes an abrupt right-angled bend, above which it flows east-southeast (Plate 27, A and B) for about ¾-mile; this section of the gorge of Joffre Creek is known as Red Gorge. At the upper (western) end of Red Gorge there is another right-angled bend, above which the creek flows in a general northeasterly direction for about 2¼ miles below Joffre Falls; this section is here called Joffre Gorge (Plate 25). Weano Gorge, Hancock Gorge and Knox Gorge are tributary gorges of the main Joffre Gorge—Red Gorge—Wittenoom Gorge drainage line of Joffre Creek.

There is steep but easy access between top and floor of both sides of Wittenoom Gorge where the Whaleback Shale Member crosses it. The right-angled bend half a mile farther south, where Wittenoom Gorge meets Red Gorge, marks the farthest point of dry access along the gorge floor, since the effectively vertical cliffs rise directly from the edges of the pool in Red Gorge (Plate 27, A and B). Upstream from this point, access to the main gorge from above is possible without mountaineering equipment at only six points: on both sides of the gully formed by the dolerite dyke, on the east side of the fault crossing, on the west cliffs at the Lower Falls, down a gully just below Joffre Falls (Plate 28D) and at Joffre Falls. No part of the gorge is recommended for recreational climbing, since the iron formation is well jointed, and liable to piecemeal collapse without warning. All of these access points except Joffre Falls, are marked by arrows on Plate 25. Access to Knox Gorge is possible at the dolerite dyke, but it is not known whether this gorge can be followed down to Red Gorge. Access to Red Gorge is reported to be possible down Hancock Gorge, but it joins the main gorge at a pool. A vertical cliff at the mouth of Weano Gorge denies access to Red Gorge by this route.

All parts of the gorges shown on Plate 25 except the outlet into Wittenoom Gorge, are best approached by the track shown entering from the south. This is reached from a southward turning off the main Wittenoom—Roy Hill road 15 miles east of Wittenoom; thereafter it is signposted to Joffre Falls. The road climbs up on to the gently undulating Hamersley plateau, into which the gorges are incised, by way of Yampire Gorge. The tracks shown extending northeastwards from Joffre Falls are only roughly graded, and their positions may change from year to year. The track which continues outside the eastern and northern edges of Plate 25 to connect Joffre Falls and Oxers Lookout is a very rough private road which is open to visitors as a courtesy. Oxers Lookout is a spectacular observation post overlooking the confluence of Joffre, Hancock, Weano and Red Gorges. A direct road linking Wittenoom Gorge and Oxers Lookout is strictly private, and normally closed by locked gates; any attempt to use it if the gates are open would be not only an offence, but also extremely dangerous.

The initial descent of Joffre Creek from its open valley on the Hamersley plateau into Joffre Gorge takes place abruptly over 120 feet of the stepped, amphitheatre-like Joffre Falls. The top-most edge-to-edge width of the gorge there averages about 150 feet (Plate 28D). The gorge widens above the Lower Falls (Plate 25), which drop more gradually another 100 feet to increase the height of the gorge walls to about 220 feet, with little increase in width. Within the next half mile downstream the gorge floor slopes down quite steeply in steps made up of huge boulder piles, and the wall height increases to about 300 feet with a topmost width of about 150 feet and a floor width of about 20 feet (Plate 28B). This height, locally increasing or decreasing slightly, is maintained throughout the remainder of the courses of Joffre and Red Gorges; in Red Gorge the top width increases to about 350 to 400 feet, and the floor, or



LEGEND TO GEOLOGICAL AND TOPOGRAPHIC SYMBOLS

- Geological boundary
- 80 Fault plane with dip
- Axial plane trace of syncline
- 5 Strike and dip of bedding
- Bedding close to horizontal
- Dolerite dyke
- 450 Stratigraphic level of adjacent gorge floor in feet above base of Joffre Member
- Steep sides of gorge
- Descent possible
- Stream with permanent pools
- Tracks

STRATIGRAPHY

(Surficial deposits omitted)

- Joffre Member
- Whaleback Shale Member
- Dales Gorge Member

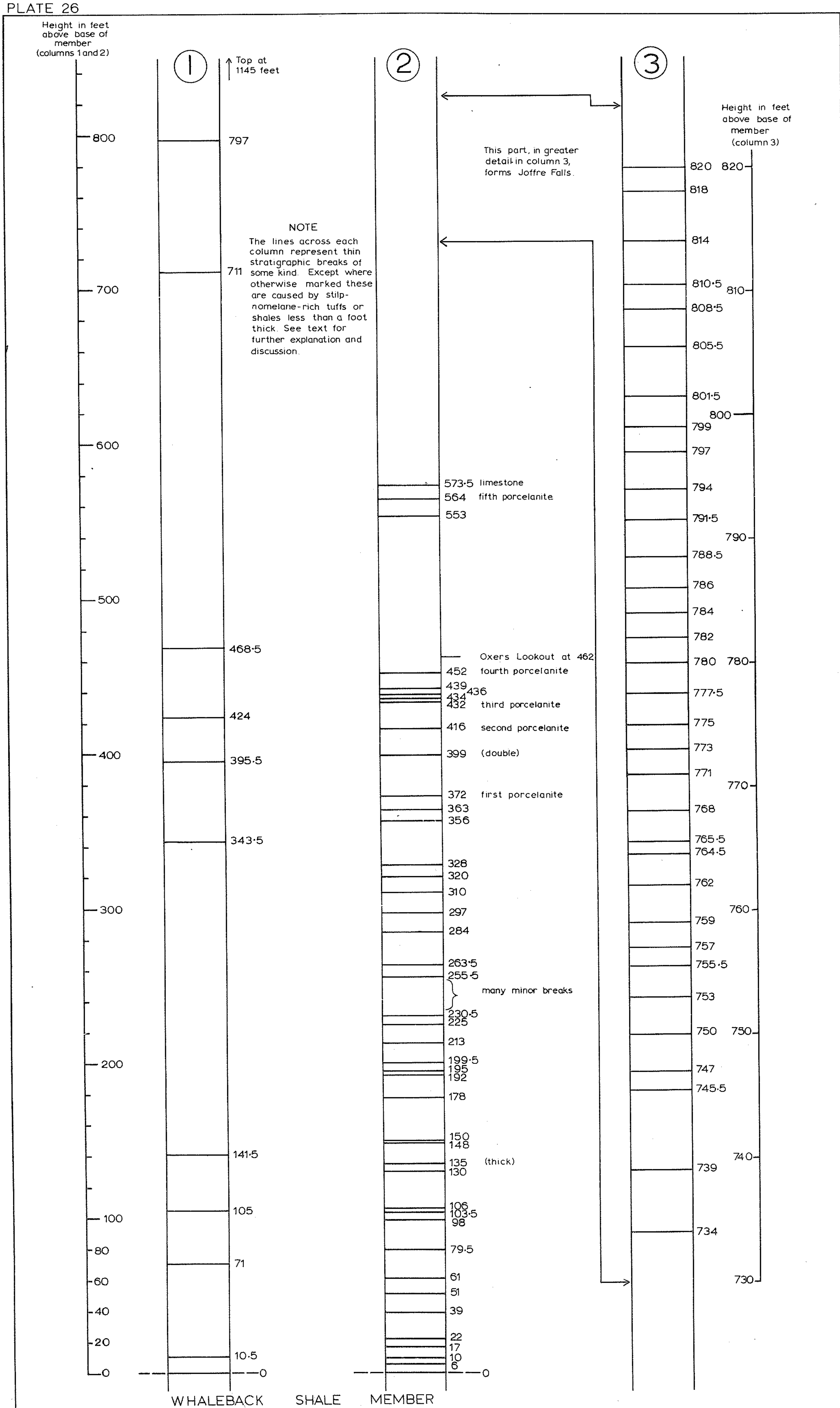
Note: These are the lower three of the four members of the BROCKMAN IRON FORMATION of the Hamersley Group.

SKETCH MAP SHOWING

THE STRUCTURE AND STRATIGRAPHY OF THE JOFFRE MEMBER

IN THE GORGES SOUTH OF WITTENOOM

PLATE 26



MEASURED STRATIGRAPHIC SECTIONS OF PART OF THE JOFFRE MEMBER OF THE BROCKMAN IRON FORMATION, AT THE TYPE SECTION (COLUMN 1) AND IN THE GORGES SOUTH OF WITTENOOM (COLUMNS 2 AND 3).

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pool, width to about 30 to 50 feet (Plate 27, A and B). Here, buttresses topped by grass slopes locally relieve the wall-like sides, but these are never sufficiently extensive to provide practicable access.

METHODS OF WORK

To measure a continuous section of the Joffre Member between the uppermost part of Wittenoom Gorge and Joffre Falls, a light portable raft was constructed using a camp bed and three inflated inner tubes; it can be seen floating on Plate 28B. This provided ample buoyancy for one person and all necessary equipment and rock samples; it was light enough to be easily carried between pools, stable enough to be boarded in awkward positions among slippery boulders, and could be paddled easily. More sophisticated craft would probably have few advantages for the purpose.

A 6-foot wooden pole marked in feet was used for measurement. It proved more practical than a tape for working along smooth cliffs rising directly from the water. Marks were made on the gorge walls at 10-foot intervals using white aerosol paint. The interval was increased in the later part of measurement to conserve paint. The measurement occupied two full days, using the access point at the dolerite dyke for the division into two sections.*

STRUCTURE

The Joffre Member in the area of the gorges forms part of the south-southwesterly dipping north limb of a broad open synclinorium (the Hamersley Range synclinorium) whose axial plane trace runs west-northwest to east-southeast not far south of Joffre Falls. The comparatively mild folding displayed on Plate 25 consists of small departures from this regional dip of about 5°. It will be appreciated from Plates 27 and 28 that folding is not intense, and that the rocks, for their age, have been subject to exceptionally slight deformation.

The single dolerite dyke of Plate 25 has a probable thickness of about 20 feet where it crosses Joffre Gorge, and dips at 80° southwestward. There is an upward displacement of 40 feet on this side, so that the plane of the dyke is a reverse fault. The fault which crosses the gorge farther south dips at 80° to the south and has a normal displacement of 30 feet. It is possible that the gentle syncline, whose axial plane trace bisects the angle between the dyke and the fault, is related to the same stress system which caused them, but this is uncertain, since it is not known whether the fault or the dyke has a lateral component of movement. Also, the fault is terminated at the dyke on Plate 25 by air photo interpretation; its extrapolated transection of Knox Gorge was not examined on the ground. Just north of the fault in Joffre Gorge a reverse (thrust) fault with a southerly dip of about 30° and a throw of only a few feet passes downwards into a small fold and finally dies away in undisturbed iron formation.

It is a structural characteristic of iron formations in the Hamersley Range area that while folds may be mapped and described on any chosen scale, they normally lie within structural components of larger folds and contain within themselves smaller folds on all scales down to very small puckers (Trendall and Blockley, in press). The strike variations along the line of Red Gorge (Plate 25) are probably related to open folds with southwesterly trending axes (compare Dales Gorge; Trendall 1966), but more work is needed, particularly on the tributary gorges, before the status of these can be known.

Many of the short, straight sections of the gorges are evidently controlled by principal joint directions, as at Dales Gorge (Trendall, 1966), but no measurements were carried out. The exact mechanism of joint control versus control by a former open valley of Joffre Creek is a difficult problem involving the regional geomorphological history, and is not discussed here.

STRATIGRAPHY

The main type of lithological discontinuity within the predominant and rather uniform iron formation of the Joffre Member is stilpnomelane-rich shale in bands between about an inch and about a foot thick. After identification of the base of the member (see under next heading) the heights of the mid-points of the thicker of these bands above the base were measured, and appear on Plate 26, columns 2 and 3. All measurements were recorded to the nearest 0.5 feet. The judgment as to whether a shale was thick enough to record was made subjectively, and may have varied through the section; any break large enough to have some potential use for field correlation was recorded. Note that the thicknesses of these shales were not recorded, and that they therefore appear with equal status on Plate 26. The shale at 135 feet is the thickest, at about a foot. That at 399 feet consists of two shales, each about 6 inches thick, separated by between one and two feet of iron formations. Wherever two shales, such as these, are separated by only a foot or two of iron formation, they tend to undulate antipathetically in open folds with a wavelength of about two or three feet, similar to those illustrated above the third porcelanite in Plate 28C.

Trendall and Blockley (in press) applied the name black porcelanite to tough flinty material in the Joffre Member consisting largely of potassic feldspar; they thought it was probably a tuff. Five bands of porcelanite were found, and also appear on Plate 26. Of these, the third is thickest (Plate 28C) and the best stratigraphic marker (Plate 27, A and B). The first porcelanite is about a foot thick, the fourth and fifth (Plate 28B) about 6 inches, and the second only about 3 inches. The lower four porcelanites all lie within 80 feet (Plate 28A). A band of yellow-weathering limestone about a foot thick occurs at 573.5 feet (Plate 28B). It has a coarse calcite mosaic, with siderite and stilpnomelane.

In spite of the subjectivity in measuring shales the following valid generalizations about gross lithological variation within the member may be made from Plate 26:

1. There is little variation between the base and the first porcelanite at 372 feet (Plate 27, A and B).

2. The lower four porcelanites form a potentially useful assemblage for identification (Plate 28A).

3. Between the fourth porcelanite at 452 feet, and 734 feet, the iron formation is uniform and similar to that below the lower four porcelanites; the fifth porcelanite is inconspicuous (Plate 28B), and the limestone of doubtful significance (see under following heading).

4. Between 734 and 820 feet, at least, frequent thin shales are regularly arranged with an average (32 intervals) separation of 2.7 feet, to give a distinctively flaggy appearance (compare Plate 28, B and D).

At Joffre Falls exposures continue to a maximum height of about 900 feet above the base of the member, but the quality of exposure deteriorates above 830 feet. The full thickness of the Joffre Member in this area is not known.

LATERAL CORRELATION WITHIN THE MEMBER

The discontinuities recorded by Trendall and Blockley (in press) in the lower part of the less cleanly exposed type section of the Joffre Member at Yandicoogina Creek appear in column 1 of Plate 26. It is clear that no confident correlation between the two sections can be made without further work.

* In August, 1966, the writer, together with J. G. Blockley and P. C. Muhling, swam and walked from the mouth of Red Gorge to the top of the Lower Falls, in one day. This appears to be the first recorded traverse of the gorges, and cannot be recommended as a geological excursion, since the water in all the pools is always very cold.

The limestone of the Joffre Member closely resembles those locally present in some S macrobands of the Dales Gorge Member (Trendall and Blockley, in press). These are products of diagenetic modification of shale, and their lateral discontinuity is demonstrable. Use of the Joffre Member limestone for attempted regional correlation should therefore be made with care.

Of the core of Hole 47A used for the type section of the Dales Gorge Member (Trendall and Blockley, 1968) a further 358.1 feet are stored in the collection of the Geological Survey of Western Australia. This length includes a complete section of the Whaleback Shale Member, 215.2 feet thick, and 142.9 feet of continuous core upwards from the base of the Joffre Member, to the drilling depth of about 500 feet where core recovery began. It is easy in this core to select a natural lithological junction between the Whaleback Shale Member and the Joffre Member, and this was identified confidently and marked in the gorge (Plate 27C), at a point just over 3 miles from the site of the drill-hole. From the broad similarity between the Dales Gorge Member and the Joffre Member in small-scale stratification (Trendall and Blockley, in press) the achievement of this correlation is not surprising. It is to be expected, but it is not yet demonstrated, that small-scale correlation within the Joffre Member is equally possible on a basin-wide scale, and the establishment of the stratigraphic section reported here should serve as the basis for future investigation of this.

IDENTIFICATION OF PUBLISHED DATA

The identity of a part of the Joffre Member illustrated by MacLeod (1966, Figure 13) is given in the caption of Plate 28D.

Of the illustrations of parts of the Joffre Member used by Trendall and Blockley (in press) their Figure 19B is just over 345 feet above the base, the boys in Figure 19C are standing on the 784-foot discontinuity (Plate 26, column 3), the surface illustrated in Trendall and Blockley's Figure 39A appears in the right hand corner of Plate 28D and is at about 720 feet, and the cross-podded structure in Figure 39D comes from about 725 feet. Of the chemical analyses reported by Trendall and Blockley (in press) analysis 4 of their Table 16 is of stilpnomelane-rich shale at 734 feet, while analysis 5, of black porcelanite, is from the first porcelanite, at 372 feet.

FIELD GUIDE

For dryshod examination of the Joffre Member the best places, in order of ease of physical accessibility, are:

(1) Joffre Falls, where the section between 715 and about 850 feet is well exposed.

(2) At the dolerite dyke, and thence along the gorge floor for about half a mile upstream, the section between about 340 and 450 feet, with the lower porcelanite is cleanly exposed, and increasingly weathered parts are accessible for about 150 feet higher.

(3) At and below the Lower Falls the section below the Joffre Falls exposures, down to about 540 feet, is very well exposed. Descend into the gorge, and down the falls, with care!

(4) The base of the member, and higher levels to about 200 feet, are best reached up Wittenoom Gorge.

Good exposures of the section between 200 and 340 feet are only available in Red Gorge, and these are not accessible dryshod; it is possible that Knox Gorge may provide better exposures here. Oxers Lookout (Plate 28A), and the south cliffs of Red Gorge (Plate 27, A and B) provide excellent views of the stratigraphy, which interested visitors will not wish to miss, but fresh rock is nowhere available along the edges of the gorges.

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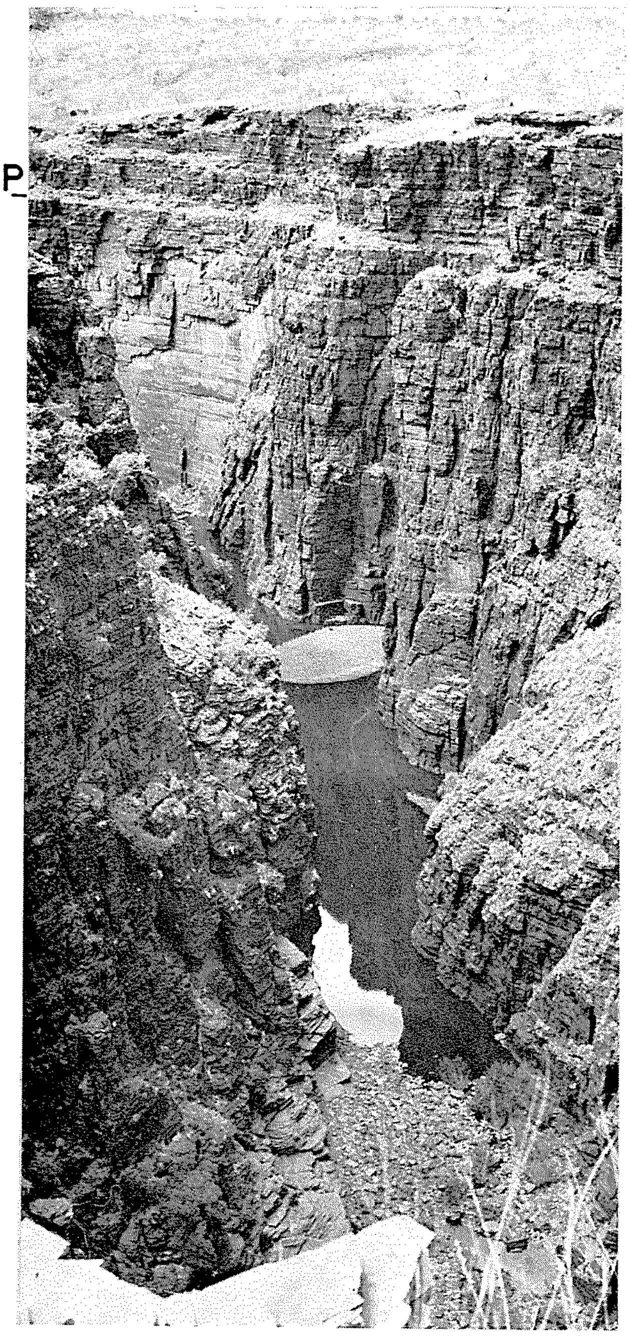
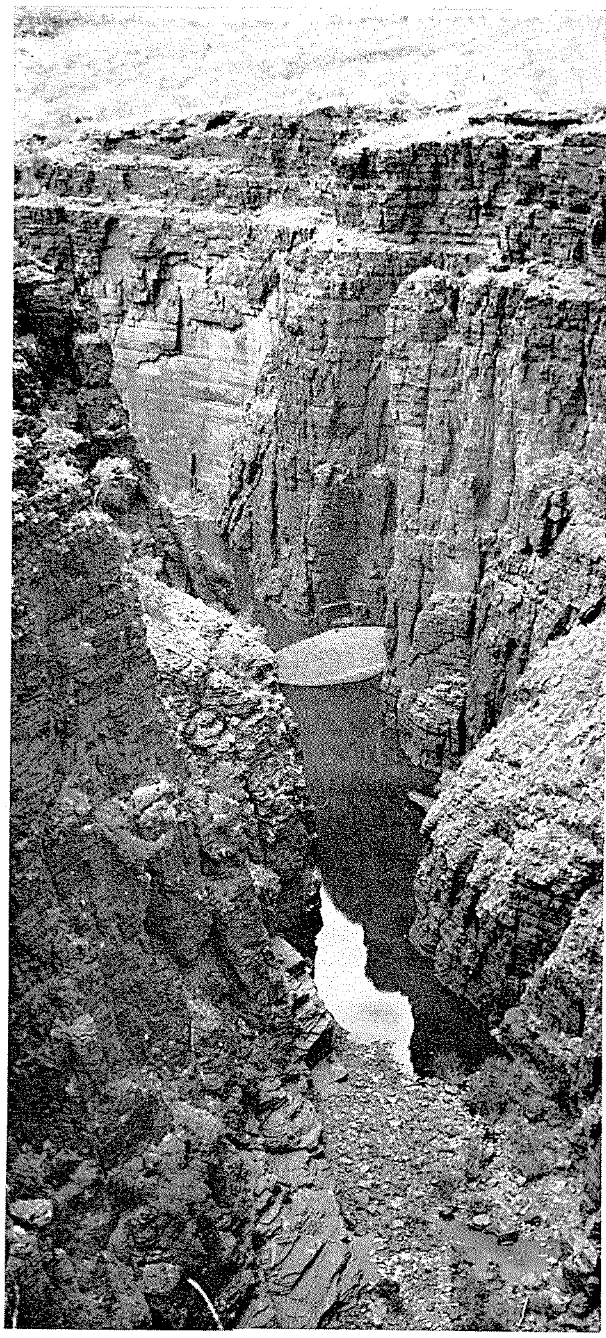
PLATE 27 (opposite)

A and B. Stereoscopic pair of photographs looking east-southeastwards down the lower part of Red Gorge from the edge of the cliffs on the south side at a point just above the figure 5 in the number 175 on Plate 25. Note the smooth flat Hamersley plateau surface in the background continuing evenly to the sharp crest of the cliffs, which reach a maximum height of about 330 feet with much of their slope close to vertical. The farthest visible end of the pool is at the right-angled bend at the mouth of Red Gorge, and is the highest point accessible on foot up Wittenoom Gorge. The coarse gravel bank in the centre of the photograph, which appears to (but does not) divide the pool into two parts, is washed out at the mouth of Knox Gorge. The third porcelanite (Plate 28C) is marked 3P, and forms the most conspicuous stratigraphic marker. The second break about 40 feet above it, best seen in the farthest cliffs, is caused by a group of strongly podded cherts (see Plate 28A) which is not shown on Plate 26, column 2. The vertical cliffs immediately behind the gravel bank demonstate the relative homogeneity of this lower part of the Joffre Member (compare Plate 28D); between water level at 160 feet and the third porcelanite at 432 feet the intervening shales can be picked out using Plate 26. The first and second porcelanites and the shales at 399 and 320 feet are the most conspicuous; other measured shales have no greater status than some unrecorded ones, which illustrates the subjectivity of measurement referred to in the text.

C. Photograph looking west-northwestward across the downstream end of the pool in the uppermost part of Wittenoom Gorge which is crossed by the base of the Joffre Member (Plate 25). The base of the member, and thin stilpnomelane shales at 6, 10, 17, 22 and 39 feet are marked at the right hand side. A paint mark showing the base of the member can be seen about 4 feet above water level just above a small twin tree at the lower margin of the photograph about one-third of the width in from the right hand margin. The positions of other paint marks at 50 and 60 feet are marked by white pointers. Other marks showing stratigraphic position were painted just outside the right hand edge of the photograph in 1968, and should remain visible for some years.





A

B

C

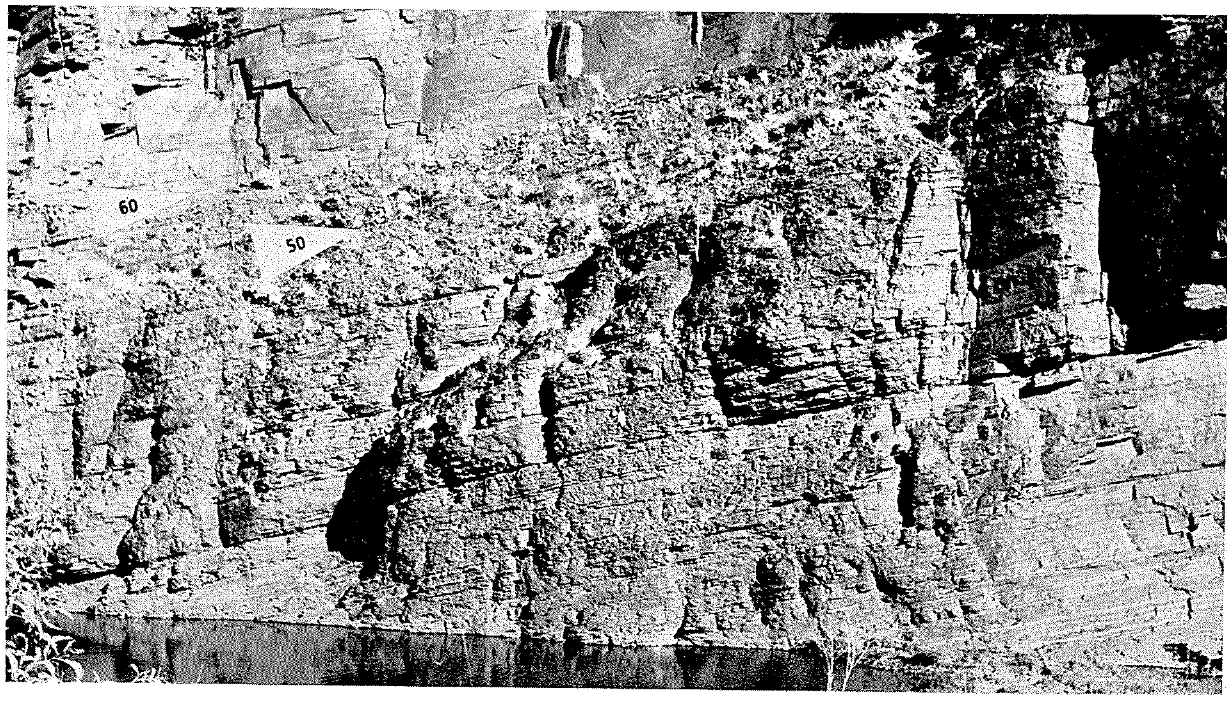
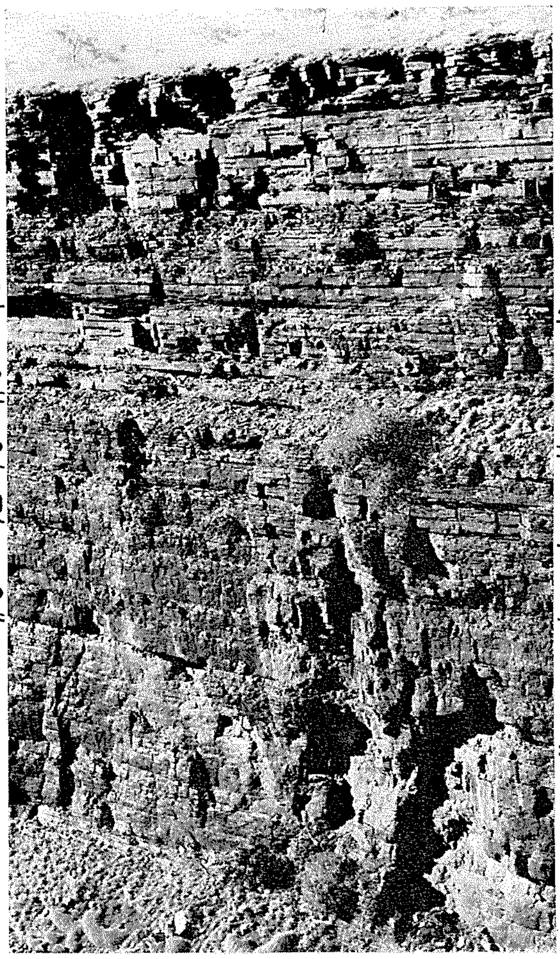
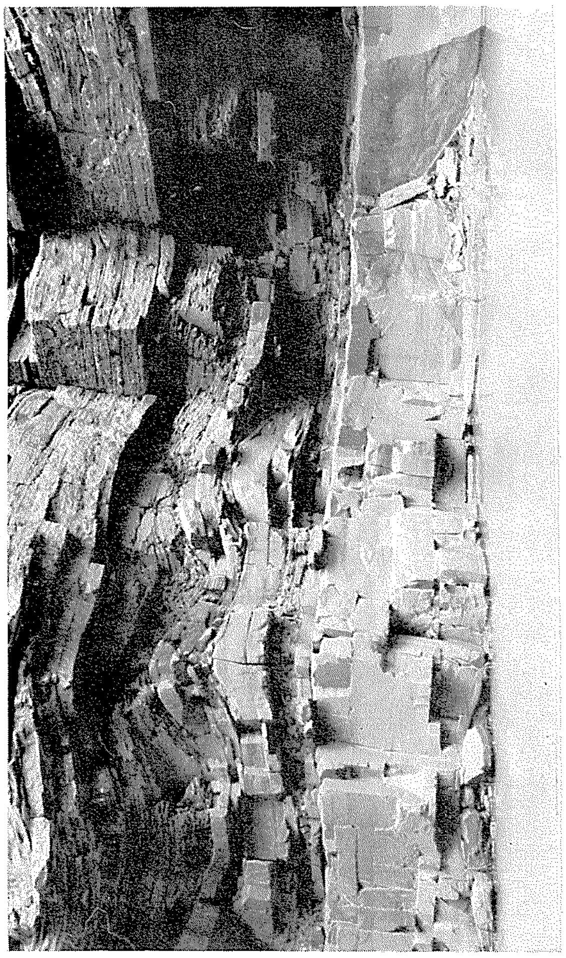


PLATE 28

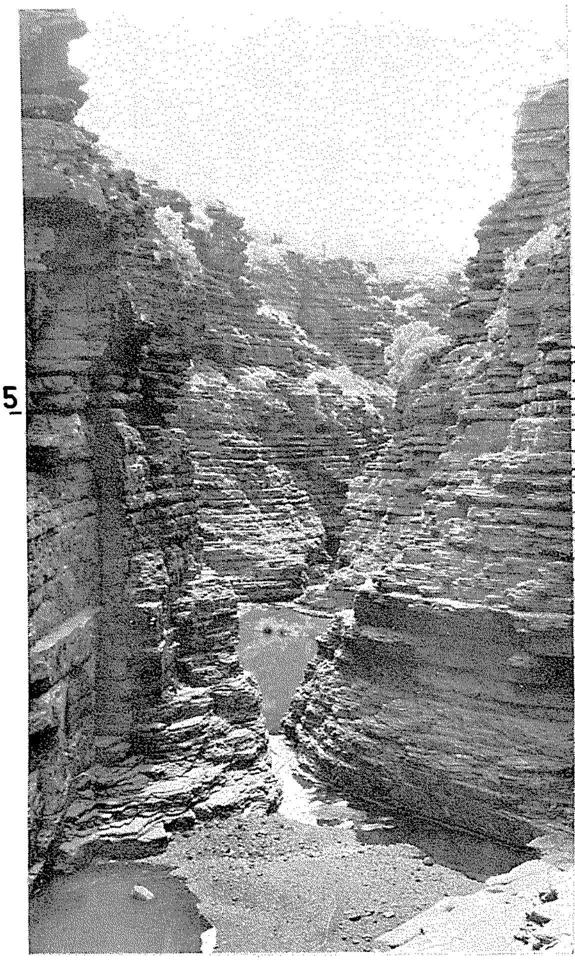


A

B



C



D

PLATE 28 (opposite)

A. Photograph of the topmost cliffs of the south side of Red Gorge, looking south-southeastward from Oxer's Lookout (Plate 25). The lower four porcelanites are marked 1P to 4P, and the double shale at 399 feet is also indicated. The band with strongly podded cherts about 40 feet above the third porcelanite (the fourth porcelanite is 20 feet above the third porcelanite), which forms a break in the cliffs farther eastwards down the gorge (Plate 25, A and B), can be clearly seen.

B. Photograph looking northeast down Joffre Gorge about half a mile downstream from Joffre Falls; the pool is that just above the figure 600 on Plate 25. The camera was held exactly in the plane of the fifth porcelanite, which is marked 5P. The limestone 9.5 feet above and the thin shale 11 feet below are also marked. The limestone, as in the cliffs above the central point of the photograph, often runs immediately below overhanging ledges. The raft used during measurement floats in the pool. The smaller width of this upper part of the gorge contrasts with Plate 27A and B. Note the size of the boulders in the foreground and in the pool; they commonly weigh up to 10 tons.

C. Photograph looking north at the third porcelanite at the foot of the cliffs of Joffre Gorge about 1¼ miles downstream from Joffre Falls, just under the 'r' of the word 'Gorge' on Plate 25. The base of the porcelanite, which is about two feet thick, is exactly at water level. Immediately above it the interbedded shale and iron formation are characteristically thrown into irregular 'rolls' with an amplitude of about a foot; these structures have no consistent axial direction. The composition of the porcelanite (largely potassic feldspar) accounts for the contrast between its tough blocky appearance here, where it is fresh, and its obviously greater susceptibility to weathering than the iron formation in A and Plate 27, A and B.

D. Photograph looking north-northeastwards down Joffre Gorge from a point halfway up Joffre Falls. The thin stilpnomelane shales between 734 and 782 feet, shown in column 3 of Plate 26, are marked on the right hand (east) side. The 775-foot discontinuity only is marked on the left hand side, from which the remainder may be counted up or down and compared with those across the gorge. Note that on the right, the twin shales at 764.5 and 765.5 appear as one discontinuity. Figure 13 of MacLeod (1966) was taken from near the base of the west cliffs close to the head of the long pool above the Lower Falls (Plate 25); the head of the pool is just visible in the central part of this photograph. MacLeod's Figure may be related to the stratigraphic scale given here for the Joffre Member by marking '730' on its right hand margin 2.3 cm up from the lower edge, by marking '739' similarly 3.9 cm up, and by equally subdividing 9 feet between the marks. The stratification here at a mean interval of 2.7 feet contrasts with the typically massive appearance at lower levels (B of this Plate, and Plate 27, A and B). Access may be gained to the gorge here by the steep gully which runs down to the central pool (with grass clumps) behind the buttress in the left foreground.

A COMPARISON OF SOME VOLCANIC ROCKS OF UNCERTAIN AGE IN THE WARBURTON RANGE AREA

by R. Peers

ABSTRACT

Four occurrences of basaltic rocks are known from the Officer Basin of Western and South Australia: the Officer Volcanics, intersected between 2,405 and 2,764 feet in the oil test well Yowalga No. 2, the Table Hill Volcanics on the Talbot 1:250,000 Sheet area, some un-named volcanics on the Cooper 1:250,000 Sheet area, and the Kulyong Volcanics on the Birksgate 1:250,000 Sheet area. The Officer, Table Hill, and Kulyong Volcanics are all vesicular and massive tholeiitic basaltic rocks.

Examination of specimens from each of these sequences of volcanic rocks demonstrates the petrographic similarity of these basalts and suggests that they may in fact be contemporaneous and co-magmatic. The un-named basalts on the Cooper 1:250,000 Sheet area are deeply weathered and were not examined at all. Results of Rb/Sr and K/Ar isotopic age-dating on the Officer Volcanics have been interpreted as indicating an age of about 1,000 m.y. (Proterozoic). K/Ar isotopic age-dating on the Kulyong Volcanics gave an age of 475 ± 20, 485 ± 20 m.y. (Ordovician). The Table Hill Volcanics have not been dated. It is suggested that further isotopic age-dating will prove that these basalts are co-magmatic and of the same age (probably Ordovician).

INTRODUCTION

Four occurrences of basaltic volcanic rocks are known in the Officer Basin of Western and South Australia, the Officer Volcanics intersected in Yowalga No. 2, the Table Hill Volcanics, the un-named volcanics on the Cooper 1:250,000 Sheet area, and the Kulyong Volcanics (see Figure 12).

Yowalga No. 2 oil test well on the northeastern corner of the Breaden 1:250,000 Sheet area was drilled for the Hunt Oil Co.—Placid Oil Co. in 1966. It passed through a formation consisting of vesicular and massive basalts, and named the Officer Volcanics, between 2,390 feet and 2,775 feet. The Officer Volcanics unconformably overlie the Babbagoola Formation and are in turn overlain by the Lennis Sandstone.

Three samples of Yowalga No. 2 basalt were submitted to three independent contractors for isotopic age determinations. Both the potassium/argon and rubidium/strontium methods were applied, and the following results obtained.

Depth	Method used	Isotopic Age (in millions of years)	Contractor
2417′–19′ (Core 3)	Rb/Sr	1,000	A.N.U.
2417′–19′ (Core 3)	Rb/Sr	446	A.N.U.
2422′ (Core 3)	K/Ar	357	Geochron
2422′ (Core 3)	K/Ar	331	Isotopes, Inc.
2760′ (Core 4)	Rb/Sr	1,143	A.N.U.
2760′ (Core4)	K/Ar	447	Geochron
2760′ (Core 4)	K/Ar	445	Isotopes, Inc.

Jackson (1966) discussed and interpreted these results and came to the following conclusions. The ages of 331-357 million years and 445-447 million years (Devonian or Ordovician) are interpreted as being the age of metamorphism in the basalts of Yowalga No. 2. It should be noted that the degree of 'metamorphism' is very mild and may be interpreted as deuteric alteration, weathering, or a combination of both. The crystallization age of the basalt is taken by Jackson as Upper Proterozoic, or at a minimum of 1,000 million years.

Birksgate No. 1 stratigraphic well, 35 miles southeast of the Kulyong Volcanics, was drilled to 6,160 feet and bottomed in an arkose which is tentatively correlated by geologists of the South Australian Geological Survey with the Lennis Sandstone in Yowalga No. 2 well (written communication). Rb/Sr isotopic ages of 845 ± 250 million years were obtained from shales in Birksgate No. 1 between 3,170 and 3,180 feet depth.

The Table Hill Volcanics crop out over an area of about 16 square miles on the Talbot 1:250,000 Sheet area, and are composed of fine-grained massive, and vesicular basaltic rocks. They are unconformably overlain by glacial sediments of probable Permian age, and in turn overlie glacial deposits of Upper Proterozoic age from which they are probably separated by an unconformity (J. L. Daniels, personal communication). Unfortunately no age-dating has been carried out on any of the samples from the Table Hill Volcanics.

The un-named volcanics on the Cooper 1:250,000 Sheet area were visited by members of a mapping party of the Geological Survey of Western Australia during the field season of 1967. They are deeply weathered, fine-grained basic volcanic rocks

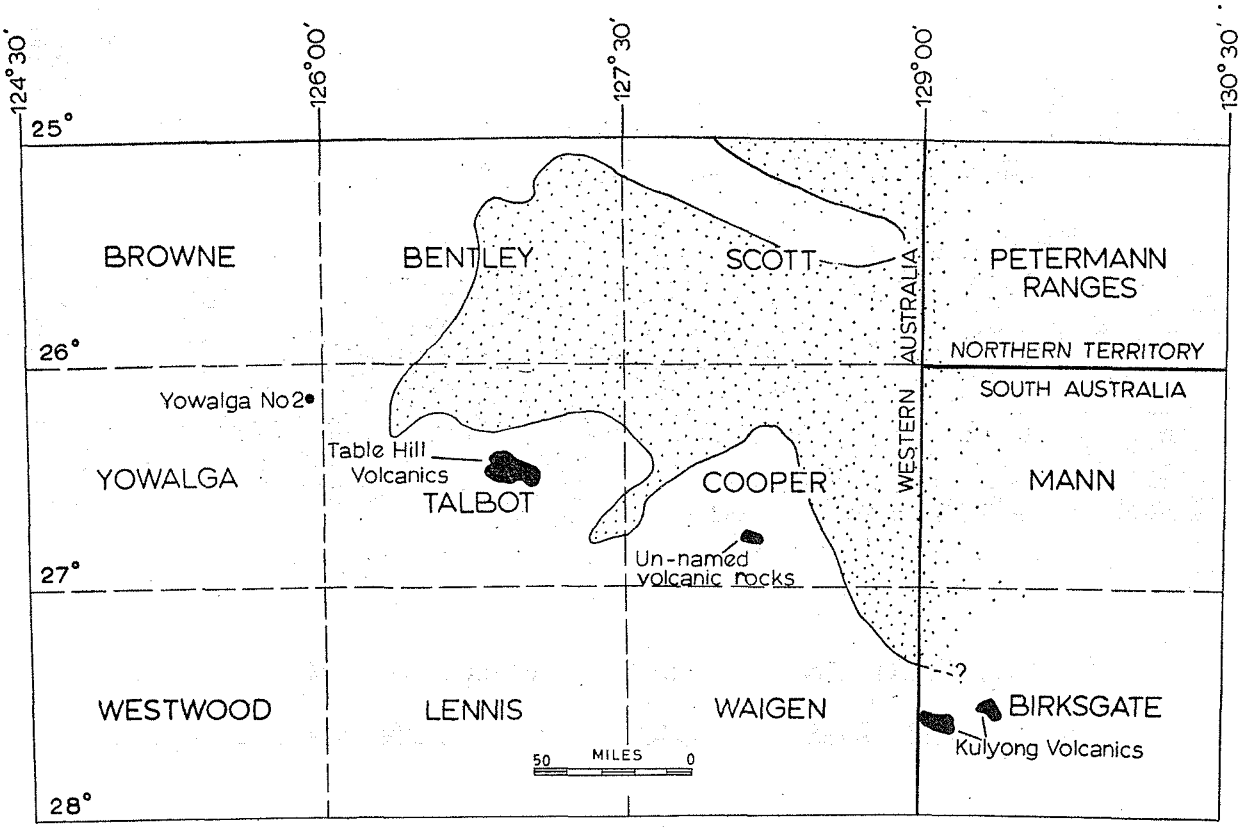


Figure 12. Distribution of volcanic rocks and Precambrian rocks in the Officer Basin.

(J. L. Daniels personal communication), and will not be discussed further in this report.

The Kulyong Volcanics are located on the Kulyong 1:63,360 Sheet area of the Birksgate 1:250,000 Sheet area. The volcanics at the type section (lat. 27° 36′ 20″S, long. 129° 26′ 00″E) are 10 feet thick and composed of both massive and vesicular basaltic rock (Major and Teluk, 1967). The Kulyong Volcanics overlie a red-brown sandstone. No rocks have been seen overlying and in contact with the volcanics, and there is no evidence such as chilled margins, disturbance, or erosion of a former upper contact. Major and Teluk (1967) refer to the occurrence as "a flow or intrusion", so it would appear that there is no field evidence as to the form of these volcanics, and whether they are in fact extrusive or intrusive.

The Kulyong Volcanics were dated by Isotopes, Inc. using the K/Ar method, and the following results obtained.

Sample number	S.A. Mines Dept petrological no.	Isotopic age (in millions of years)
18013	P671/66	485 ± 20
18014	P672/66	475 ± 20

The Ordovician age is supported by regional mapping in South Australia (written communication from South Australia Department of Mines).

The purpose of this report is to compare the petrography of the basalts from Yowalga No. 2, the Kulyong Volcanics, and the Table Hill Volcanics.

ACKNOWLEDGEMENTS

I wish to thank the Director of the South Australia Department of Mines for the loan of thin-sections of specimens from the Kulyong Volcanics, and for access to the two reports on these volcanic rocks by A. B. Simpson of the Australian Mineral Development Laboratories, Adelaide (1966a, 1966b).

PETROGRAPHY OF THE OFFICER VOLCANICS

Three cores were taken from the Officer Volcanics Formation.

Split halves of each core are stored at the core library of the Geological Survey. The following samples were selected for thin-sectioning and examination.

Core number	Depth From	Depth To	Amount recovered
2	2,405′	2,413′	1′6″
3	2,413′	2,423′	9′6″
4	2,754′	2,764′	10′0″

Core 2—between 2,404′ and 2,413′
Core 3—2,419′ (approx)
Core 3—2,421′ „
Core 3—2,323′ „
Core 4—2,756′ „
Core 4—2,759′ „
Core 4—2,764′ „

These samples conveniently fall into two groups, (a) altered amygdaloidal basalt at depths of between 2,404 and 2,413; 2,419, 2,421 and 2,423 feet, and (b) unaltered basalt at depths of 2,756, 2,759, and 2,764 feet.

The following descriptions are based primarily on the report of the consultant petrologist (J. E. Glover) from the completion report for Yowalga No. 2 (Jackson, 1966).

ALTERED AMYGDALOIDAL BASALTS

Hand specimen. The altered amygdaloidal basalts are both amygdaloidal and slightly porphyritic. They are composed of rare phenocrysts of pink feldspar set in a fine-grained, dark pinkish-brown groundmass. Their most striking feature however is the presence of numerous, more or less round, bright green amygdales, with maximum diameters of 5 mm.

Thin-section. The phenocrysts are subhedral and range up to 1.5 mm in length. They are composed of plagioclase which is so altered to a mixture of clay, hematite, and minor epidote as to preclude a more specific identification. However, refractive index determinations by Glover (1966), indicate the present composition to be albite. Multiple twinning can still be distinguished. In the sample taken from between 2,404′ and 2,413′, the plagioclase phenocrysts are evenly and normally zoned from labradorite to andesine, and only slightly altered to albite, sericite, and chlorite.

The groundmass is composed of a meshwork of plagioclase laths up to 0.5 mm long, with interstitial pale green chlorite and a turbid brown material which may be devitrified glass now represented by hematite-impregnated K-feldspar. Some of the cloudy patches may represent altered pyroxene, but none of the original mineral remains. Skeletal frameworks of magnetite commonly enclose patches of antigorite. The shape of many of these grains is strongly reminiscent of olivine, but none of the original mineral remains to support this conjecture, and they could equally well be pyroxene pseudomorphs (see Plate 29F).

The amygdales vary considerably in size, and their contents have been identified by the Government Chemical Laboratories as mainly chlorite with smaller amounts of hematite, muscovite, and calcite (see Plate 30A, B, and C). In well-developed amygdales the sequence from margins to centre is: chlorite, a mixture of chlorite and muscovite, and muscovite (see Plate 30B). In most amygdales however, chlorite is the predominant mineral developed. The specimen from between 2,404′ and 2,413′ has no vesicles *sensu stricto*, but has developed irregular patches infilled with chalcedony and commonly rimmed by hematite. It is grouped with the amygdaloidal basalts because it seems to have stronger affinities here than with the massive basalts.

Opaque minerals include anhedral grains of magnetite and hematite. Texturally these rocks may be described as intersertal and amygdaloidal (see Plate 29B).

UNALTERED BASALTS

Hand specimen. The unaltered basalts are very basalts are brownish-green, reddish-brown, or dark grey. They have no amygdales, lack any obvious fabric and are composed of an interlocking meshwork of plagioclase and pyroxene crystals.

Thin-section. The predominant minerals are plagioclase and clinopyroxene. Plagioclase forms altered laths up to 1.5 mm long which are normally zoned from bytownite to labradorite. Two clinopyroxenes are present. The coarser-grained, relatively unaltered pyroxene with the moderate 2V is augite. The calcium-poor equivalent, pigeonite, forms smaller anhedral grains which are extensively altered to uralite, and stained by hematite. Pigeonite is more abundant than augite.

Other minerals include anhedral magnetite and hematite grains. The interstitial material is a brown, poorly crystallized mineral of low relief which may be K-feldspar, and probably represents devitrified glass, with minor chlorite. These areas include numerous minute grains of hematite and acicular crystals of apatite. The texture of these rocks varies from subophitic to intergranular (see Plate 29A).

PETROGRAPHY OF THE KULYONG VOLCANICS

The following descriptions are based on the two petrological reports made by A. E. Simpson of the Australian Mineral Development Laboratories, Adelaide, with some modification suggested by my own examination of thin-sections of samples from the Kulyong Volcanics kindly made available by the South Australian Department of Mines.

Four samples are considered, P671/66 (T.S.18013), P672/66 (T.S.18014), P1042/66 (T.S.18288), and P1043/66 (T.S.18289).

N.B. The numbers are those of the South Australian Department of Mines collection.

FINE TO MEDIUM-GRAINED BASALT

Hand specimens. The fine to medium-grained basalts are brownish-green, reddish-brown or dark grey. They have no amygdales, lack any obvious fabric and are composed of an interlocking meshwork of plagioclase and pyroxene crystals.

Thin-section. The textures developed in these holocrystalline basalts vary between subophitic and intersertal, and all except specimen 18014 are sparsely porphyritic with scattered plagioclase phenocrysts up to 0.8 mm long (see Plate 29C). The predominant minerals are plagioclase and pyroxene. The plagioclase is polysynthetically twinned and normally zoned from labradorite to andesine in all except specimen 18289 where it is zoned from labradorite to a more sodic labradorite. The lath-shaped plagioclase crystals range between 0.1 mm and 0.5 mm in length and are sometimes extensively sericitized.

Three pyroxenes occur in this group of rocks, a calcic clinopyroxene, its calcium-poor equivalent, pigeonite, and an orthopyroxene. The calcic clinopyroxene (augite) occurs in each thin-section, and has a $2V\gamma$ of 40° or more. It is colourless to pale brown and partly altered to bastite and uralite(?). Simpson (1966) reports very fine exsolution lamellae of pigeonite(?) developed parallel to the (001) plane of the augite in specimen 18288. This may in fact be a preferential development of alteration products along the (001) cleavage. Hematite is commonly concentrated along cleavage and fracture planes of the augite. Orthopyroxene occurs only in specimen 18288, and is subordinate to the augite which commonly mantles it. In specimen 18289 the predominant pyroxene is pigeonite with the co-existing augite forming larger crystals by comparison.

Scattered grains of an opaque mineral (magnetite or titanomagnetite) altering to limonite and hematite occur throughout these rocks, and general hematite staining is widespread.

The interstitial areas of these rocks are variously composed of a devitrified glassy mesostasis (alkali feldspar?) and chlorophaeite. A poorly crystallized brownish material of low relief occurs in all except specimen 18014. Simpson (1966) regards this material as a devitrified glassy mesostasis which includes minute grains of hematite and acicular apatite crystals. For specimen 18288 Simpson (1966) suggests that this material is actually an alkali feldspar. It seems likely that all of the brownish interstitial material in these rocks is an alkali feldspar heavily charged with hematite and other products of incipient crystallization as the result of devitrification of an acid glass. Specimen 18014 has in addition a patchy development of an olive green material which Simpson (1966) identified as chlorophaeite (see Plate 30E). Sarbadhikari and Bhattacherjee (1966) suggest that chlorophaeite is a mixture of clay minerals (montmorillonoids, vermiculite and kaolinite) chiefly derived by the alteration of pyroxenes, iron ores, and primary glass. The specific mineralogical composition of this chlorophaeite is unknown, as it its genesis. In specimen 18289 Simpson (1966) notes that "certain other cavities in the rock are filled with a colloform deposit of a brownish fibrous silica mineral with low birefringence which is probably ?lussatite". Lussatite is defined by Frondel (1962) as a fibrous cristobalite. The colloform mineral in question is certainly a fibrous form of silica, but it may be either lussatite or chalcedony (see Plate 30D).

Major and Teluk (1966) report that the lower seven feet of the Kulyong Volcanics are vesicular, but none of this vesicular basalt was available for examination.

PETROGRAPHY OF THE TABLE HILL VOLCANICS

Seven specimens from this formation were selected, thin-sectioned and described. Six (specimens 18206, 18210, 18212, 18214 and 18216) are fine-grained massive basalts, and specimen 18209A is an amygdaloidal basalt. A description of the altered amygdaloidal basalt, and a composite description of the six massive basalts follow.

ALTERED AMYGDALOIDAL BASALT

Hand specimen. The altered amygdaloidal basalt is a very fine-grained pinkish brown rock. The amygdales comprise some 50 per cent of the rock and are infilled with a yellow-green material which has been leached from the weathered surfaces leaving a scoriaceous framework.

Thin-section. Examination reveals that the specimen is highly altered. Euhedral and subhedral plagioclase phenocrysts up to 0.5 mm long are arranged in glomeroporphyritic groups, and are extensively altered to clay minerals and albite. Numerous small areas of antigorite enclosed by a frame-work of hematite are probably pseudomorphous after olivine. Many retain the bipyramidal form typical of euhedral olivine crystals.

The groundmass is composed of a network of plagioclase laths up to 0.3 mm long with interstitial areas composed of chlorite (after pyroxene?) and a turbid brown material which is probably hematite-charged K-feldspar representing devitrified glass.

The amygdales have a maximum diameter of 5.0 mm and although not always spherical, are rounded in shape. They are lined by a narrow rim of chlorite and infilled with a colourless zeolite which has a radiating form.

Texturally this rock may be described as intersertal and amygdaloidal.

FINE-GRAINED BASALT

Hand specimen. These rocks are fine to medium-grained, grey and pinkish brown in colour and composed of an intermeshing network of plagioclase and pyroxene crystals with rare phenocrysts of plagioclase. The weathered surface is an orange-brown, somewhat hackly skin.

Thin-section. The plagioclase phenocrysts are subhedral and anhedral, and are twinned on Carlsbad and albite laws. They range between 1 mm and 3 mm in length, and are evenly and normally zoned from labradorite to andesine in all except one specimen in which they are zoned from bytownite to labradorite. Alteration is typically concentrated in the more calcic cores of the phenocrysts, and alteration products include sericite, carbonate, chlorite, zoisite, chalcedony and prehnite. Not all alteration products are developed in each rock specimen.

The plagioclase laths of the groundmass vary in length between 0.2 mm and 0.5 mm, and are not as well twinned as the phenocrysts. They are normally zoned from labradorite to andesine, and commonly the cores of these crystals are obscured by a mixture of the alteration products sericite, chlorite and minor carbonate.

Three pyroxenes occur in these rocks, augite, pigeonite and orthopyroxene. Augite and pigeonite are present in every thin-section examined, whereas the orthopyroxene was noted in only two of them. Typically pigeonite forms small anhedral grains with a $2V\gamma$ between 0° and 10°, and is often altered to a pale yellowish-green chlorite (bastite) particularly along the (001) cleavage. In some sections it is difficult to distinguish from augite, but as a group the pigeonite crystals are smaller and more common than the co-existing augite crystals. Augite forms anhedral grains which sub-ophitically enclose plagioclase laths (see Plate 29E). It is recognized by a moderate positive optic axial angle, and is sometimes twinned on (100). In one of the thin-sections examined the augite grains exhibited an 'hour-glass' structure which may be a type of zoning. Intense staining with hematite along cleavage and fracture planes is common, and patchy alteration to bastite occurs. The orthopyroxene crystals tend to occur as clusters of larger crystals in a poorly developed glomeroporphyritic texture. They are anhedral grains which sub-ophitically include plagioclase laths, and are free from alteration and iron-staining. They are distinguished by low birefringence, a negative optic axial angle, and parallel extinction.

In one of the slides a few skeletal frameworks of hematite infilled with a bright green chlorite were noted. These are very similar to the relict crystals common in the amygdaloidal basalts from Yowalga No. 2, and may also be pseudomorphs after olivine.

The interstitial areas of these rocks are composed of potassium feldspar (orthoclase?) intensely charged with hematite, and including crystallites of magnetite and acicular apatite crystals. The composition of the feldspar was checked by staining with sodium cobaltinitrate. This interstitial material may be the result of devitrification of a glass, or alternatively just the product of crystallization of residual magma trapped in the interstices between the earlier-crystallized plagioclase and pyroxene. Some of the interstitial areas are infilled with pale green chlorite, bright green chlorite (see Plate 30F), prehnite, and chalcedony or combinations of these. Several rounded areas of antigorite and chalcedony are probably weakly developed amygdales. However none of these specimens could be described as amygdaloidal.

Texturally these rocks may be described as mildly microporphyritic, and partly sub-ophitic and partly intergranular (see Plate 29D).

DISCUSSION

Yoder and Tilley (1962, p. 353) define the term 'tholeiite' in the following way. "Tholeitte in the strict sense has as essential minerals an augite or a subcalcic augite, plagioclase (near An_{50}), and iron oxides. Olivine is present in subordinate amounts or may be absent. Characteristically an interstitial vitreous acid residuum, commonly pigmented, is developed, often providing the intersertal texture of this rock type, or this residuum may be represented by a quartzo-feldspathic intergrowth. The critical feature in this definition is the nature of the pyroxene or pyroxenes which may consist of augite zoned to subcalcic augite with pigeonite, or hypersthene or both (Tilley, 1961)."

Wilkinson (1967) states that an essential and critical feature of tholeiites is the reaction relation between olivine and Ca-poor pyroxene, often indicated by pyroxene mantling olivine. Olivine when present in tholeiitic basalts typically occurs only as phenocrysts, which are not commonly zoned.

The residual glass may be altered to ferruginous chlorophaeite, and the abundance of zeolites, chlorophaeite, various hydrated silicates containing iron (chlorites, clay minerals, etc.), carbonates, and chalcedony testify to the activity of late magmatic solutions charged with silica, carbon dioxide, iron, soda, and lime (Turner and Verhoogen, 1960).

The three suites of basaltic rocks described in this report, the Officer Volcanics, the Kulyong Volcanics and the Table Hill Volcanics, are petrographically very similar. All have a weakly

DESCRIPTION OF PHOTOMICROGRAPHS—PLATE 29

A. Tholeiitic basalt, Officer Volcanics, W.A., showing granular augite and pigeonite with intermeshing plagioclase laths arranged to form intergranular and sub-ophitic textures. The opaque grains are magnetite and hematite, and the interstitial areas are composed of hematite-impregnated K-feldspar.
Plane-polarized light, X45.

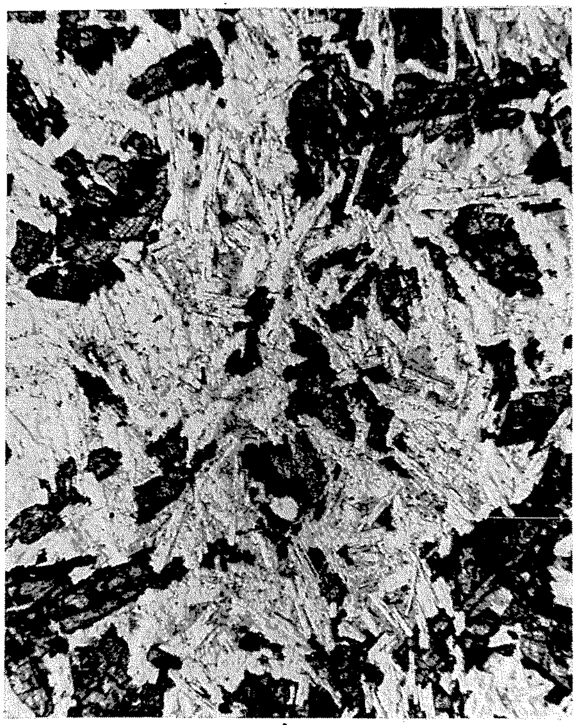
B. Tholeiitic amygdaloidal basalt, Officer Volcanics, W.A., showing irregularly-shaped amygdales infilled with chlorite (white) and a mixture of chlorite and muscovite (grey). The skeletal crystal (top right) is composed of magnetite, chlorite, and antigorite, and is thought to be pseudomorphous after olivine. The groundmass is an intermeshing network of altered plagioclase laths with interstitial hematite-impregnated K-feldspar (devitrified glass?) and scattered magnetite granules.
Plane-polarized light, X20.

C. Tholeiitic basalt, Kulyong Volcanics, S.A., showing a subhedral microphenocryst of plagioclase which is slightly altered to K-feldspar, in a sub-ophitic and intersertal groundmass of plagioclase laths, granular augite, opaque magnetite or titanomagnetite, and interstitial hematite-impregnated K-feldspar (devitrified glass?).
Plane-polarized light, X20.

D. Tholeiitic basalt, Table Hill Volcanics, W.A., showing an anhedral microphenocryst of lightly sericitized plagioclase set in a sub-ophitic and intergranular matrix of plagioclase laths, granular augite and pigeonite, irregular magnetite and hematite grains, and interstitial hematite-impregnated K-feldspar (devitrified glass?).
Plane-polarized light, X20.

E. Tholeiitic basalt, Table Hill Volcanics, W.A., showing a large, anhedral, augite phenocryst, ophitically enclosing small laths of plagioclase and set in a groundmass of granular augite and pigeonite, plagioclase laths, and interstitial K-feldspar.
Plane-polarized light, X45.

F. Tholeiitic amygdaloidal basalt, Officer Volcanics, W.A., showing glomeroporphyritically arranged magnetite, chlorite, and antigorite pseudomorphs after olivine (?) in a fine-grained groundmass of altered plagioclase laths, interstitial chlorite and hematite-impregnated K-feldspar, and grains of magnetite.
Plane-polarized light, X20.



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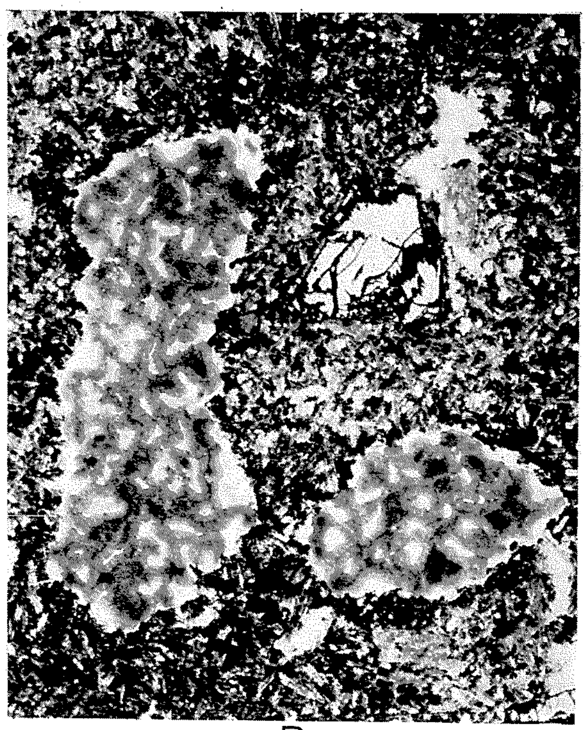

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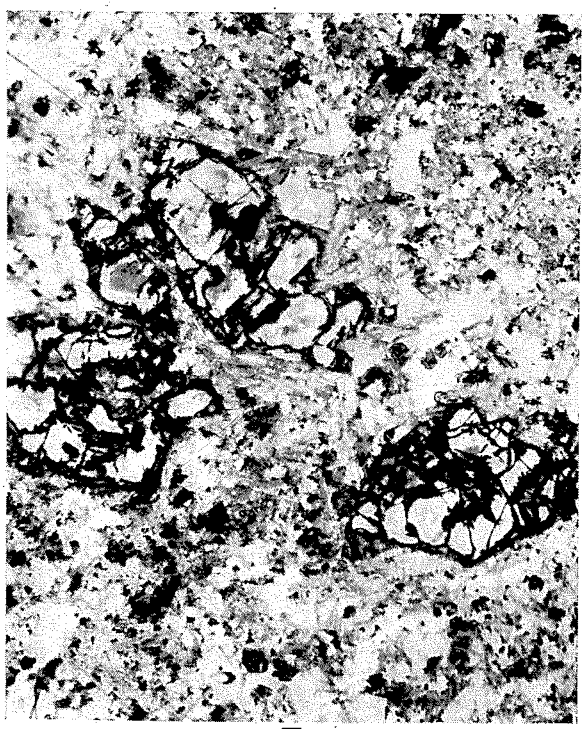

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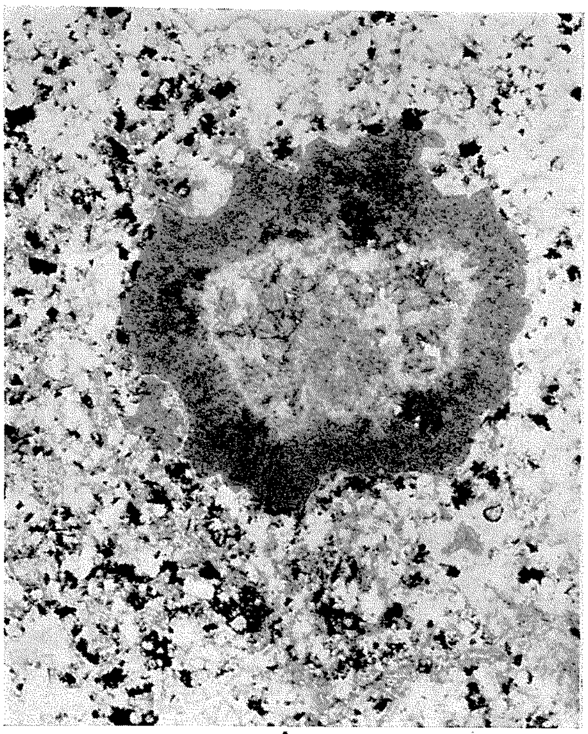
PLATE 30



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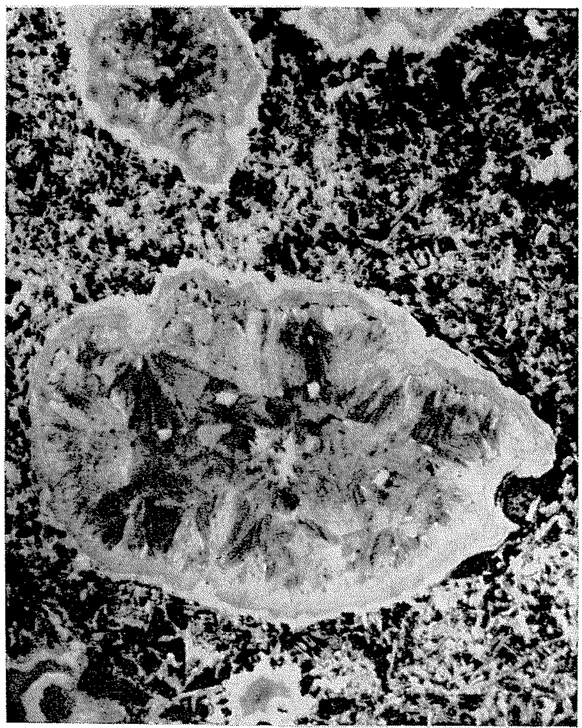

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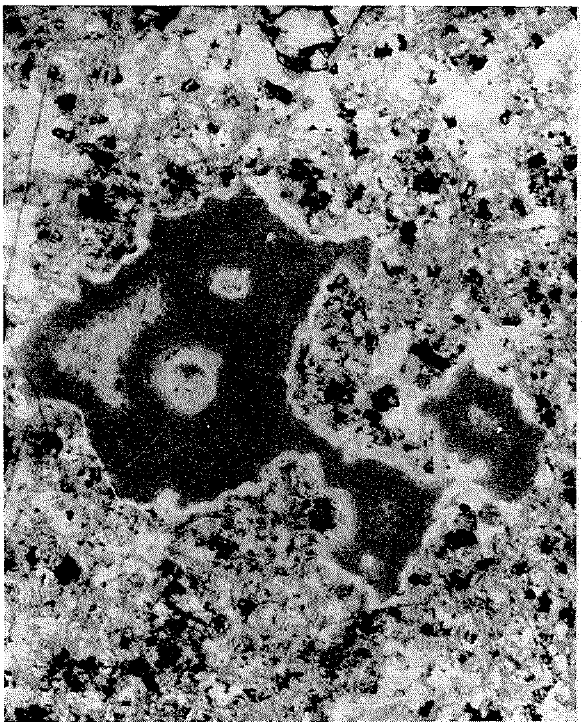

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F

DESCRIPTION OF PHOTOMICROGRAPHS—PLATE 30

A. Tholeiitic amygdaloidal basalt, Officer Volcanics, W.A., showing an irregular amygdale infilled with a mixture of muscovite and chorite (dark grey), muscovite (pale grey, radiating), and chlorite (pale grey, finely divided). The groundmass is composed of a mixture of altered plagioclase laths, magnetite grains, and hematite-impregnated K-feldspar.
Plane-polarized light, X20.

B. Tholeiitic amygdaloidal basalt, Officer Volcanics, W.A., showing an irregular amygdale infilled with chlorite (white at margin), a mixture of muscovite and showing an irregular amygdale infilled with chlorite radiating structure in centre of amygdale). The groundmass is made up of altered plagioclase laths, hematite-impregnated K-feldspar, and magnetite. Parts of several smaller amygdales are visible.
Plane-polarized light, X20.

C. Tholeiitic amygdaloidal basalt, Officer Volcanics, W.A., showing an irregular amygdale infilled with a mixture of muscovite and chlorite (dark grey) and muscovite (pale grey). The groundmass is composed of altered plagioclase laths, hematite-impregnated K-feldspar, magnetite grains, and olivine pseudomorphs.
Plane-polarized light, X20.

D. Tholeiitic basalt, Kulyong Volcanics, S.A., showing an irregular cavity infilled with colloform, fibrous silica, (either lussatite or chalcedony) with large grains of augite in a groundmass of plagioclase laths, granular pigeonite, and interstitial hematite-impregnated K-feldspar.
Plane-polarized light, X20.

E. Tholeiitic basalt, Kulyong Volcanics, S.A., showing interstitial areas infilled with chlorophaeite (dark grey) in a rock composed of plagioclase laths, granular augite and interstitial hematite-impregnated K-feldspar with minor chalcedony.
Plane-polarized light, X55.

F. Tholeiitic basalt, Table Hill Volcanics, W.A., showing irregular interstitial areas infilled by chlorite, in a rock composed of plagioclase laths, granular augite and pigeonite, interstitial hematite-impregnated K-feldspar, and scattered grains of magnetite.
Plane-polarized light, X45.

developed microporphyritic texture with scattered phenocrysts of plagioclase zoned from labradorite to andesine, or bytownite to labradorite. The phenocrysts are set in an intermeshing network of plagioclase laths and pyroxene grains. Plagioclase in the groundmass is composed of labradorite zoned to andesine, with two exceptions where it is a little more calcic. In every specimen which was sufficiently unaltered for the pyroxenes to be identified, augite is present, either singly, or in association with pigeonite and/or an orthopyroxene. Possible pseudomorphs after phenocrystal olivine are present in both the Officer and Table Hill Volcanics. Anhedral grains of an opaque mineral (magnetite or titanomagnetite) are present in every thin-section examined.

The interstitial areas of all specimens are composed of partially devitrified glassy material, or an intensely pigmented (iron-stained) acid residuum which was identified positively in the Table Hill Volcanics as a potassium feldspar. Late-stage deuteric action is substantiated by scattered interstitial pockets infilled with chlorite, chalcedony, and prehnite. Chlorophaeite fills scattered pockets in the Kulyong Volcanics.

Amygdaloidal basalts occur in each of the Officer Volcanics, Kulyong Volcanics and Table Hill Volcanics. The amygdaloidal basalts from the Officer Volcanics and Table Hill Volcanics are very similar. Unfortunately none of the vesicular basalt from the Kulyong Volcanics has been described.

Clearly then these three groups of basaltic rocks all belong to the tholeiitic magma suite. Although petrographic resemblance alone cannot prove their contemporaneity there is sufficient similarity for further evidence on this point to be sought, and for interpretation of the available evidence to be examined. The most pertinent data available for reinterpretation are the isotopic analyses of the Officer and the Kulyong Volcanics.

The Officer Volcanics have been dated by both the Rb/Sr and K/Ar methods. Using the Rb/Sr method, Bofinger (*in* Jackson, 1966) found that the three samples taken between 2,417 and 2,419 feet defined an isochron at 446 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0.7136. Bofinger interprets this as a 'metamorphic' age for three reasons. Firstly, all samples show alteration, and loss of radiogenic Sr^{87} is considered by him to be a distinct possibility; but there is no proof that this has in fact occurred. Secondly, vesicles constitute about 50 per cent of the volume of the rock and Bofinger considers these to have been infilled some time after the consolidation of the basalt, with consequent interference in the apparent age obtained; but infilling of vesicles is almost certainly a deuteric process which would have taken place during the closing stages of crystallization of the basalt. Thirdly, Bofinger considers the high initial Sr^{87}/Sr^{86} value of 0.7136 to be unlikely for an olivine basalt, since these normally have a low and constant initial Sr^{87}/Sr^{86} value of about 0.702. On this evidence he rejects 446 m.y. as the age of crystallization. His preference for a minimum crystallization age of 1,000 m.y. was obtained by assuming an initial Sr^{87}/Sr^{86} value of 0.702 and using only the least altered sample. An age of 1,143 m.y. for a core from 2,760 feet depth would follow from the same assumption. However, the Officer Volcanics are tholeiitic rather than olivine basalts, and a comparison of the initial Sr^{87}/Sr^{86} values of other tholeiitic rocks indicates that there is little justification for assuming an initial Sr^{87}/Sr^{86} ratio of 0.702. Compston, McDougall and Heier (1968, p. 133) found tholeiitic sills from Antarctica to have initial Sr^{87}/Sr^{86} ratios closely comparable with the indicated 0.7136 of the Officer Volcanics isochron.

K/Ar dates for core from 2,760 feet gave ages of 445 m.y. (Isotopes, Inc.) and 447 m.y. (Geochron). This fits very well with the Rb/Sr and age of 446 m.y. for core between 2,417 and 2,419 feet. The two K/Ar dates for core from 2,422 feet, 357 m.y. (Geochron) and 331 m.y. (Isotopes Inc.) appear to be anomalous and are probably due to argon leakage. K/Ar isotopic ages of the Kulyong Volcanics gave results of 475 ± 20 m.y. and 485 ± 20 m.y. The simplest interpretation of all available petrographic and isotopic evidence is that the Officer Volcanics, Table Hill Volcanics, and Kulyong Volcanics are probably all of Ordovician age.

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