GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REPORT

FOR THE YEAR

1969

1970

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

ANNUAL REPORT

FOR THE YEAR

1969

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.

Alex. B. DAVIES, Government Printer, Perth

1970

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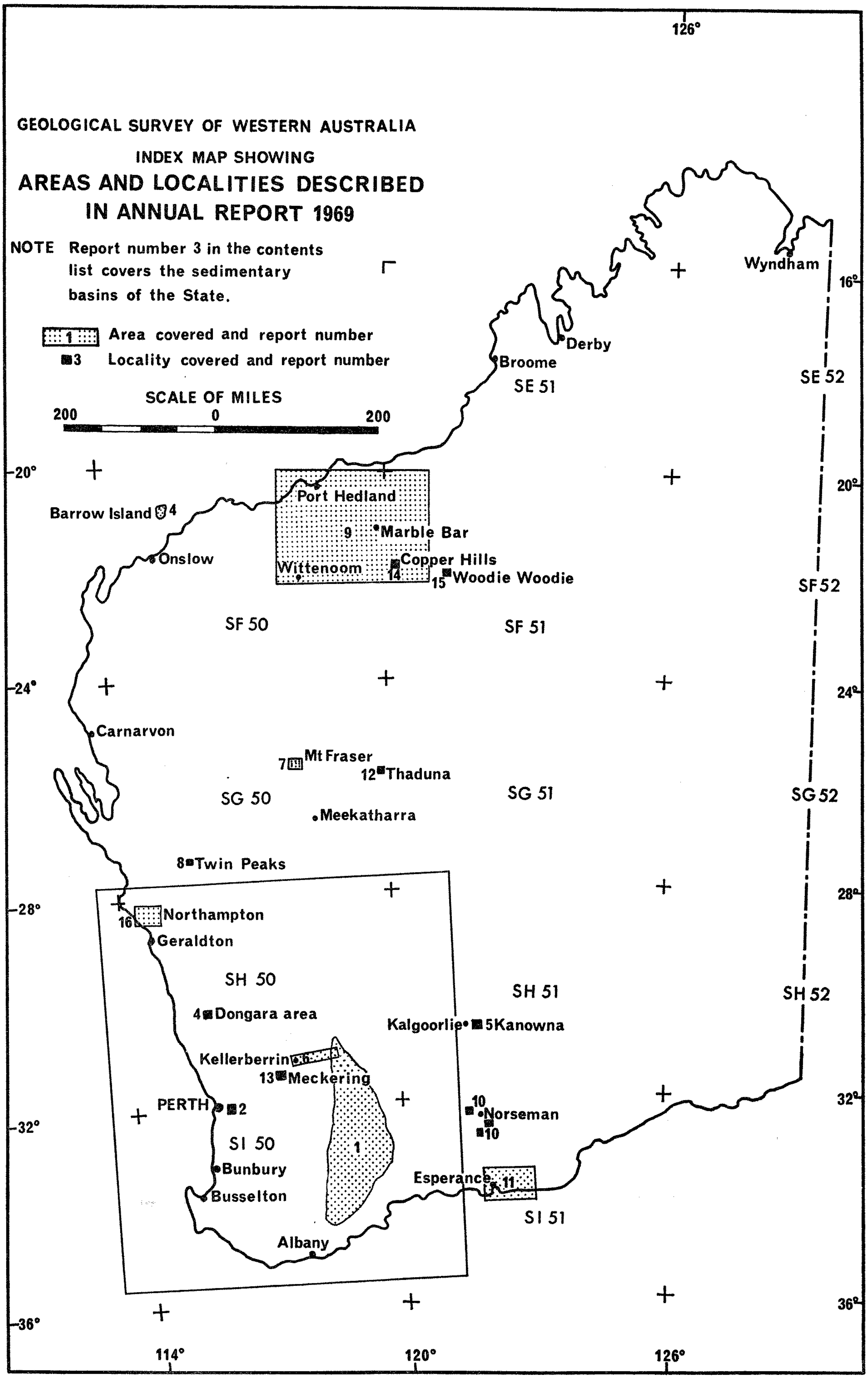
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
INDEX MAP SHOWING
AREAS AND LOCALITIES DESCRIBED
IN ANNUAL REPORT 1969
NOTE Report number 3 in the contents list covers the sedimentary basins of the State.
1 Area covered and report number
3 Locality covered and report number
SCALE OF MILES
200
0
200
126°
16°
20°
24°
28°
32°
36°
114°
120°
126°
Wyndham
Derby
Broome
SE 51
SE 52
Port Hedland
Barrow Island 4
9 Marble Bar
Onslow
Wittenoom
Copper Hills
14
15 Woodie Woodie
SF 50
SF 51
SF 52
Carnarvon
7 Mt Fraser
12 Thaduna
SG 50
SG 51
SG 52
Meekatharra
8 Twin Peaks
16 Northampton
Geraldton
SH 50
SH 51
SH 52
4 Dongara area
Kalgoorlie 5 Kanowna
Kellerberrin 6
13 Meckering
PERTH 2
10
Norseman
10
SI 50
1
Bunbury
Busselton
Esperance 11
SI 51
Albany

Fig. 1.

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1969

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DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1969

The Under Secretary for Mines :

For the information of the Honourable Minister for Mines, I submit my report on activities of the Geological Survey of Western Australia for the year 1969, together with some of the reports on investigations made for departmental purposes.

INTRODUCTION

The exploration boom reached unexpected heights during 1969. It was expected that there would be a stabilization of activity after 1968, but the reverse has been the case. More overseas companies and a great number of smaller Australian companies have helped to boost the boom.

The two major developments have been the decisions to mine the iron deposits at Paraburdoo and the bauxite deposit on the Mitchell Plateau near Admiralty Gulf in the north Kimberley. Nickel mineralization at scales suggesting that detailed examination may disclose mineable orebodies was found at Pioneer, Widgiemooltha, Mount Monger, Carr Boyd Rocks and Mount Windarra, while mining development has commenced on the Scotia and Nepean nickel prospects.

The oil search during 1969 was somewhat disappointing, the only significant development being the further successul testing of the Dongara oil and gas field, which should warrant development to supply gas to Perth. Most exploration activity was offshore.

Due to the exploration activity in this State, the demand on the services provided by this Branch increased immensely. Companies using the library and seeking professional advice, references, and publications have caused staffing problems and delayed to a marked degree the normal progress date on the Branch's own programme.

It was possible to arrange only one lecture and field excursion this year. This was on the Cue 1 : 250,000 Sheet. Despite the remote locality, 110 people attended the lecture and over 90 continued on for the two-day excursion. It is hoped to arrange three such excursions in 1970 as it allows interested geologists and others to hear and to see the results of mapping without waiting for the publication which is normally very slow.

ACCOMMODATION

Because of delays in construction, the anticipated move to Mineral House did not eventuate in 1969 ; we trust the long awaited move will take place early in 1970 to improve working conditions for the staff.

A new equipment store and vehicle park was built in Russell Street, Morley. The Public Works Department is complimented on providing such a satisfactory building.

The core library at Dianella is again becoming crowded and further expansion of this storage facility will be required shortly.

STAFF

Due to the present mineral activity, there were eight resignations during the year, the majority to accept more lucrative positions in private enterprise. It has been found difficult to find replacements for these positions, particularly for those which need experience.

The most serious loss was that of Dr. W. N. MacLeod, Deputy Director, who had been with the Branch for some eight years and had made a major contribution to the development of the Survey' While the present demand for geologists continues, the Branch will probably lose more senior and junior staff unless there is some action to prevent the drift to private enterprise.

There have been many changes in the clerical and general staff. These have caused difficulties in general administration and provision of services within the Branch.

A doctorate of Philosophy from the University of London was gained by A. D. Allen for his research in hydrogeology.

The establishment of the Branch at the end of 1969 was 49 professional, seven clerical and 13 general officers.

PROFESSIONAL

Appointments

Name	Positions	Effective Date
Nowak, I., M.Sc.	Geophysicist, Grade 2	6/1/69
Dedman, R. E., B.Sc. (Hons.)	Geologist, Grade 2	10/1/69
Cope, R. N., B.Sc. (Hons.), Ph.D.	Senior Geologist	29/1/69
Ryan-MacMahon, M., B.Sc.	Geologist, Grade 2	19/3/69
Brown, W., B.Sc.	Geologist, Grade 2	12/5/69
Gower, C. F., M.Sc.	Geologist, Grade 2	17/9/69
Bunting, J. A., B.Sc. (Hons.)	Geologist, Grade 2	7/10/69

Resignations

Redman, M. E.	Geologist, Grade 2	31/1/69
Hancock, P. M.	Geologist, Grade 2	10/2/69
Morgan, K. H.	Geologist, Grade 1	9/5/69
Koehn, P. R.	Geologist, Grade 2	13/6/69
Dedman, R. E.	Geologist, Grade 2	18/8/69
Passmore, R. J.	Geologist, Grade 1	29/9/69
Cockbain, A. E.	Palaeontologist	10/10/69
MacLeod, W. N.	Deputy Director	31/10/69

Promotions

Trendall, A. F.	Deputy Director	26/11/69

CLERICAL AND GENERAL

Appointments

Burrage, V.	Library Assistant	20/1/69
Schreuders, M.	Technical Officer, Grade 3	5/5/69
Leeder, K.	Geological Assistant	26/5/69
Paganelli, F.	Laboratory Assistant	26/5/69
Mitchell, P.	Clerk	9/9/69
Bruce, R.	Library Assistant	29/9/69
Birch, S.	Typist	29/9/69
Petzold, V.	Laboratory Assistant	1/10/69

Transfers In

Knox, K.	Clerk	19/2/69
Abbott, J.	Clerk	30/7/69
Smith, P.	Clerk	16/12/69

Transfers Out

Peters, R. E.	Clerk	31/12/69

Resignations

Aleksandrow, B.	Laboratory Assistant	18/7/69
Knox, K.	Clerk	1/8/69
Burrage, V.	Library Assistant	5/9/69
Quigley, M. S.	Geological Assistant	19/12/69

OPERATIONS

HYDROLOGY AND ENGINEERING GEOLOGY DIVISION

E. P. D. O'Driscoll (Chief Hydrogeologist), K. Berliat, F. R. Gordon, T. T. Bestow (Senior Geologists), A. D. Allen, P. Whincup, C. C. Sanders, W. A. Davidson, B. R. Paterson, D. D. Boyer, A. S. Harley, J. G. Barnett, M. Ryan-MacMahon, J. A. Bunting.

Hydrology

Because of the severe drought, a Government-assisted scheme of exploratory drilling was instituted in a number of agricultural areas. Bore sites were selected and their drilling was supervised by teams of geologists from the Division, assisted by others on temporary loan from other Divisions. The work is proceeding.

Exploratory drilling in the Perth Basin west of Watheroo was continued, and the first stage has now been completed. Results have still to be assessed.

Drilling and test pumping of a number of bores in the Pinjarra district were done, in conjunction with a private company, to assess whether the available groundwater supplies would be sufficient for industrial needs. A report is in progress.

Near Wiluna sixteen relatively shallow bores were drilled in a partly calcreted drainage system, and eight were test pumped. The calcrete was more discontinuous than expected, and the results were disappointing from an irrigation viewpoint.

There is a rapidly expanding need for comparatively large supplies of potable water in the Pilbara district, especially near Port Hedland, and field investigations including bore census work, and seismic refraction and test drilling are in progress on the De Grey-Shaw-Strelley-Coongan river system. Nine bores have so far been drilled on selected sections across the Shaw and Strelley Rivers.

Investigation of the shallow sand aquifers in the Lake Gnangara area just north of Perth has continued, as the Metropolitan Water Board expect to augment the city water supply from this source. The Board has an interest also in the deep pressure-water aquifers, and has drilled near Mount Yokine, Hamersley, and Mount Bold Park.

In addition to the commitments in the drought relief areas, some eighty inspections were made for private landholders and another dozen or so for Government Departments and Instrumentalities. However the Survey has been forced to discontinue this service to private landholders until the drought relief programme is completed.

A field census of existing bores has continued mainly in the Upper Swan and Bunbury areas.

Engineering Geology

Due to the shortage of experienced staff it was necessary to employ a consultant to handle the on-site geology at the Ord River dam during construction, although a full-time assistant geologist was provided by this Branch. At the nearby Moochalabra Creek damsite, diamond drilling cores were also examined and the bore logs written up.

A major project was the detailed mapping of the Meckering earthquake area. Field work was completed in May, and a Bulletin on the geological aspects of this interesting event was commenced.

In the Kimberley region seven possible damsites along the Fitzroy and its main tributaries were reconnoitred by helicopter, three being recommended for feasibility studies. One site is in Sir John gorge and two are in Hann River gorges through the Phillips Range.

The Darling Range has a number of potential damsites of interest to the Department of Public Works and to the Metropolitan Water Board. Of these, the foundations at Glen Mervyn dam were mapped during construction, preliminary mapping of a proposed damsite and its surroundings on Helena River has been reported on, and auger and diamond drilling on the Upper Helena and also in the Darkin River has been supervised as part of the feasibility studies. There are also two damsites on the North Dandalup and the South Dandalup Rivers, and a review of site conditions has been issued for the latter, but further field work is still needed at the North Dandalup site.

SEDIMENTARY (OIL) DIVISION

P. E. Playford (Supervising Geologist), A. H. Pippet (Production Geologist), R. N. Cope (Senior Geologist), G. H. Low, D. C. Lowry.

The results of company oil exploration and production activities were appraised and collated. Exploration continued at a similar rate to that of 1968. Special studies were made of the economic potential of the Dongara and Yardarino fields.

Surface mapping of the Perth Basin was completed during the year, and map compilation is proceeding.

Detailed study of material collected for the Bugle Gap project is in progress and a summary account of stromatolitic limestones from that area was published by P. E. Playford and A. E. Cockbain.

The draft manuscript for a bulletin on " Geology of the Eucla Basin in Western Australia " was completed. The explanatory notes for Eucla Basin 1 : 250,000 Sheets were prepared.

The draft manuscript for most of the Phanerozoic stratigraphy for the forthcoming publication on the Geology of Western Australia was prepared.

REGIONAL GEOLOGY DIVISION

R. C. Horwitz (Supervising Geologist), J. L. Daniels (Senior Geologist), I. R. Williams, J. J. G. Doepel and C. F. Gower.

Eastern Goldfields area

Geological mapping was completed on the Norseman 1 : 250,000 Sheet and compilation is in progress. Field work has been commenced on the Edjudina 1 : 250,000 Sheet.

Compilation and drawing of Kurnalpi, Menzies, Zanthus, Balladonia, Malcolm, Esperance, Mondrain Island and Cape Arid Sheets is continuing.

Blackstone-Warburton area

Compilation of Scott, Cooper, Bentley and Talbot 1 : 250,000 Sheets is complete and drawing of Talbot, Cooper and Bentley finalized. Drawing of Scott is nearly finished.

A Bulletin on the geology of the Blackstone-Warburton area is in progress.

North-West Division

Compilation of the Peak Hill 1 : 250,000 Sheet was completed and drawing is in progress. Field work was suspended in the Robinson Range 1:250,000 Sheet area.

A photogeological interpretation and reconnaissance traverses were made in the Glenburg and Mount Phillips 1 : 250,000 Sheets in collaboration with Mineral Resources Division.

General

Compilation of a new State Geological Map is in progress.

Field investigations in connection with the Meckering Earthquake have been compiled.

Compilation of the Geraldton 1 : 250,000 Sheet is complete.

The progress of geological mapping at 1 : 250,000 scale to the end of 1969 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.

North-West Division

The mapping of the tin deposits in the Pilbara Goldfield was completed, and the results are to be incorporated in a Mineral Resources Bulletin on the State's tin deposits.

Mapping of the mineral resources, regional geology, and hydrogeology of the Yalgoo 1 : 250,000 Sheet was commenced. Compilation of the Cue Sheet was almost completed, and compilation of the Murgoo Sheet was commenced.

A detailed geological and geochemical survey was made of a cuproferous area at Twin Peaks, 100 miles north of Mullewa.

An investigation was made of a suspected carbonatite occurrence near Mount Fraser in the Robinson Range, and a mapping and sampling programme of iron deposits in the range was also carried out.

A reconnaissance investigation of the Glenburg and Mount Phillips 1 : 250,000 Sheets was made, in collaboration with the Regional Mapping Division, and a traverse was made into the Rudall Sheet area to collect specimens for age determination.

Miscellaneous inspections for aggregate, sand, limestone, lead, and water were also made.

South-West Division

Miscellaneous inspections were carried out on non-metallic deposits.

Eastern Goldfields

A survey was made of the tin-bearing pegmatites in the Norseman area.

COMMON SERVICES DIVISION

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

During 1969 this section continued to provide petrological services to all Divisions of the Geological Survey, both in written reports, of which 28 were produced during the year, and by personal discussion. A total of 996 thin-sections and 45 other types of preparation were made by the laboratory staff.

Mr. J. D. Lewis visited field parties in the eastern goldfields in September, but field visits by petrological staff were fewer than normal, partly due to Dr. Trendall's absence overseas between March and August.

Geochronological liaison with the Physics Department of Western Australian Institute of Technology, which was established in 1968, continued successfully during 1969, and the first results of this re-establishment of such work in Perth appears later in this Annual Report.

As in previous years, chemical and mineralogical work carried out at the Government Chemical Laboratories has materially assisted many of the projects dealt with.

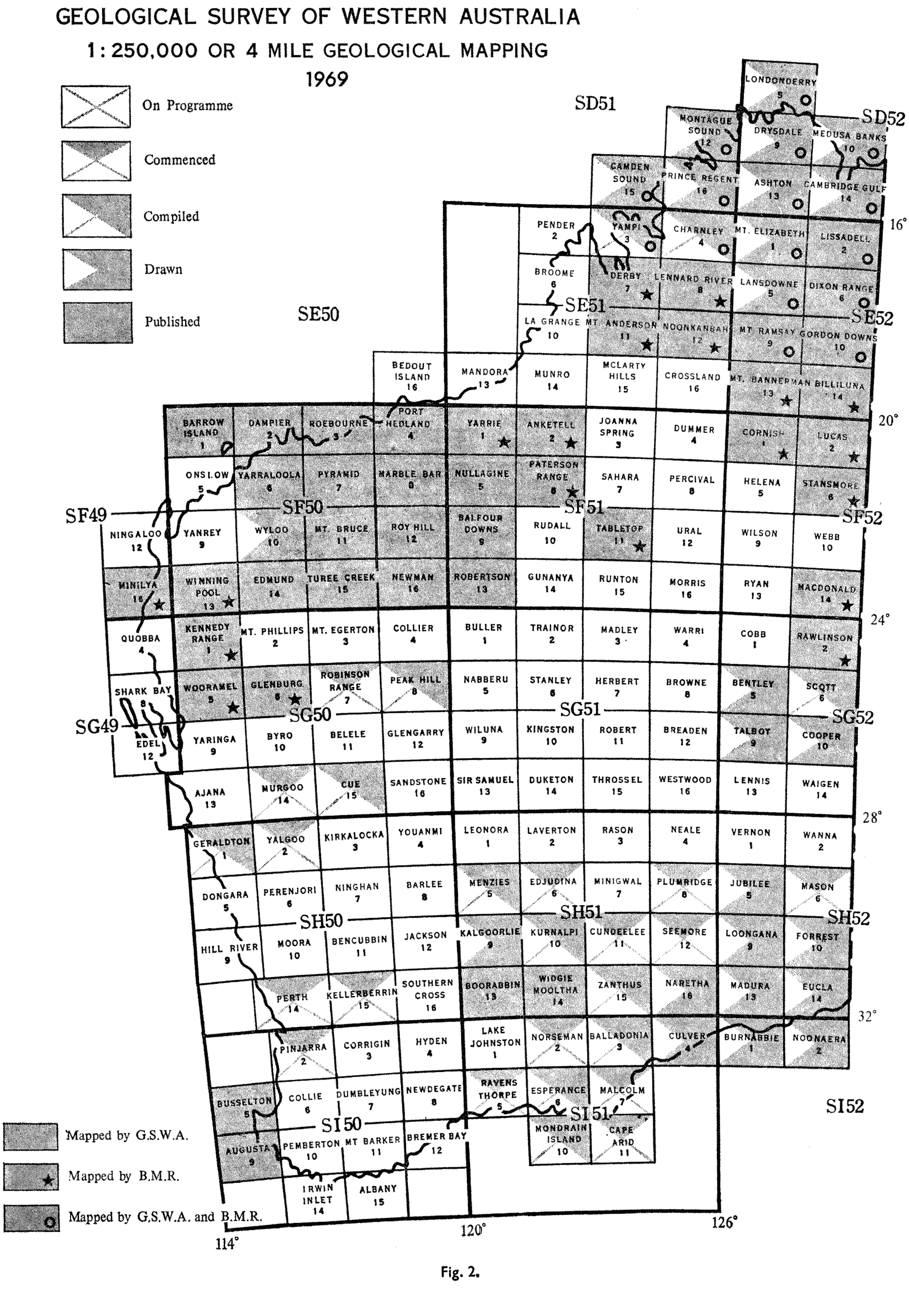
Palaeontology (A. E. Cockbain, B. S. Ingram an J. Backhouse).

Forty-six file reports were prepared during 1969 most of which were palynological investigations for the Hydrology and Engineering Geology Division on bore samples from the Perth Basin.

Division requesting report	Field of Palaeontology		
	Palynology	Micropalaeontology	Macropalaeontology
Hydrology/Engineering	34	....	1
Sedimentary (Oil)	3	....	1
Regional Geology/Mineral Resources	2	1	2
Miscellaneous	1	....	....

Prior to resigning, Dr. Cockbain continued his study of the systematics of Cheilostomatous Bryozoa from the Eucla, Eundynie and Plantagenet Groups and the detailed biostratigraphical and palaeoecological examination of the Devonian reef complexes.

A cored drill hole near Gingin was put down to obtain material for the palaeontological study of the Upper Cretaceous of the Perth Basin.



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
1:250,000 OR 4 MILE GEOLOGICAL MAPPING
1969
On Programme
Commenced
Compiled
Drawn
Published
Mapped by G.S.W.A.
Mapped by B.M.R.
Mapped by G.S.W.A. and B.M.R.
SD51
SD52
SE50
SE51
SE52
SF49
SF50
SF51
SF52
SG49
SG50
SG51
SG52
SH50
SH51
SH52
SI50
SI51
SI52
16°
20°
24°
28°
32°
114°
120°
126°
LONDONDERRY 5
MONTAGUE SOUND 12
DRYSDALE 9
MEDUSA BANKS 10
CAMDEN SOUND 15
PRINCE REGENT 16
ASHTON 13
CAMBRIDGE GULF 14
PENDER 2
YAMPI 3
CHARNLEY 4
MT. ELIZABETH 1
LISSADELL 2
BROOME 6
DERBY 7
LENNARD RIVER 8
LANSDOWNE 5
DIXON RANGE 6
LA GRANGE 10
MT ANDERSON 11
NOONKANBAH 12
MT RAMSAY 9
GORDON DOWNS 10
BEDOUT ISLAND 16
MANDORA 13
MUNRO 14
MCLARTY HILLS 15
CROSSLAND 16
MT. BANNERMAN 13
BILLILUNA 14
BARROW ISLAND 1
DAMPIER 2
ROEBOURNE 3
PORT HEDLAND 4
YARRIE 1
ANKETELL 2
JOANNA SPRING 3
DUMMER 4
CORNISH 1
LUCAS 2
ONSLOW 5
YARRALOOLA 6
PYRAMID 7
MARBLE BAR 8
NULLAGINE 5
PATERSON RANGE 6
SAHARA 7
PERCIVAL 8
HELENA 5
STANSMORE 6
NINGALOO 12
YANREY 9
WYLOO 10
MT. BRUCE 11
ROY HILL 12
BALFOUR DOWNS 9
RUDALL 10
TABLETOP 11
URAL 12
WILSON 9
WEBB 10
MINILYA 16
WINNING POOL 13
EDMUND 14
TUREE CREEK 15
NEWMAN 16
ROBERTSON 13
GUNANYA 14
RUNTON 15
MORRIS 16
RYAN 13
MACDONALD 14
QUOBBA 4
KENNEDY RANGE 1
MT. PHILLIPS 2
MT. EGERTON 3
COLLIER 4
BULLER 1
TRAINOR 2
MADLEY 3
WARRI 4
COBB 1
RAWLINSON 2
SHARK BAY 8
WOORAMEL 5
GLENBURG 6
ROBINSON RANGE 7
PEAK HILL 8
NABBERU 5
STANLEY 6
HERBERT 7
BROWNE 8
BENTLEY 5
SCOTT 6
EDEL 12
YARINGA 9
BYRO 10
BELELE 11
GLENGARRY 12
WILUNA 9
KINGSTON 10
ROBERT 11
BREADEN 12
TALBOT 9
COOPER 10
AJANA 13
MURGOO 14
CUE 15
SANDSTONE 16
SIR SAMUEL 13
DUKETON 14
THROSSEL 15
WESTWOOD 16
LENNIS 13
WAIGEN 14
GERALDTON 1
YALGOO 2
KIRKALOCKA 3
YOUANMI 4
LEONORA 1
LAVERTON 2
RASON 3
NEALE 4
VERNON 1
WANNA 2
DONGARA 5
PERENJORI 6
NINGHAN 7
BARLEE 8
MENZIES 5
EDJUDINA 6
MINIGWAL 7
PLUMRIDGE 8
JUBILEE 5
MASON 6
HILL RIVER 9
MOORA 10
BENCUBBIN 11
JACKSON 12
KALGOORLIE 9
KURNALPI 10
CUNDEELEE 11
SEEMORE 12
LOONGANA 9
FORREST 10
PERTH 14
KELLERBERRIN 15
SOUTHERN CROSS 16
BOORABBIN 13
WIDGIE MOOLTHA 14
ZANTHUS 15
NARETHA 16
MADURA 13
EUCLA 14
PINJARRA 2
CORRIGIN 3
HYDEN 4
LAKE JOHNSTON 1
NORSEMAN 2
BALLADONIA 3
CULVER 4
BURNABBIE 1
NOONAERA 2
BUSSELTON 5
COLLIE 6
DUMBLEYUNG 7
NEWDEGATE 8
RAVENSTHORPE 5
ESPERANCE 6
MALCOLM 7
AUGUSTA 9
PEMBERTON 10
MT BARKER 11
BREMER BAY 12
MONDRAIN ISLAND 10
CAPE ARID 11
IRWIN INLET 14
ALBANY 15

Fig. 2.

A visit to the Exmouth area was made to collect microfossil and megafossil samples from the Upper Cretaceous—Lower Tertiary strata.

A systematic study of the benthonic foraminifera of the Plantagenet Group near Esperance has been undertaken.

The Survey's fossil collection has been reorganized in preparation for the move to Mineral House.

Geophysics (D. L. Rowston and I. Nowak).

Well-logging activity continued to increase during 1969 when 103 individual bores (80 in 1968) were logged in 107 (99) operations. However the reduction in the number of deep exploratory water bores in the Perth Basin resulted in a decrease in the total terminal depths to 39,050 (52,600) feet. Intermediate logging operations were fewer and, including all runs, the total footage logged amounted to only 67,150 feet.

The decrease in water salinity determinations to 400 (700) samples was more than offset by the time spent in laboratory maintenance and calibration of field salinity bridges and other hydrological equipment.

The acquisition of a portable refraction seismic unit enabled a major investigation for the Port Hedland town water supply to be made on the Shaw, Strelley and De Grey rivers system. The survey involved 29 line miles of refraction shooting and 16 miles each of gravity and magnetic work. Test drilling substantiated the interpretation of geophysical data and further work is programmed for 1970.

A gravity survey over a manganese deposit at M.C. 431 near Woodie Woodie in the Pilbara demonstrated the efficacy of the method as a prospecting tool and the importance of terrain corrections in areas of rough topography.

Geochemistry (X. K. Williams).

A mobile field laboratory caravan equipped for routine trace element analyses by atomic absorption spectroscopy was completed and ready for operation in May.

A detailed geochemical survey was made of the Twin Peaks copper prospect, 100 miles north of Mullewa, the results of which are recorded in this Report.

A reconnaissance geochemical survey was made of the Northampton lead deposits, the results of which are being assessed.

Technical Information (R. R. Connolly, W. Brown and S. M. Fawcett).

Although no complaints have been received, the service provided by this section has probably been less satisfactory than usual because of the frequency and urgency of requests from exploration companies and the public generally, acting under the stimulus of the present intense mineral exploration activity.

The situation has been aggravated by the lack of working and storage space, and the exhaustion of stocks of available publications, which necessitated reprinting or revival of preliminary issue forms.

In anticipation of the move to new integrated accommodation, the Geological Survey library assumed control of accessioning, circulation and storage of the Mines Department Head Office library at the beginning of the year. Library loans to staff members totalled 2,392 and loans to other than staff 598. The number of external users of the library almost trebled.

Requisitions to the Mines Surveys and Mapping Branch for drafting services and photocopying totalled 1,094, but of necessity this year, a large part of the photocopying requirements from out of print publications was re-directed to the State Library Board and private organizations.

Twenty-seven Records and two Information Pamphlets were prepared, duplicated and issued during the year, and the time spent in preparing manuscripts for printing can be gauged from ' Publications and Records ' listed later.

Again the requirements of planning for Mineral House demanded attention ; in particular, the preparation of a display for the proposed new rock and mineral gallery necessitated the employment of a technical assistant who, with the initial guidance of Mr. G. Shaw, Curator of Display at the W.A. Museum, had almost completed construction of the exhibits by the end of the year.

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 sheets 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 the Survey's studies.
3. Aeromagnetic and radiometric survey of the Cue, Kirkalocka, Belele and portions of Murgoo and Yalgoo 1 : 250,000 Sheets at 1 mile spacings.
4. Regional helicopter gravity survey of a western portion of the southern half of the State.

PROGRAMME FOR 1970

HYDROLOGY AND ENGINEERING GEOLOGY DIVISION

Hydrology

1. Continuation of the hydrological survey of the Perth Basin including deep drilling.
2. Hydrogeological investigation and/or exploratory drilling for groundwater in the following areas :
    - (a) Watheroo—Agaton project (completion of write-up)
    - (b) Lake Gnangara (continuation)
    - (c) Mandurah—Pinjarra project (final write-up)
    - (d) Wiluna district (report to be completed and further investigations)
    - (e) Esperance for industrial supplies
    - (f) Port Hedland district
    - (g) Allanooka (assessment of supplies)
    - (h) Bunbury (assessment of supplies)
    - (i) Town supplies for Weaber Plains, Still Bay and Green Head
    - (j) Others may be added.

3. Kimberley—hydrological assistance to pastoralists :
   (a) Bore site selection as required
   (b) Completion of compilation of hydrological mapping in conjunction with the Bureau of Mineral Resources.
4. Continuation of bore census work in selected areas.
5. Drought relief—continuation of inspections and drill supervision in declared areas while drought persists.
6. Miscellaneous investigations as requested by Government.

Engineering

1. Ord River Dam—geological assistance during construction.
2. Moochalabra Creek dam site—mapping foundation as exposed during construction.
3. Helena River (lower) dam site—mapping foundation as exposed during construction.
4. Upper Helena Valley and Darkin dam sites—completion of mapping and geophysical investigations.
5. South Dandalup dam site—additional geological mapping and supervision of drilling.
6. North Dandalup dam site—complete field work and compile report.
7. Meckering earthquake—complete write-up of bulletin on investigations.
8. Other engineering geological investigations as may be requested.

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. Compilation of mapping completed in the Perth Basin and commencement of the preparation of the bulletin.
4. Preparations for a geological survey of the Officer Basin in conjunction with the Bureau of Mineral Resources.
5. Completion of study of the stromatolites from the Bugle Gap areas.

REGIONAL GEOLOGY DIVISION

1. Continuation of the mapping of the Edjudina 1 : 250,000 Sheet in the Eastern Goldfields.
2. Compilation of a new State Geological map 1 : 2,500,000.
3. Complete compilation of Norseman, Balladonia, Geraldton and Esperance 1 : 250,000 maps.

MINERAL RESOURCES DIVISION

1. Continuation of the mineral survey of the Yalgoo and Murchison Goldfields.
2. Compilation of a mineral resources bulletin on the tin deposits of Western Australia.
3. Detailed geological, geochemical and petrological survey of the carbonatite occurrence near Mount Fraser, Peak Hill Goldfield.
4. A survey of the mineral sands resources of Western Australia.
5. Miscellaneous investigations as required.

PUBLICATION AND RECORDS

Issued during 1969 :

Annual Report 1968.

Publications catalogue 1969 (revised and reprinted).

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

Bulletin 120 : Geology of the Kimberley Region, Western Australia : The East Kimberley.

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 Robertson 1 : 250,000 Sheet (SF/51–13 International Grid) with explanatory notes.

Geological map of Lissadell 1 : 250,000 Sheet (SE/52–2 International Grid) with explanatory notes.

Geological map of Dixon Range 1 : 250,000 Sheet (SE/52–6 International Grid) with explanatory notes.

Geological map of Gordon Downs 1 : 250,000 Sheet (SE/52–10 International Grid) with explanatory notes.

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

In press

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

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

Geological map of Wyloo 1 : 250,000 Sheet (SF/50–10 International Grid) with explanatory notes.

Geological map of Culver 1 : 250,000 Sheet (SI/51–4 International Grid) with explanatory notes.

Geological map of Naretha 1 : 250,000 Sheet (SH/51–16 International Grid) with explanatory notes.

Geological map of Loogana 1 : 250,000 Sheet (SH/52–9 International Grid) with explanatory notes.

In preparation

Bulletin 121, Devonian corals from the Canning Basin, Western Australia.

Bulletin 122, Geology of the Eucla Basin in Western Australia.

Bulletin 123, Geology of the Blackstone Region, Western Australia.

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

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J. H. LORD,
Director.

1st February, 1970

PRELIMINARY REPORT ON AN EMERGENCY PROGRAMME OF UNDERGROUND WATER INVESTIGATION FOR DROUGHT RELIEF

by J. H. Lord

INTRODUCTION

The rainfall in the southwest portion of Western Australia during 1969 was below the annual average, and was proportionately least in the 12 to 20 inch per year belt. This belt covers the eastern portion of the wheat belt, extending to the south coast (see Plate 1). The rainfall during 1969 generally occurred as relatively light falls with little or no runoff with the result that many dams received no replenishment during the year. New dams, particularly those in recently developed areas, received little or no water. Some farmers in this belt and beyond the comprehensive water scheme were carting water in August and Shires were declaring drought areas.

The Western Australian Government established a Drought Relief Advisory Committee in August, 1969 to control and to advise on all aspects of the drought situation and authorised the existing Farm Water Supply Advisory Committee (F.W.S.A.C.) to investigate and to control water supplies for the drought areas, to arrange for water cartage, where necessary, and to search for underground water. The F.W.S.A.C. has Mr. J. P. Gabbedy, Commissioner of the Rural and Industries Bank as Chairman, and one representative each from the Department of Agriculture, Public Works Department and the Geological Survey.

The F.W.S.A.C. proposed a scheme to assist the search for underground water in severe drought areas even though geologically the chances of success were very slight.

In drought areas of greatest need it was decided that any farmer who had stock, feed, and a water problem, would be accepted into the scheme. The property was inspected by a geologist, who selected the most promising sites for drilling, even if the chances of success were thought to be remote. Each farmer was allowed up to a total of 1,000 feet to test selected sites. The cost to the farmer was 25 cents per foot of drilling if no water was found or 50 cents per foot if a suitable supply of stock water was located in any bore.

As the search was for stock (sheep) water, a success bore was considered as one producing at least 1,000 gallons per day with a salinity of less than 11,000 p.p.m.

INSPECTIONS

In an area selected for the scheme, a liaison officer from the Rural and Industries Bank visited all applicants to ensure that they were eligible, and arranged for the landholder to sign an agreement. In this he agreed to pay according to the scale of charges and to allow any success bores beyond his own requirements to be used as a community supply, if required.

The properties eligible were then inspected by a geologist, and drill sites were pegged. A report form was completed for each inspection, and drill sites were plotted on air-photographs and lithos. The holes were numbered in order of priority of drilling in relation to the chances of locating water. This allowed the farmer or the geologist to stop the drilling when the results were not encouraging, if either wished. In many instances, the footage recommended was not the maximum allowed under the scheme.

Each selected area was worked as a whole, and the drill or drills followed the inspecting geologists fairly closely. With each drill was a geological assistant who was briefed daily by the geologist on the proposed sites for each property. The assistant was responsible for ensuring that the driller carried out the geologist's instructions for each site and for recording the results.

DRILLING

The drilling was done by Gardner-Denver Air Trac (Model ATD-3100) and Mayhew 1000 drills using compressed air.

The cuttings blown from the hole were sampled every ten feet or at the change of strata, and were logged and recorded on a standard form. The depth of drilling was controlled by the geologist's recommendation, assisted by observations made during the progress of the hole.

If water was encountered, the hole was ' blown ' and the water collected and measured. An effort was made to blow each hole for one hour if possible.

Contractors were used for all drilling, and final costs will be about $1.25 per foot. These were only test bores of 2½ to 4½ inches diameter and if successful the hole had to be redrilled for production purposes.

While it is easy to point out the imperfections of the methods used, it should be remembered that this was an emergency project. If any more normal methods, such as casing, pump testing, and so forth, were used, it would have greatly decreased the drilling rate and greatly increased the cost of drilling.

GENERAL GEOLOGY

The areas investigated (see Plate 1) are all on the Precambrian Yilgarn Block which consists chiefly of granite and gneiss, with occasional bands of metasediments. Dolerite dykes, with a general east-west strike, occur throughout the area. Suitable water is occasionally present in the weathered granite profile or in joints in the bedrock.

There are scattered small areas of sand, and also sand dunes near the numerous salt lakes. The only unaltered sediments with any extent are the beds of the Plantagenet Group of Eocene age which occur towards the south coast in the Ongerup area only. Although this group is prospective for water in favourable localities, there is a salinity problem, particularly in the northern portion of the occurrence.

The topography is subdued, and the principal features are granite rocks which crop out particularly on the eastern side of the belt, forming good catchments in some instances. There are very few surface drainage features as most of the drainage is to shallow salt pans and lakes, many of which link up in periods of floods.

RESULTS AND CONCLUSIONS

The results of the investigation and drilling to the end of 1969 are summarised in Table 1.

The results of all inspections carried out and holes drilled were recorded on forms designed for the purpose. These, together with base sheets showing the position of each bore, are being incorporated in the hydrological records of the Geological Survey. This will provide valuable information should any further investigations be required in these areas. It was found in the course of these current investigations that there have been similar projects in some areas, on a smaller scale during earlier droughts, for which the results have not been kept.

The first geological party commenced operation during the last week of August with one drill. The project gradually expanded until there were five parties with seven drills operating on a seven-day-week basis. The target of 100,000 feet of drilling by the end of the year was achieved.

When examining the results it should be remembered that such areas as Lake Grace and Nyabing—Pingrup were considered to be geologically unfavourable for the occurrence of suitable supplies of underground water.

In the case of a severe drought it is necessary to check any remote possibility of obtaining water supplies. It is considered that using this quick and cheap method of investigating doubtful areas was warranted in the circumstances, even though the results may, in retrospect, appear poor in many areas Valuable information has been recorded which will be of great assistance in the future planning of water supplies in these areas.

TABLE 1. SUMMARY OF INSPECTIONS AND DRILLING FOR DROUGHT RELIEF PURPOSES TO 31st DECEMBER, 1969

	Westonia	Mount Walker	Ongerup	Nyabing-Pingrup	Lake Grace	Burracoppin South	Holt Rock	Totals
No. of properties inspected	24	32	121	48	56	19	6	306
No. of reserves inspected	7	2	5	70	78	1	53	216
Total	31	34	126	118	134	20	59	522
No. of properties recommended for drilling	22	25	115	48	48	19	6	283
No. of reserves recommended for drilling	6	2	5	44	43	1	20	121
Total	28	27	120	92	91	20	26	404
No. of properties drilled successfully	9	8	35	7	0	3	0	62
No. of reserves drilled successfully	2	1	1	6	4	1	10	25
Total	11	9	36	13	4	4	10	87
No. of properties drilled unsuccessully	13	17	76	37	4	5	0	152
No. of reserves drilled unsuccessfully	4	1	4	38	33	0	10	90
Total	17	18	80	75	37	5	10	242
Bores—								
Dry	159	85	160	172	87	52	21	736
Wet—insufficient supply	76	15	38	21	9	14	4	177
Wet—saline supply	22	14	134	73	12	4	3	262
Wet—suitable supply	22	12	43	30	4	8	10	129
Abandoned	4	19	32	19	7	9	1	91
Total	283	145	407	315	119	87	39	1,395
Total Footage Drilled	17,553	14,396	37,272	20,482	10,238	8,022	2,905	110,868
Ratios—								
Properties drilled successfully 1 in	2·5	3·0	3·2	6·0	10·2	2·2	2·2	3·8
Successful bores 1 in	12·8	12·1	9·5	10·5	29·8	10·9	3·9	10·8
Feet drilled per successful bore	796	1,183	867	683	2,559	1,009	290	860

SEQUENCE OF DEVELOPMENT OF SOME STRUCTURES IN THE GRANITE OF THE LOWER HELENA VALLEY

by P. Whincup

ABSTRACT

The Archaean granite in the lower part of the Helena Valley has been intruded by north-trending dolerite dykes and later cut by shear zones striking 060° and 120° in which the granite has been reconstituted to a sericite schist.

The granite is well jointed and several periods of joint formation can be recognized. The first joints were probably consequent to the cooling of the granite magma but have since been masked by prominent joint sets imposed on the granite during shearing. These were succeeded by topographically controlled sheet joints.

INTRODUCTION

As part of an investigation into the siting of a small concrete weir about five miles downstream from Mundaring Weir, an area along the lower reaches of the Helena River first studied by Clarke and Williams in 1926 has been geologically remapped at a scale of 100 feet to an inch. In this investigation the geological succession previously established has been confirmed, but considerably more detail has been added concerning the geological structure of the area (Whincup, 1969).

GENERAL GEOLOGY

The major rock type varies from porphyritic biotite muscovite granite to a medium, even-grained biotite granite of similar Archaean age, both being intruded by metadolerite dykes. Where the granite is faulted, shear zones 100 feet or more wide have developed and the rock has been reconstituted to a sericite schist. Steeply dipping quartz veins and stringers have developed concordantly with the schist, their volume increasing with the intensity of shearing ; at the intersection of two prominent shear zones for example, a quartz reef 100 feet wide has formed. Shallow-dipping quartz and aplite veins in the granite are not seen in the shears, and possibly represent a residium of the granite magma.

STRUCTURE

Joints, dykes and shear zones, summarized on Plate 2, are the structural elements of the granite with which this paper is concerned.

Joints

At least four main periods of joint formation can be recognized, the earliest formed joints probably being consequential to the cooling of the granite magma. These have been masked by the later jointing and now appear as irregular poorly developed joints with no recognizable pattern. Open and persistent joints which are now the major control on outcrop shape and distribution were imposed on the granite during shearing. This is evident from an examination of the three joint rosettes shown on Plate 2, each rosette referring to an area of granite crossed by one of the major shears. Near Shear 2 for example, the main joint set is parallel to the direction of the schistosity. It is also significant that the subordinate joint set has an orientation (115°) coincident with that of the adjacent Shear 3. In many instances the joints are serocite-filled and they have a steep northerly dip, generally about 60 to 80 degrees, similar to that of the schistosity. The following table summarizes the relationship between shear direction and the main joint orientation of the adjacent granite.

	Strike of schistosity	Main joint sets in granite in order of intensity
Shear 1	065°	085° ; 055°
Shear 2	055°	065° ; 115°
Shear 3	120°	125° ; 030° ; 065°

Sheet joints are usually subparallel to the present-day topography and are the youngest joints to develop. They are of importance from an engineering standpoint because diamond drilling has shown that they still persist as open joints 30 feet below the river bed. Two series of sheet joints can be recognized, the first dipping towards the river at 10 to 20 degrees, the second at 50 to 60 degrees. It is thought that the gently dipping joints formed during a period of standstill in the valley development when the topography was mature. Renewed erosion at a later date resulted in a steeper topography and subsequently the formation of the steeper joint set. There is no dislocation of the sheet joints along the older, shear imposed joints.

Metadolerite dykes

On average the metadolerite dykes in the area strike a few degrees east of north but they are not rectilinear, ranging in strike from 030° to 330°. There are several poorly developed joints approximating this direction which are considered to belong to the first period of joint development.

The dykes are cut off at the shear zones and may close jointing parallel to the schistosity.

Shears

The shear zones are the most continuous and prominent of the structural features. The two trends already noted, namely 060° and 120° with dips of 60 to 80 degrees north, have also been observed upstream of this area. At Mundaring Weir the Helena River follows a narrow shear zone of sericite schist which strikes 115°, dips 60 degrees north and was traced by Maitland (1899) for 200 feet downstream and 500 feet upstream of the centre line of the weir. During construction of the weir it was necessary to excavate the schist about 90 feet below the cut in the massive granite. Campbell (1904) continued the geological mapping downstream of the weir ; on his map, one belt of mica schist is shown striking from 050° to 080°. It is possible therefore that these two shear trends may be of significance elsewhere in the Darling Range.

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PETROLEUM EXPLORATION IN WESTERN AUSTRALIA IN 1969

by P. E. Playford and R. N. Cope

INTRODUCTION

No new commercial discoveries of petroleum were made in Western Australia during 1969, although non-commercial discoveries were made of oil in Gage Roads No. 1 well (offshore Perth Basin) and gas in Flinders Shoal No. 1 (offshore Carnarvon Basin). The Dongara oil and gas field (first discovered in 1966) moved closer to commercial development as a result of drilling during 1969, and this field is discussed in another article by A. H. Pippet.

The amount of exploratory drilling during 1969 decreased slightly as compared to the previous year, as illustrated in the following table :

	1968	1969
New field wildcat wells	10	14
Extension test wells	1	3
Stratigraphic test wells	14	4
Total footage	164,637	149,521

Three of the wells completed in 1969 had been commenced in 1968, and one new field wildcat well was still drilling at the end of 1969.

Geophysical activity decreased slightly compared with 1968, amounting to 20·05 party months of land seismic (19·62 in 1968) and 12·13 party months of marine seismic (17·71 in 1968). No gravity surveys were conducted during 1969 (4·42 party months in 1968), but 10,675 line miles of aeromagnetic surveys were flown (nil in 1968). Field geological surveys declined from 30 geologist months in 1968 to 6·25 in 1969.

OIL TENEMENTS

The Petroleum Act 1967 was proclaimed on 5 September 1969. This act relates to petroleum exploration and production in the onshore areas of Western Australia. It provides that onshore petroleum exploration permits shall cover no more than 200 5-minute graticular blocks and that the initial tenure for each permit shall be five years. At the end of this period 25 per cent of the original permit area must be relinquished, and a similar amount is to be relinquished after each succeeding five years, until the permit covers only 16 blocks. For the purposes of determining work conditions the State has been divided into four Petroleum Exploration Zones known as Zones A, B, C, and D (Figure 3). Zone A covers the Perth and Carnarvon Basins, Zone B that part of the Canning Basin that is within 150 miles of the coast, Zone C the remainder of the Canning Basin and the Bonaparte Gulf Basin, and Zone D the rest of the State. The minimum financial work commitment in each of these zones over five years amounts to $7,000 per block in Zone A, $6,000 per block in Zone B, $3,000 per block in Zone C, and $1,000 per block in Zone D. Excess expenditure in any one year can be credited to the next succeeding year, and may be credited to following years if approved by the Hon. Minister for Mines. Grouping of two contiguous permits for work commitments will be allowed in Zones C and D, but not in others. Individual permits can cross the boundary between Zones B and C (in the Canning Basin), but may not cross other zonal boundaries. Tenements held under the Petroleum Act (1936), which is now repealed, will shortly be converted to the new system.

The positions of petroleum tenements held in Western Australia (both onshore and offshore) are shown on Plate 4. Details of these are as follows :

PETROLEUM TENEMENTS UNDER THE PETROLEUM (SUBMERGED LANDS) ACT 1967

Exploration Permits

Number	No. of graticular sections	Expiry date of current term	Registered holder
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	10/7/75	do. do. do.
WA-8-P	18	17/6/75	Coastal Petroleum N.L.
WA-9-P	56	17/6/75	do. do.
WA-10-P	36	15/6/75	do. do.
WA-12-P	5	11/9/75	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	20/3/75	Australian Aquitaine Petroleum Pty, Arco Limited
WA-16-P	354	16/4/75	do. do. do.
WA-17-P	378	22/4/75	do. do. do.
WA-18-P	322	16/4/75	do. do. do.
WA-19-P	142	20/3/75	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 Australian Oil Co. Inc.
WA-27-P	294	18/5/75	do. do. do.
WA-28-P	375	24/3/75	Woodside (Lakes Entrance) Oil Company No Liability, Shell Development (Australia) Proprietary Ltd, B.O.C. of Australia Ltd
WA-29-P	400	18/5/75	do. do. do.
WA-30-P	400	2/7/75	do. do. do.
WA-31-P	400	18/5/75	do. do. do.
WA-32-P	395	2/7/75	do. do. do.
WA-33-P	389	18/5/75	do. do. do.
WA-34-P	397	2/7/75	do. do. do.
WA-35-P	400	2/7/75	do. do. do.
WA-36-P	57	18/5/75	do. do. do.
WA-37-P	118	2/6/75	do. do. do.
WA-39-P	104	12/3/75	BP Petroleum Development Australia Pty Ltd, Abrolhos Oil N.L.
WA-40-P	102	12/3/75	BP Petroleum Development Australia Pty Ltd, Hawkstone Minerals Limited
WA-41-P	33	15/6/75	Coastal Petroleum N.L.

PETROLEUM TENEMENTS UNDER THE PETROLEUM ACT 1936

Permits to Explore

Number	Area (square miles)	Expiry date of current term	Registered holder
27H	12,900	Pending	West Australian Petroleum Pty Ltd
28H	15,100	do.	do. do. do.
106H	11,800	do.	Lennard Oil N.L.
127H	7,250	28/3/70	Alliance Oil Development Australia N.L.
151H	10,710	7/2/70	Beach General Exploration Pty Ltd, Australian Aquitaine Petroleum Pty Ltd
152H	8,720	7/2/70	do. do. do.
153H	9,770	7/2/70	do. do. do.
193H	10	5/2/70	BP Petroleum Development Australia Pty Ltd, Abrolhos Oil N.L.
205H	16,700	Pending	Australian Aquitaine Petroleum Pty Ltd
213H	10	20/6/70	Woodside (Lakes Entrance) Oil Co. N.L., B.O.C. Aust. Ltd, Shell Development (Aust.) Pty Ltd
217H	3,350	30/5/70	West Australian Petroleum Pty Ltd
221H	950	28/7/70	Australian Aquitaine Petroleum Pty Limited, Arco Ltd
226H	23,870	6/4/70	West Australian Petroleum Pty Ltd
227H	8,530	6/4/70	do. do. do.
228H	2,200	13/5/70	do. do. do.
251H	4,228	29/6/70	do. do. do.
253H	3,850	Pending	Lennard Oil N.L.
259H	12,930	1/2/70	West Australian Petroleum Pty Ltd
260H	5,860	19/4/70	do. do. do.
261H	3,000	19/4/70	do. do. do.
270H	83,070	3/9/71	do. do. do.

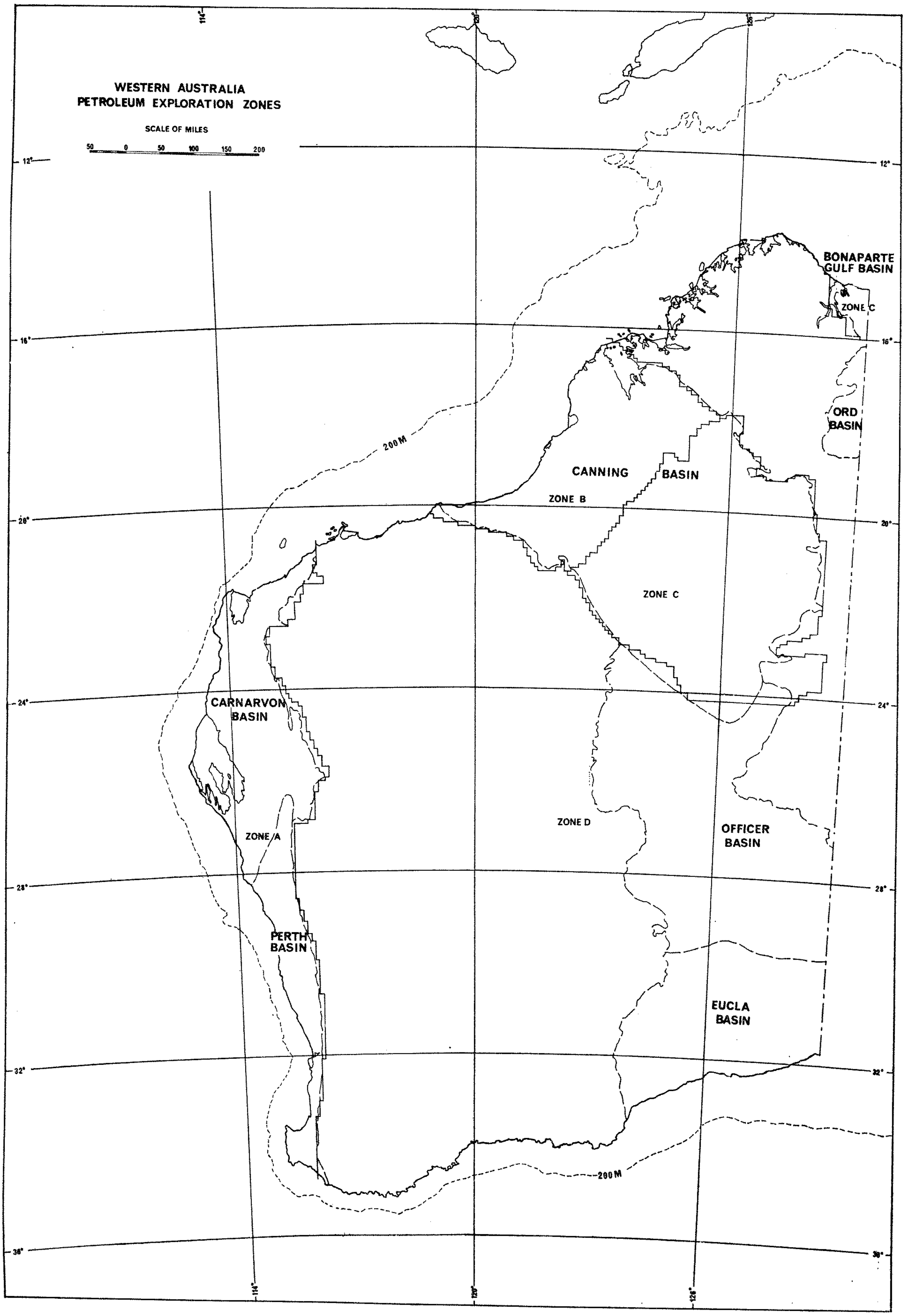
WESTERN AUSTRALIA
PETROLEUM EXPLORATION ZONES
SCALE OF MILES
50 0 50 100 150 200
BONAPARTE GULF BASIN
ZONE C
ORD BASIN
CANNING BASIN
ZONE B
ZONE C
200M
CARNARVON BASIN
ZONE A
ZONE D
OFFICER BASIN
PERTH BASIN
EUCLA BASIN
200M
12°
16°
24°
32°

Fig. 3.

Licenses to Prospect

Number	Area (square miles)	Expiry date of current term	Registered holder
154H	160·200	Pending	Beach General Exploration Pty Ltd, Australian Aquitaine Petroleum Pty Ltd
199H	198·926	8/8/70	do. do. do.
219H	....	3/9/71	Lennard Oil N.L.
221H	150·00	7/7/70	West Australian Petroleum Pty Ltd
222H	197·00	3/9/71	do. do. do.
223H	196·41	3/9/71	do. do. do.
224H	194·76	3/9/71	Lennard Oil N.L.
225H	195·00	3/9/71	West Australian Petroleum Pty Ltd

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 1969 are shown on Plates 3 and 6. Drilling was carried out during the year on the following permits :

EXPLORATION PERMIT WA-13-P

Exploration Permit WA-13-P (offshore) is held by West Australian Petroleum Pty. Ltd. in the offshore Perth Basin. The company completed one well, Gage Roads No. 1, in the concession during the year. This well had commenced drilling at the end of 1968. It was abandoned as a non-commercial oil well after recovering oil by swabbing and flowing from a reservoir sand in the basal part of the Lower Cretaceous South Perth Formation. The maximum production obtained by swabbing amounted to about 350 barrels per day. Traces of oil were also obtained from the Lower Cretaceous part of the Yarragadee Formation in this well. Although the well is non-commercial, this is the first oil discovery in the Cretaceous of the Perth Basin, and it is therefore of considerable importance to future exploration. Details of the well are as follows :

Gage Roads No. 1

Type : New field wildcat.

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

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

Commenced : 27th December, 1968.

Completed : 10th February, 1969.

Total depth : 12,009 feet.

Bottomed in : Upper Jurassic.

Status : Non-commercial oil well, plugged and abandoned. A test of the intervals 5,775–5,781 feet and 5,790–5,804 feet recovered 40 bbl. of oil (37° API) and 82 bbl. of water (by flowing and swabbing). Another test, over the interval 5,838–5,847 feet, recovered 58·5 bbl. of oil (41·2° API) and 25 bbl. of water (by flowing and swabbing). The maximum production rate by swabbing of this interval was about 350 bbl. per day.

EXPLORATION PERMIT WA-19-P

Exploration Permit WA-19-P is held by Alliance Oil Development Aust. N.L. and is farmed out to Arco Ltd. (operator), Canadian Superior Oil (Aust.) Pty. Ltd., Australian Superior Oil Co. Ltd., and Newmont Pty. Ltd. These companies drilled their first test well, Lacrosse No. 1, in the concession during 1969. It was abandoned as a dry hole, but obtained positive indications of oil in the Permian sequence. Details of this well are as follows :

Lacrosse No. 1

Type : New field wildcat.

Latitude and Longitude : 14° 17′ 51″S, 128° 34′ 58″E.

Elevation : W. D. 92 feet, K. B. 85 feet.

Commenced : 21st February, 1969.

Completed : 8th May, 1969.

Total depth : 10,020 feet.

Bottomed in : Lower Carboniferous.

Status : Dry hole, plugged and abandoned.

Traces of low-gravity oil were obtained in a drill stem test of the interval 5,634–5,770 feet in the Lower Permian sequence.

EXPLORATION PERMIT WA-23-P

Exploration Permit WA-23-P is held by West Australian Petroleum Pty. Ltd. and covers part of the offshore Carnarvon Basin. The company completed one test well, Flinders Shoal No. 1, on this concession during the year, and another, Flag No. 1, was still drilling at the end of the year. Flinders Shoal No. 1 was abandoned, but it produced a flow of gas (non-commercial) and minor oil from the Birdrong Formation over the interval 2,597–2,622 feet. Details of these wells are as follows :

Flag No. 1

Type : New field wildcat.

Latitude and Longitude : 20° 27′ 55″S, 115° 38′ 45″E.

Elevation : W. D. 120 feet, R. T. 76 feet.

Commenced : 2nd September, 1969.

Status : Drilling ahead at 10,871 feet on 31st December.

Flinders Shoal No. 1

Type : New field wildcat.

Latitude and Longitude : 21° 04′ 16″S, 115° 31′ 18″E.

Elevation : W. D. 49 feet, R. T. 84 feet.

Commenced : 10th April, 1969.

Completed : 9th July, 1969.

Total depth : 11,864 feet.

Bottomed in : ?Permian.

Status : Dry hole, plugged and abandoned.

A drill-stem test of the interval 2,597–2,622 feet produced gas at 2·38 mmcf/day with ½ bbl. of oil (23° API) on a 7-hour test through a 24/64-inch choke.

EXPLORATION PERMIT WA-24-P

Exploration Permit WA-24-P is held by West Australian Petroleum Pty. Ltd., and covers part of the offshore Carnarvon Basin. The company drilled one dry test well, Anchor No. 1, on this concession during 1969. Details are as follows :

Anchor No. 1

Type : New field wildcat.

Latitude and Longitude : 21° 32′ 51″S, 114° 42′ 37″E.

Elevation : W.D. —59 feet, R.T. 80 feet.

Commenced : 27th July, 1969.

Completed : 1st September, 1969.

Total depth : 10,002 feet.

Bottomed in : Lower Jurassic.

Status : Dry hole, plugged and abandoned.

EXPLORATION PERMIT WA-26-P

Exploration Permit WA-26-P is held by Canadian Superior Oil (Aust.) Pty. Ltd., Australian Superior Oil Company Ltd., Phillips Australian Oil Company, and Sunray D. X. Oil Company, and is farmed out to Genoa Oil N.L. (operator), Pexa Oil N.L., Hartog Oil N.L., and Flinders Petroleum N.L. During 1969 this group drilled one well, Pendock No. 1, on the concession. It was abandoned as a dry hole. Details are as follows :

Pendock No. 1

Type : New field wildcat.
Latitude and Longitude : 23° 17′ 02″S, 113° 20′ 10″E.
Elevation : W.D. —435 feet, R.T. 34 feet.
Commenced : 29th July, 1969.
Completed : 17th November, 1969.
Total depth : 8,205 feet.
Bottomed in : Silurian.
Status : Dry hole, 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 northernmost offshore Carnarvon Basin. The companies drilled two wells, Dampier No. 1 and Madeleine No. 1 in the permit during the year. Both encountered numerous oil and gas showings in the Lower Cretaceous—Upper Jurassic sequence, but the sandstones are tight, and the holes were abandoned as dry. Details are as follows :

Dampier No. 1

Type : New field wildcat.
Latitude and Longitude : 19° 52′ 21″S, 116° 00′ 49″E.
Elevation : W.D. —250 feet, R.T. 30 feet.
Commenced : 22nd November, 1968.
Completed : 5th May, 1969.
Total depth : 13,588 feet.
Bottomed in : Upper Jurassic.
Status : Dry hole, plugged and abandoned.
Shows of oil and gas were recorded below 9,440 feet in the basal Cretaceous and Upper Jurassic sediments.

Madeleine No. 1

Type : New field wildcat.
Latitude and Longitude : 19° 38′ 56″S, 116° 21′ 31″E.
Elevation : W.D. —226 feet, R.T. 30 feet.
Commenced : 16th May, 1969.
Completed : 9th December, 1969.
Total depth : 14,526 feet.
Bottomed in : Upper Jurassic.
Status : Dry hole, plugged and abandoned.
Shows of oil and gas were recorded, mainly below 12,880 feet, in the Upper Jurassic sequence.

PREMIT TO EXPLORE 27H

Permit to Explore 27H is held by West Australian Petroleum Pty. Ltd. and covers part of the onshore Perth Basin. The company drilled three extension test wells to evaluate the Mondarra field during the year. Mondarra No. 2 was completed as a potential gas well, and Nos. 3 and 4 were abandoned as dry holes. Another well, Strawberry Hill No. 1, was put down on a different structure in the same area, but it was also dry. Details are as follows :

Mondarra No. 2

Type : Extension test well.
Latitude and Longitude : 29° 21′ 07″S, 115° 06′ 05″E.
Elevation : G.L. 87 feet, R.T. 101 feet.
Commenced : 20th December, 1968.
Completed : 18th February, 1969.
Total depth : 9,363 feet.
Bottomed in : Permian.
Status : Shut-in gas well. Production test of interval 8,975–8,991 feet in the basal Triassic sandstone yielded 5 mmcf/day through a 24/64-inch choke.

Mondarra No. 3

Type : Extension test well.
Latitude and Longitude : 29° 17′ 32″S, 115° 06′ 44″E.
Elevation : G.L. 325 feet, R.T. 337 feet.
Commenced : 5th April, 1969.
Completed : 10th May, 1969.
Total depth : 9,800 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.
Minor oil recovery on drill-stem test of interval 9,271–9,333 feet.

Mondarra No. 4

Type : Extension test well.
Latitude and Longitude : 29° 19′ 09″S, 115° 05′ 58″E.
Elevation : G.L. 148 feet, R.T. 162 feet.
Commenced : 19th July, 1969.
Completed : 22nd August, 1969.
Total depth : 9,499 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.
Minor oil and gas shows.

Strawberry Hill No. 1

Type : New field wildcat.
Latitude and Longitude : 29° 15′ 17″S, 115° 07′ 13″E.
Elevation : G.L. 192 feet, R.T. 201 feet.
Commenced : 27th May, 1969.
Completed : 7th July, 1969.
Total depth : 9,416 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.
Minor oil shows.

PERMIT TO EXPLORE 106H

Permit to Explore 106H is held by Lennard Oil N.L. in the northern Canning Basin. During 1969 the company drilled one test well, Napier No. 1, on this permit area. Another well, Napier No. 2, was put down on the adjoining Permit 253H. Particulars of Napier No. 1 are as follows :

Napier No. 1

Type : New field wildcat.
Latitude and Longitude : 17° 12′ 20″S, 124° 31′ 36″E.
Elevation : G.L. 231 feet, K.B. 244 feet.
Commenced : 4th July, 1969.
Completed : 10th August, 1969.
Total depth : 5,910 feet.
Bottomed in : Precambrian.
Status : Dry hole, plugged and abandoned.

PERMIT TO EXPLORE 217H

Permit to Explore 217H is held by West Australian Petroleum Pty. Ltd. in the northern Carnarvon Basin. During 1969 the company drilled four stratigraphic wells in this concession. Details are as follows :

Beagle No. 1

Type : Stratigraphic test.
Latitude and Longitude : 21° 11′ 50″S, 115° 38′ 00″E.
Elevation : G.L. 15 feet, R.T. 20 feet.
Commenced : 31st May, 1969.
Completed : 16th June, 1969.
Total depth : 1,835 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.

Fortescue No. 1

Type : Stratigraphic test.
Latitude and Longitude : 21° 01′ 00″S, 115° 51′ 00″E.
Elevation : G.L. 15 feet, R.T. 20 feet.
Commenced : 20th June, 1969.
Completed : 26th June, 1969.
Total depth : 2,000 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.

Mardie No. 2

Type : Stratigraphic test.
Latitude and Longitude : 21° 20′ 42″S, 115° 43′ 28″E.
Elevation : G.L. 20 feet, R.T. 26 feet.
Commenced : 7th May, 1969.
Completed : 12th May, 1969.
Total depth : 541 feet.
Bottomed in : Lower Cretaceous.
Status : Dry hole, plugged and abandoned.

Wonangarra No. 1

Type : Stratigraphic test.
Latitude and Longitude : 22° 09′ 03″S, 114° 41′ 20″E.
Elevation : G.L. 20 feet, R.T. 26 feet.
Commenced : 21 April, 1969.
Completed : 2nd May, 1969.
Total depth : 1,888 feet.
Bottomed in : Permian.
Status : Dry hole, plugged and abandoned.

PERMIT TO EXPLORE 253H

Permit to Explore 253H is held by Lennard Oil N.L. in the northern Canning Basin. The company drilled one dry hole Napier No. 2, in the permit area during 1969. Details are as follows :

Napier No. 2

Type : New field wildcat.
Latitude and Longitude : 17° 04′ 55″S, 124° 21′ 20″E.
Elevation : G.L. 264 feet, R.T. 277 feet.
Commenced : 9th October, 1969.
Completed : 28 November, 1969.
Total depth : 5,272 feet.
Bottomed in : Precambrian.
Status : Dry hole, 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 Aust. Pty. Ltd. The company drilled two dry holes, Matches Spring No. 1 and Mowla No. 1, in this area during 1969. Details are as follows :

Matches Spring No. 1

Type : New field wildcat.
Latitude and Longitude : 18° 41′ 28″S, 124° 03′ 11″E .
Elevation : G.L. 473 feet, R.T. 487 feet.
Commenced : 26th August, 1969.
Completed : 15th November, 1969.
Total depth : 9,300 feet.
Bottomed in : Ordovician.
Status : Dry hole, plugged and abandoned.
Minor oil shows.

Mowla No. 1

Type : New field wildcat.
Latitude and Longitude : 18° 43′ 50″S, 123° 42′ 35″E.
Elevation : G.L. 404 feet, K.B. 418 feet.
Commenced : 24th November, 1969.
Completed : 5th December, 1969.
Total depth : 2,500 feet.
Bottomed in : Devonian.
Status : Dry hole, plugged and abandoned.

PERMIT TO EXPLORE 260H

Permit to Explore 260H is held by West Australian Petroleum Pty. Ltd. and was farmed out to Marathon Petroleum Australia Ltd. However, after Remarkable Hill No. 1 well was completed as a dry hole, Marathon withdrew from the agreement. Details of the well are as follows :

Remarkable Hill No. 1

Type : New field wildcat.
Latitude and Longitude : 22° 57′ 20″S, 114° 09′ 20″E.
Elevation : G.L. 350 feet, K.B. 364 feet.
Commenced : 15th October, 1968.
Completed : 4th February, 1969.
Total depth : 10,520 feet.
Bottomed in : Permian or Carboniferous.
Status : Dry hole, plugged and abandoned.

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 dry hole, Blackwood No. 1, on the permit during 1969. Details are as follows :

Blackwood No. 1

Type : New field wildcat.
Latitude and Longitude : 34° 08′ 55″S, 115° 21′ 20″E.
Elevation : G.L. 206 feet, D.F. 227 feet.
Commenced : 18th August, 1969.
Completed : 13th October, 1969.
Total depth : 10,939 feet.
Bottomed in : Lower Permian.
Status : Dry hole, plugged and abandoned.

GEOPHYSICAL OPERATIONS

Seismic

During 1969 seismic operations were conducted in the Perth, Carnarvon, Canning, Browse and Bonaparte Gulf Basins. This work was distributed as follows :

Company	Concession	Basin	Party Months
West Australian Petroleum Pty Ltd	PL 1	Carnarvon	0·7 (marine)
Do. do.	WA-2-P	Canning	0·5 (marine)
Do. do.	WA-13-P	Perth	2·7 (marine)
Do. do.	WA-14-P	Perth	1·0 (marine)
Do. do.	WA-20-P	Perth	0·1 (marine)
Do. do.	WA-21-P	Canning	0·4 (marine)
Do. do.	WA-22-P	Canning	0·1 (marine)
Do. do.	WA-23-P	Carnarvon	0·3 (marine)
Do. do.	WA-24-P	Carnarvon	0·5 (marine)
Do. do.	WA-25-P	Carnarvon	0·3 (marine)
Do. do.	27H	Perth	3·0 (land)
Do. do.	28H	Carnarvon	0·4 (marine)
Do. do.	30H	Canning	5·0 (land)
B.O.C. of Aust. Ltd	WA-1-P	Carnarvon	0·90 (marine)
Do. do.	WA-28-P	Carnarvon-Canning	0·05 (marine)
Do. do.	WA-29-P	Canning	0·50 (marine)
Do. do.	WA-30-P	Canning	0·27 (marine)
Do. do.	WA-31-P	Canning	0·90 (marine)
Do. do.	WA-32-P	Canning	0·66 (marine)
Do. do.	WA-33-P	Browse	0·30 (marine)
Do. do.	WA-34-P	Browse	0·73 (marine)
Do. do.	WA-35-P	Browse	0·66 (marine)
Do. do.	WA-36-P	Bonaparte Gulf	0·08 (marine)
Do. do.	WA-37-P	Bonaparte Gulf	0·08 (marine)
Union Oil Development Corp.	261H	Perth	1·75 (land)
Australian Aquitaine Petroleum Pty Ltd	151H, 152H, 153H, 205H	Canning	3·80 (land)
Arco Ltd	WA-15-P, WA-16-P, WA-17-P	Bonaparte Gulf	0·06 (marine)
Total Exploration Australia Pty Ltd	259H	Canning	3·5 (land)
Lennard Oil N.L.	106H	Canning	3·0 (land)

Aeromagnetic

Aeromagnetic surveys were carried out during the year in the Perth, Carnarvon, and Canning Basins, principally on the continental shelf. Details are as follows :

Company	Concession	Basin	Line Miles
West Australian Petroleum Pty Ltd	WA-13-P	Perth	3,375
Do. do.	WA-14-P	Perth	2,309
Do. do.	WA-20-P	Perth	400
Do. do.	WA-21-P	Canning	991
Do. do.	WA-24-P	Carnarvon	1,696
Do. do.	WA-25-P	Carnarvon	558
Do. do.	27H	Perth	100
Do. do.	28H	Carnarvon	686
Do. do.	30H	Canning	410
Do. do.	228H	Perth	50
Do. do.	261H	Perth	100

GEOLOGICAL OPERATIONS

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

Company	Permit	Basin	Geologist Months
West Australian Petroleum Pty Ltd	28H	Carnarvon	0·5
Do. do.	30H	Canning	1·75
Australian Aquitaine Petroleum Pty Ltd	151–153H	Canning	3·0
Lennard Oil N.L.	106H	Canning	1·0

PETROLEUM DEVELOPMENT AND PRODUCTION IN WESTERN AUSTRALIA IN 1969

by A. H. Pippet

Barrow Island

Development of the Barrow Island Field continued throughout the year with the drilling of 86 Windalia producing wells, 8 Muderong wells and 71 Windalia water-injection wells. The positions of all wells drilled on the field to the end of 1969 are shown on Plate 5.

The total footage of holes drilled on Barrow Island during the year amounted to 433,605 feet, an increase of 176,424 feet over the 1968 figure.

Oil production rose from an average of 30,000 barrels per day in December 1968 to 45,400 barrels per day in November 1969, giving an increase for the year of 2,615,882 barrels. The increase was adversely affected by lack of storage space arising out of tanker delays, and as a result in 1970 the company will install an additional 200,000 barrel storage tank. Storage capacity on the island will then amount to some 1,000,000 barrels.

The increase in production was achieved partly by additional drilling and partly by extending gas-lift and pumping facilities to a further 99 and 24 wells respectively, combined with some encouraging results from the water flood project.

At present the gas-lift system is operated by producing Jurassic gas wells. However it is anticipated that compressors will have been installed by mid-1970 enabling the use of low-pressure Windalia gas.

It is estimated that production for 1970 from Barrow Island will be in the order of 17 million barrels of oil and 12 billion cubic feet of gas. Details of well status (by reservoirs), productions figures, and wells drilled during the year on Barrow Island are tabulated below.

TABLE 1. BARROW ISLAND OIL AND GAS PRODUCTION 1969

Reservoir	Production for year 1969			Cumulative production		
	Oil (bbls)	Water (bbls)	Gas (mcf)	Oil (bbls)	Water (bbls)	Gas (mcf)
Windalia	12,970,008	727,582	8,838,279	28,092,865	727,582	19,814,997
Muderong	145,920	42,705	147,434	166,731	42,929	156,759
Jurassic 6,200′	10,820	18,345	404,573	20,243	23,115	470,750
Jurassic 6,600′	51,447	72,233	103,826	157,545	119,853	445,314
Jurassic 6,700′	220,072	55,871	835,370	659,835	95,518	1,540,453
Jurassic 5,500′	296	7	9,982	296	7	9,982
Total Field	13,398,563	916,743	10,339,464	29,097,515	1,009,004	22,438,255

Water injected, 23,152,097 bbls. Cumulative water injected, 25,196,416 bbls.

TABLE 2. BARROW ISLAND WELL STATUS BY RESERVOIRS AT 31ST DECEMBER, 1969

Reservoir	Flowing	Pumping	Gas lift	Non-producing	Total wells
Windalia	137	40	116	22	315
Muderong	7	....	5	....	9
Jurassic 5,500′	1	....	....	....	1
Jurassic 6,200′	2	....	....	....	2
Jurassic 6,600′	1	....	....	....	1
Jurassic 6,700′	3	....	1	1	5
Total	151	40	122	23	333

Grand Total, 333 Wells.

TABLE 3. BARROW ISLAND OIL AND GAS DISPOSAL 1969

	Oil (bbls)	Gas (mcf)
Total production	13,398,563	10,339,464
Used in drilling	10	....
Field fuel	7,638	238,915
Gas flared	....	10,100,549
Oil shipments	13,140,280	....
Percentage of field utilization	0·0057	2·4
Percentage gas flared	....	97·6
Royalty received	$1,657,663	....

TABLE 4. WELLS DRILLED ON BARROW ISLAND 1/1/69 TO 31/12/69

Well	Elevation		Total depth (feet)	Commenced	Completed	Original status*
	Rotary table (feet)	First flange (feet)				
B 17	59	48	2,195	31/5/69	3/6/69	P
B 26	56	46	2,338	10/8/69	15/8/69	P
B 47	50	40	4,025	14/7/69	21/7/69	Abx
E 11	180	169	2,401	13/1/69	21/1/69	WI
E 13	149	139	2,431	17/2/69	20/2/69	WI
E 22	113	103	2,351	15/10/69	19/10/69	P
E 24	87	77	2,458	9/11/69	12/11/69	P
E 31	97	86	3,028	6/2/69	11/2/69	WI
E 32	93	82	2,545	15/4/69	18/4/69	P
F 13	151	141	2,312	28/3/69	1/4/69	WI
F 17	159	148	2,372 (1,890)	31/12/69	3/1/69	WI
F 24 M	155	144	3,034	6/8/69	10/8/69	P (M)
F 26 M	140	130	3,007	4/1/69	11/1/69	P (M)
F 28	140	130	2,290	17/2/69	22/3/69	P
F 35	114	....	350 (202)	31/12/69	7/1/69	Abx
F 35	114	103	2,224	30/1/69	6/2/69	WI
F 42	129	118	2,257	31/3/69	4/4/69	P
F 44	115	105	2,256	26/3/69	30/3/69	P
F 44 M	108	97	2,891	26/8/69	31/8/69	P (M)
F 46 M	96	86	2,914	19/10/69	26/10/69	P (M)
F 62	102	....	330	12/2/69	13/2/69	Abx
F 62	102	92	2,580	24/2/69	2/3/69	P
F 71	93	83	2,224	7/1/69	10/1/69	P
G 22	93	83	2,446	27/5/69	30/5/69	P
G 24	127	116	2,401	2/4/69	8/4/69	Abx
G 24	109	98	2,401	28/4/69	1/5/69	P
G 26	135	125	2,401	9/4/69	11/4/69	P
G 28 M	184	174	3,035	11/1/69	15/1/69	P
G 42	105	94	2,436	4/6/69	7/6/69	P
G 44	146	136	2,341	15/1/69	19/1/69	P
G 46	176	165	2,380	19/1/69	22/1/69	P
G 48	192	182	2,370	13/2/69	17/2/69	P
G 62	142	132	2,500	20/5/69	23/5/69	P
G 64	123	112	2,380	27/1/69	30/1/69	P
G 66	119	109	2,341	23/1/69	26/1/69	P
G 68	125	114	2,270	2/3/69	5/3/69	WI
G 88	64	53	2,203	9/4/69	15/4/69	P
H 28	102	92	2,528	29/9/69	2/10/69	P
H 48	121	111	2,544	3/10/69	7/10/69	P
H 68	143	133	2,574	7/10/69	10/10/69	P
J 48	151	140	2,561	8/12/69	10/12/69	WI
J 68	87	77	2,561	10/12/69	15/12/69	WI
K 13	127	117	2,531	17/11/69	21/11/69	WI
K 15	170	154	2,505	11/8/69	21/8/69	WI
K 17	174	163	2,498	9/8/69	11/8/69	WI
K 22	142	132	2,552	23/9/69	26/9/69	P
K 24	193	182	2,552	26/9/69	3/10/69	P
K 26	168	158	2,490	4/10/69	8/10/69	P
K 28	187	176	2,490	9/10/69	11/10/69	P
K 31	145	135	2,574	27/11/69	30/11/69	WI
K 35	173	161	2,458	3/8/69	8/8/69	WI
K 37	196	185	2,527	30/7/69	3/8/69	WI
K 42	134	124	2,463	1/9/69	4/9/69	P
K 44	164	154	2,513	4/9/69	9/9/69	P
K 46	177	166	2,483	9/9/69	12/9/69	P
K 48	180	170	2,437	14/6/69	18/6/69	P
K 51	113	103	2,531	15/12/69	18/12/69	WI
K 53	120	109	2,423	30/11/69	3/12/69	WI
K 55	140	129	2,412	27/7/69	30/7/69	WI
K 57	166	156	2,457	25/7/69	27/7/69	WI
K 62	138	128	2,483	12/9/69	15/9/69	P
K 64	129	118	2,436	11/6/69	14/6/69	P
K 66	175	164	2,466	15/5/69	19/5/69	P
K 68	168	158	2,415	24/4/69	27/4/69	P
K 82	130	120	2,513	15/9/69	19/9/69	P
K 84	130	120	2,437	8/6/69	11/6/69	P
K 86	180	170	2,311	20/4/69	23/4/69	P
K 88	186	175	2,431	12/4/69	19/4/69	P
L 11	153	143	2,470	18/11/69	22/11/69	WI
L 13	195	184	2,513	22/11/69	27/11/69	WI
L 22	181	170	2,458	12/10/69	15/10/69	P
L 25	225	212	2,473	19/9/69	23/9/69	P
L 31	181	171	2,439	24/11/69	26/11/69	WI
L 33	183	172	2,438	21/11/69	24/11/69	WI
L 34	204	194	2,443	25/10/69	28/10/69	P
L 35	213	202	2,501	27/11/69	29/11/69	WI
L 37	186	176	2,470	30/11/69	3/12/69	WI
L 42	195	185	2,400	22/5/69	25/5/69	P
L 44	195	185	2,413	28/5/69	31/5/69	P
L 46	202	191	2,458	30/10/69	2/11/69	P
L 48	187	176	2,460	27/10/69	30/10/69	P
L 51	168	158	2,401	25/5/69	28/5/69	WI
L 55	203	192	2,416	22/1/69	26/1/69	WI
L 57	208	198	2,462	22/1/69	30/1/69	WI

For footnotes, see end of table.

TABLE 4—*continued*

Well	Elevation: Rotary table (feet)	Elevation: First flange (feet)	Total depth (feet)	Commenced	Completed	Original status*
L 62 M	184	173	3,075	5/11/69	9/11/69	P (M)
L 64 M	166	154	3,066	14/9/69	19/9/69	P (M)
L 64	161	151	2,362	15/11/69	18/11/69	P
L 66	219	209	2,466	12/5/69	14/5/69	P
L 75	166	156	2,339	30/1/69	2/2/69	WI
L 77	201	191	2,420	2/2/69	5/2/69	WI
L 82 M	147	137	2,979	5/4/69	8/4/69	P (M)
L 84	162	151	2,306	3/11/69	5/11/69	P
L 84 M	161	151	3,012	30/6/69	6/7/69	P (M)
L 86	222	211	2,416	22/6/69	24/6/69	P
L 88	203	193	2,416	25/6/69	30/6/69	P
M 11	170	159	2,490	6/2/69	9/2/69	WI
M 13	192	182	2,549	9/2/69	12/2/69	WI
M 15	146	135	2,550	24/4/69	27/4/69	WI
M 17	141	131	2,580	23/3/69	27/3/69	WI
M 22	139	129	2,458	11/9/69	14/9/69	P
M 24	153	143	2,519	22/7/69	24/7/69	P
M 26	140	130	2,594	6/7/69	9/7/69	P
M 28	124	114	2,617	22/4/69	24/4/69	WI
M 31	179	168	2,457	24/2/69	26/2/69	WI
M 33	142	132	2,460	12/2/69	15/2/69	WI
M 35	125	115	2,496	13/3/69	16/3/69	WI
M 37	124	114	2,580	20/3/69	23/3/69	WI
M 42	150	140	2,476	21/7/69	24/7/69	P
M 44	128	118	2,446	24/7/69	27/7/69	P
M 46	98	87	2,506	27/7/69	30/7/69	P
M 48	113	103	2,617	18/4/69	21/4/69	WI
M 51	169	158	2,458	19/2/69	24/2/69	WI
M 53	140	130	2,459	16/2/69	19/2/69	WI
M 55	129	119	2,488	27/2/69	2/3/69	WI
M 57	92	82	2,520	16/3/69	19/3/69	WI
M 62	143	132	2,446	30/7/69	2/8/69	P
M 64	181	171	2,486	2/8/69	6/8/69	P
M 66	107	96	2,496	21/6/69	26/6/69	P
M 71	170	159	2,401	11/3/69	16/3/69	WI
M 73	178	168	2,480	21/2/69	24/3/69	WI
M 75	146	136	2,490	6/3/69	10/3/69	WI
M 77	111	101	2,600	2/3/69	5/3/69	WI
M 82	128	118	2,377	24/5/69	27/5/69	P
M 84	145	134	2,466	18/6/69	22/6/69	P
P 15	170	160	2,580	18/5/69	21/5/69	WI
P 17	176	165	2,612	5/9/69	8/9/69	WI
P 26	152	142	2,551	2/9/69	5/9/69	P
P 31	209	198	2,536	8/7/69	11/7/69	WI
P 32	179	169	2,507	11/7/69	14/7/69	P
P 33	165	155	2,476	11/7/69	14/7/69	WI
P 34	147	136	2,507	18/6/69	21/6/69	P
P 35	161	150	2,556	9/5/69	11/5/69	WI
P 37	128	118	2,531	15/5/69	17/5/69	WI
P 42	181	170	2,502	9/7/69	12/7/69	P
P 44	138	128	2,502	12/7/69	15/7/69	P
P 46	166	155	2,610	29/8/69	1/9/69	P
P 48	115	104	2,551	5/6/69	7/6/69	WI
P 51	219	209	2,551	10/5/69	12/5/69	WI
P 53	166	156	2,557	2/5/69	4/5/69	WI
P 55	120	109	2,527	30/4/69	2/5/69	WI
P 57	127	116	2,541	12/5/69	15/5/69	WI
P 62	165	155	2,486	26/8/69	29/8/69	P
P 64	141	130	2,491	7/6/69	10/6/69	P
P 66	141	130	2,491	11/6/69	14/6/69	P
P 68	102	92	2,551	1/6/69	4/6/69	WI
P 71	164	153	2,522	7/5/69	9/5/69	WI
P 73	163	152	2,540	27/4/69	29/4/69	WI
P 75	136	126	2,522	4/5/69	7/5/69	WI
P 77	99	88	2,522	1/5/69	4/5/69	WI
P 78	91	81	2,536	15/6/69	18/6/69	P
P 82	200	190	2,536	16/8/69	19/8/69	P
P 84	140	129	2,536	19/8/69	22/8/69	P
P 86	138	128	2,564	22/8/69	25/8/69	P
P 88	104	94	2,556	5/5/69	8/5/69	WI
Q 62	161	151	2,513	29/10/69	1/11/69	P
Q 71	162	152	2,470	5/12/69	7/12/69	WI
Q 73	167	157	2,470	3/12/69	5/12/69	WI
Q 76	192	181	2,490	19/9/69	22/9/69	P
Q 82	204	194	2,502	21/10/69	24/10/69	P
R 55	130	119	2,574	15/12/69	19/12/69	WI
R 66	137	126	2,513	11/11/69	15/11/69	P
R 68	112	102	2,483	1/11/69	5/11/69	P
R 75	159	149	2,574	7/12/69	14/12/69	WI
R 77	180	169	2,513	3/12/69	6/12/69	WI
R 84	115	104	2,521	21/8/69	25/8/69	P
R 86	157	147	2,513	14/10/69	17/10/69	P
R 88	201	191	2,533	17/10/69	21/10/69	P
S 47	166	155	3,641	15/7/69	21/7/69	P
U 82	134	124	2,581	8/9/69	11/9/69	WI
YS 88	169	159	2,694	23/9/69	29/9/69	Abx
WSW 5 A (P 43)	154	143	4,202	6/3/69	13/3/69	....
WSW 6 A (K 36)	225	214	4,100	27/6/69	6/7/69	....
WDW D (P 42)	....	....	845	10/10/69	13/10/69	....
WDW J (L 64)	....	....	945	13/11/69	17/11/69	....

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 injection well. WSW = Water source well. WDW = Water disposal well. Abx = Abandoned.

Total Development Drilling Barrow Island 1,969,433,605 feet.

Dongara Field

During the year an active drilling programme was maintained in the Dongara—Mondarra area, with the drilling of an additional 13 wells. Although the Mondarra field failed to live up to early expectations it is anticipated that the Dongara field (where 10 wells were drilled) will eventually be economic. The positions of wells drilled in the Dongara area are shown on Plate 6.

Wapet has recently established a gas-sales organization which will co-ordinate a feasibility study of a gas transmission line between Dongara and the Perth—Kwinana area, with field surveying of the pipeline route.

Details of those wells drilled during the year in the Dongara field are given in Table 5.

TABLE 5. DONGARA DEVELOPMENT WELLS

Well No.	8	9	10	11	12	13	14	15	16	17
Latitude S	29° 15′ 08″	29° 13′ 24″	29° 14′ 17″	29° 15′ 59″	29° 14′ 18″	29° 12′ 46″	29° 13′ 26″	29° 16′ 29″	29° 16′ 13″	29° 17′ 06″
Longitude E	115° 01′ 13″	115° 00′ 00″	115° 00′ 07″	115° 00′ 25″	115° 01′ 10″	114° 59′ 40″	115° 00′ 56″	115° 00′ 55″	114° 59′ 28″	115° 01′ 29″
Elevation G.L.	162	273	227	208	84	274	241	205	83	255
Elevation R.T.	176	284	236	219	95	289	253	216	96	269
Total depth	6,229	6,266	6,700	6,019	6,603	6,669	6,293	6,363	6,312	6,393
Formation bottomed in	Irwin River Coal Measures	Holmwood Shale	Holmwood Shale	Irwin River Coal Measures	Holmwood Shale	Holmwood Shale	High Cliff Sandstone	Holmwood Shale	Holmwood Shale	Irwin River Coal Measures
Perforated interval	5,605–5,615	5,533–5,665	5,670–5,690	5,594–5,610	5,422–5,442	Plugged and abandoned	5,720–5,755	5,359–5,636	5,421–5,457	....
Producing formation	Basal Triassic	Basal Triassic and Irwin River Coal Measures	Basal Triassic	Basal Triassic	Basal Triassic		Basal Triassic	Basal Triassic and Irwin River Coal Measures	Basal Triassic	Basal Triassic
Production rate	600–800 b/d	10 mmcf/d	6 mmcf/d	9 mmcf/d	10 mmcf/d	....	1,400 b/d	10 mmcf/d	9·5 mmcf/d	....
Choke size	⅜″	½″	⅜″	½″	½″	....	½″	½″	½″	....
Date spudded	13/5/69	15/4/69	14/6/69	9/7/69	30/7/69	21/8/69	21/9/69	16/10/69	8/11/69	5/12/69
Date completed	2/6/69	8/5/69	1/7/69	25/7/69	17/8/69	13/9/69	9/10/69	4/11/69	29/11/69	27/12/69

		feet
Development drilling Dongara Field	....	63,847
Development drilling Barrow Island	....	433,605
Total Development drilling	....	497,452
Exploration drilling	....	149,521
GRAND TOTAL DRILLING	....	646,973

DEPOSITIONAL STRUCTURES IN THE ARCHAEAN GINDALBIE FORMATION AT KANOWNA, WESTERN AUSTRALIA

by I. R. Williams

ABSTRACT

Graded beds, scour structures, slumps and dropped blocks from the Archaean Gindalbie Formation near Kanowna, Western Australia, are briefly described and illustrated. The structural origin of the strongly aligned clasts in the conglomerate beds is uncertain.

Some well preserved sedimentary structures in mixed waterlain pyroclastic and clastic deposits near Kanowna, are briefly described and illustrated.

The exposure is situated 2 miles south-west of the abandoned mining centre of Kanowna and lies 200 yards south of the Kanowna Town Dam (lat. 30° 38′S. ; long. 121° 36′E.). The outcrop covers an area of about half an acre at the foot of a low breakaway.

The rock units are now largely reduced to clay minerals due to deep weathering processes associated with the formation of laterite. However the original bedding together with numerous sedimentary structures have been perfectly preserved in the weathered rock.

The deposits are Archaean and belong to the Gindalbie Formation which is the acid volcanic-clastic association of cycle 1 on the Kurnalpi 1 : 250,000 Sheet area (Williams, 1970).

The beds face and dip steeply to the southeast and lie near the nose of a southeasterly plunging anticlinal structure. The deposits are regionally situated southwest of a thick pile of acid volcanic flows and associated pyroclastic rocks, and adjacent to a thick sequence of oligomictic conglomerates.

The lithology varies from coarse conglomerate through sandstone, siltstone to shale. Sorting improves with decreasing grain size. The clasts in the conglomerate are almost exclusively acid igneous material. They are mainly porphyry and felsite with the former predominating among the larger clasts. The finer grained material represents successively smaller fragments of the same acid igneous material. Green, angular fragments of a chrome-rich clay are the only obvious exotic material present.

Graded bedding is the commonest sedimentary structure. The graded units range from 2 to 3 inches thick to beds up to 12 feet thick. They generally occur in groups which are separated by normal, well bedded units, mainly siltstone and shale (Plate 7A and 7B). Flame structure is commonly present at the base of the graded bedded units.

Clasts in the conglomerate beds consistently show a strong alignment at steep angles to the bedding (Plate 8A). The long axes of the clasts lie approximately parallel to a coarse cleavage which is emphasized by grooves in the weathered rock. Whether the orientation of the clasts is the product of their post-depositional rotation by the compression which imposed the cleavage, or of the enhancement of a primary imbrication structure by this compression, is not known. The clasts appear undeformed, and if the structure is tectonic the rotation must have taken place in a relatively unconsolidated matrix. However, the orientation of the clasts is also consistent with a current direction from north to south, away from the volcanic rise which is the supposed source of the clastic material.

Scour channels, some up to 5 and 6 feet deep are present. The coarse grained material filling the channel always shows a crude graded bedding (Plate 8B).

Large-scale slumping involving a number of lithological units and small-scale slumping of individual units consistently show a southerly direction of transport (Plate 9A). This is consistent with the location of volcanic activity to the north on a contemporaneous topographic rise.

Scattered exotic blocks, dropped pebbles and cobbles are also present (Plate 9B). The mechanics of their emplacement are not known. However the large clasts are consistently acid igneous rocks, particularly porphyry. This strongly suggests some type of volcanic origin, possibly by direct contribution from explosive activity.

Because of the regional proximity to an acid volcanic complex and the preponderance of acid volcanic rocks in the clastic components, there is little doubt as to the source of the material. The sedimentary structures indicate the presence of turbidity currents with a strong scouring action. It is thought that the material in the deposits is derived directly from volcanic activity and by erosion from the accumulating volcanic piles in a sub-aqueous environment.

REFERENCE

Williams, I. R., 1970, Explanatory notes on the Kurnalpi 1 : 250,000 geological map: West. Australia Geol. Survey Record 1970/1 (unpublished).

LAYERED APLITE DYKES NEAR MERREDIN AND MECKERING, WESTERN AUSTRALIA

by J. J. G. Doepel

ABSTRACT

Layered aplite dykes cut granites and granitic gneiss near Merredin and Meckering, Western Australia. Pegmatitic portions favour hanging wall positions and in some dykes biotite is concentrated towards the base. From footwall to hanging wall the aplites are progressively enriched in potassium and lithium while their soda content decreases.

INTRODUCTION

Layered aplite dykes* cut granites and granitic gneiss in the Archaean of South West Australia. Some of the dykes contain portions which are of coarser grain size than the rest of the dyke. These portions, which are called pegmatitic in this paper, favour a hanging wall position. In two dykes differentiation from a more sodic footwall to a more potassic hanging wall has occurred.

All but one of the dykes described are exposed in the abandoned quarry immediately south-east of Merredin townsite. The remaining one is exposed in a quarry just north of the railway line about two miles west of Meckering. Other representatives of the layered aplite suite are exposed in most other quarries and Standard Gauge Railway cuttings of the Kellerberrin—Merredin area.

Various authors have described or noted layered aplite-pegmatite bodies and a review of the subject has been given by Jahns and Tittle (1963).

Published geological work on the Precambrian of the Kellerberrin—Merredin area is restricted to a map at a scale of 20 miles to an inch by Wilson (1958) and to engineering geology reports by Gordon (1967a, 1967b). An unpublished report by Lewis (1969) concerns the Precambrian geology of the Meckering area.

* Although most of the aplites described have dips of the order of 20 degrees, they cut across the foliation of the enclosing granitic rocks and have all been called dykes rather than sills.

GEOLOGICAL SETTING

Between Kellerberrin and Merredin there is an anticlinal body of syntectonic granite, about 35 miles wide, which has a porphyritic granite border facies and an even-grained core (Figure 4). To the east it intrudes granitic gneisses. The gneisses near the contact are intruded by numerous aplites and pegmatites. To the west is an area of mixed granitic material, migmatitic at a regional scale, which contains gneissic granite with or without basic xenoliths, even-grained granite, and porphyritic granite.

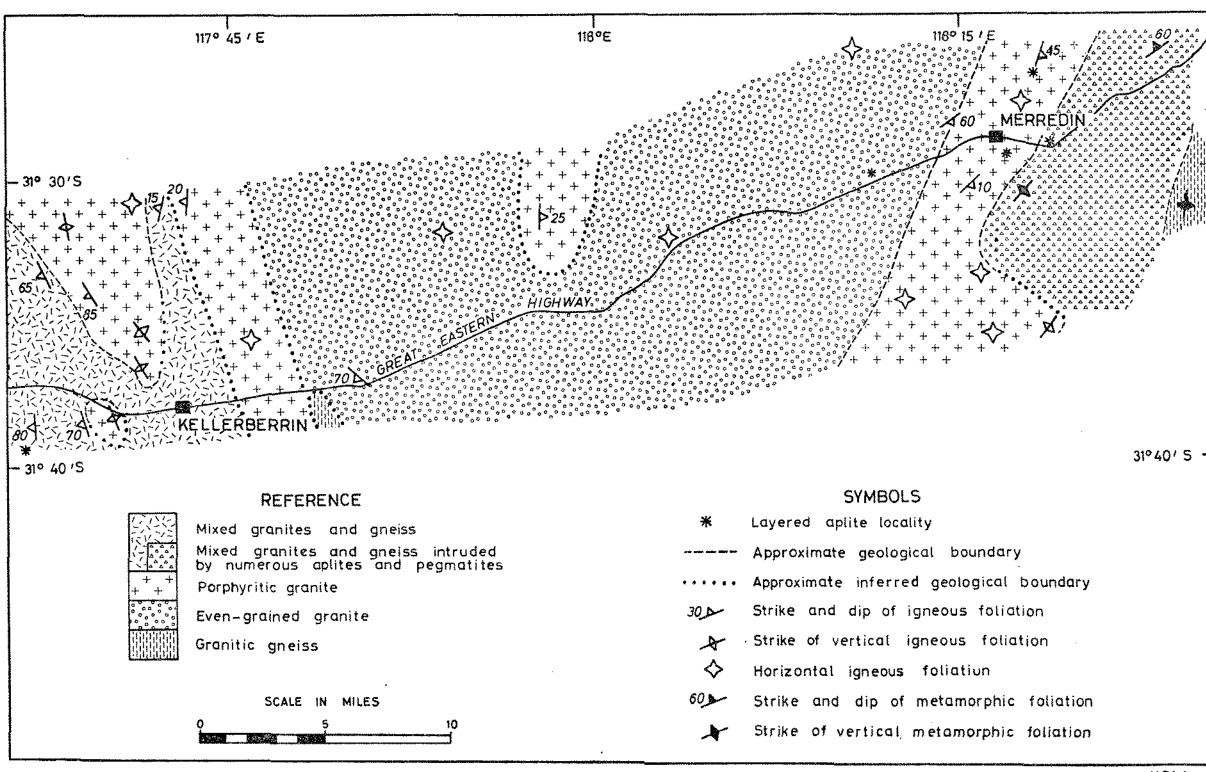

Fig. 4—Interpretive geological sketch map of Kellerberrin-Merredin area, W.A.

LAYERED APLITES

Near Merredin numerous aplite dykes up to 4 feet thick cut the granite and the border zone. They have a moderate westerly dip into the granite mass. Although the dykes are not seen to be folded, some of them have their biotites aligned in planes parallel to the foliation of the granite or gneiss which they intrude. Similar dykes cut the mixed granite area west of Kellerberrin. Some of these dykes dilate earlier structures.

A number of these dykes contain pegmatitic portions, especially where the dykes narrow up dip (Figure 5, A and B). The pegmatitic portions are commonly on or towards the hanging wall of the dykes and have never been seen in a footwall position (Figure 5C). Cores of quartz are sometimes present in the pegmatitic portions. In one dyke the quartz has a hanging wall position within the pegmatite (Figure 5D). Some dykes have more than one pegmatitic band.

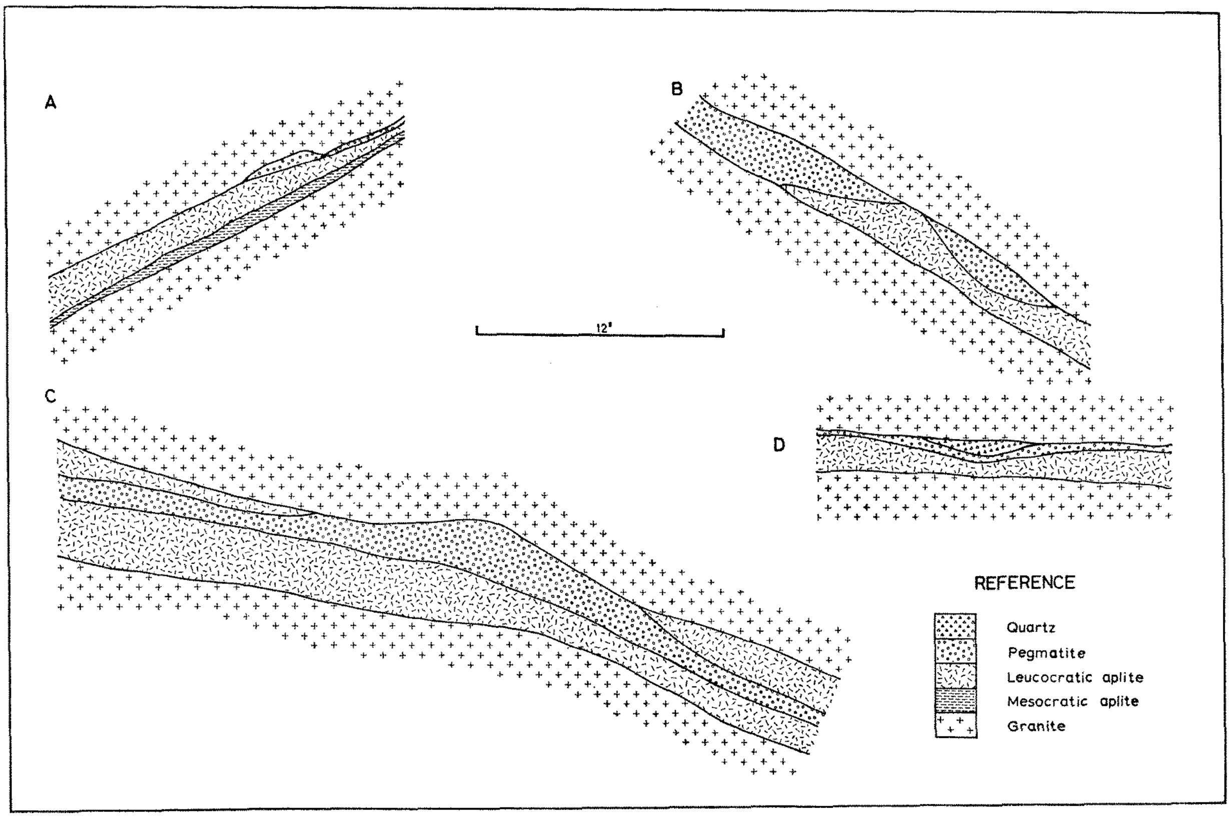

Fig. 5—Sketches of layered aplite dykes in a vertical quarry wall, southeast of Merredin.

Major minerals of both the aplitic and the pegmatitic portions are microcline, which is the predominant feldspar, quartz, plagioclase and biotite. Aplitic portions of the dykes normally have a grain size of less than 1 mm.

Lewis (1969) notes that in a quarry west of Meckering an aplite dyke cutting porphyritic granite contains concentrations of biotite in a zone at the base of the dyke and in another narrow zone near its upper margin. Further studies of a specimen collected by him from this dyke (specimen 15012, Plate 10A) are reported here. A similar 5 cm-thick aplite exposed in the north wall of the quarry at Merredin has a 2 cm-thick footwall layer which contains more biotite than the rest of the dyke. Specimen 10675 is from this dyke (Plate 10B). Up dip the dyke narrows and the portion adjacent to the hanging wall is pegmatitic (Figure 5A).

From the above two specimens samples were sawn across the plane of each dyke. The sample positions are shown on Plate 10. These samples were analysed for alkalis. Thin-sections were cut from approximately the same positions. Results of the chemical analyses and accompanying modal analyses are given in Table 1.

TABLE 1

	CHEMICAL ANALYSES*					MODAL ANALYSES					
Sample No.	Thickness of sample (mm)	Na_2O (per cent. on dry basis)	K_2O (per cent. on dry basis)	Li_2O (per cent. on dry basis)	K_2O / Na_2O	Plagioclase	Quartz	Microcline	Biotite	Chlorite	Accessories
15012 P	12	1·97	8·74	0·25	4·43	11·7	33·9	53·2	0·2	0·2	0·9
15012 O	15	3·07	5·95	0·19	1·94	31·5	29·9	36·3	1·1	0·3	1·1
						40·2	29·5	27·4	1·1	0·3	0·6
15012 N	23	3·76	5·45	0·17	1·45	30·1	30·9	36·3	1·6	0·5	0·5
15012 M	17	3·36	4·75	0·16	1·41	33·8	34·6	25·0	5·6	0·0	1·0
15012 L	11	3·63	2·52	0·12	0·69	45·2	34·7	10·0	7·9	0·2	2·0
15012 K	8	3·26	1·02	0·05	0·31	....	....	....	....	....	....
16075 C	12·5	2·64	5·81	0·18	2·20	....	....	....	....	....	....
16075 B	14·5	2·88	5·34	0·16	1·86	15·0	42·0	41·0	2·0	....	0·0
16075 A	11	3·48	4·72	0·14	1·36	33·0	31·0	31·0	3·0	....	1·0

* Analyses by Western Australian Government Chemical Laboratories.

In specimen 15012, sample K, from the footwall, is thus a tonalite, successively higher samples being granodiorite, adamellite, and granite. In specimen 10675, the footwall layer is an adamellite.

Thus, although differentiation appears to be more complete in specimen 15012, the same trends are present in both aplites. The plagioclase contents decrease upwards from the footwalls, while the microcline contents increase. The biotite contents, though fluctuating, tend to be greatest at the base. The microcline is microperthitic in the uppermost sample of specimen 15012. The plagioclase is zoned from oligoclase to albite. The biotite is altered to chlorite, the amount of alteration being greatest higher in the dykes. The common accessories are iron oxide, sphene and muscovite.

The variations in the mineralogy are reflected in the alkali variations. In both examples Na_2O decreases, while K_2O and Li_2O increase towards the hanging wall.

The Li_2O contents are high compared with average Li_2O contents of world granitic rocks which various authors place between 0·005 per cent and 0·09 per cent (Heier and Adams, 1964). However lithium is not normally extracted from magma until a late stage of differentiation when it is usually accommodated in micas or forms discrete lithium minerals, commonly lepidolite, spodumene, petalite, and amblygonite (Mason, 1958). No lithium minerals were recognized in the specimens analysed. It seems that most of the Li_2O cannot be present in the biotite as the biotite contents of the dykes seem to bear no relationship to their Li_2O contents.

A plot of Li_2O against K_2O for specimen 15012 is linear (Figure 6A). Points for specimen 10675 almost fit on this line. Plots of K_2O and of Li_2O against modal per cent microcline are also linear (Figure 6, B and C). It is therefore suggested that Li_2O is accommodated in the microcline. A Li_2O content of approximately 0·5 per cent is indicated for the microcline if the Li_2O is present solely in this mineral. Hess (1940) reports a microcline containing 2·6 per cent Li_2O from a spodumene pegmatite. However, according to Heier and Adams (1964) only small amounts of lithium are usually present in feldspars. They record that, of 125 analysed potassium feldspars from pegmatites, 93 contained less than 0·01 per cent Li_2O and the rest contained less than 0·09 per cent Li_2O.

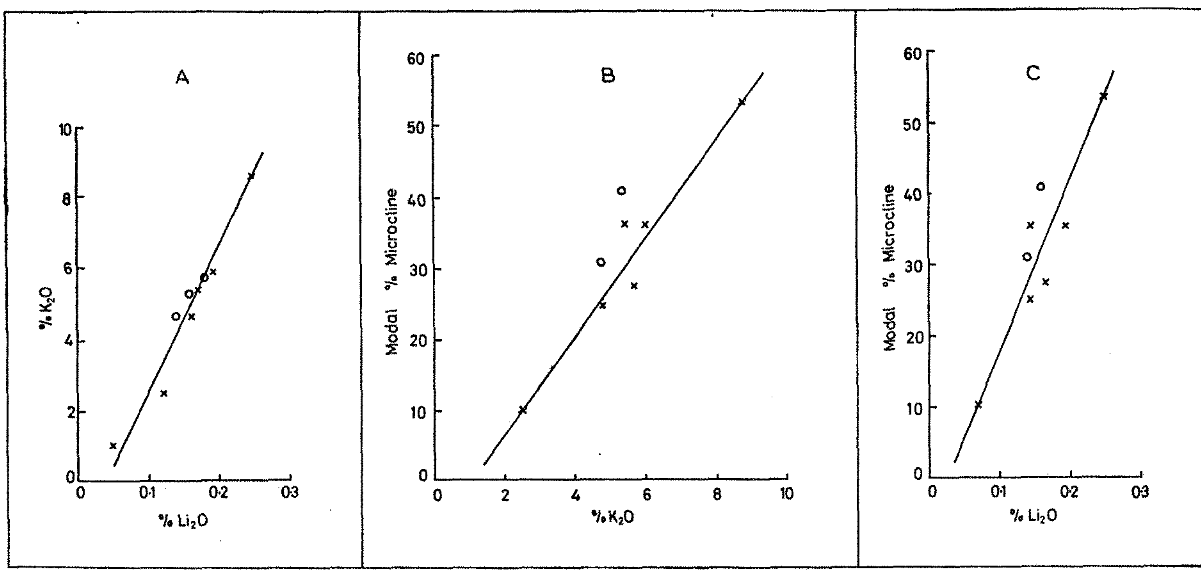

Fig. 6—Plots of K_2O, Li_2O, and microcline contents through aplite dykes from Meckering and Merredin. Crosses: Specimen 15012 Meckering. Circles: Specimen 16075 Merredin.

It is thought that the dykes crystallized from the footwalls upwards. This assumption is deduced from the hanging wall position of the pegmatitic residua and the progressive potassium enrichment with height.

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INTRUSIVE CARBONATE ROCKS OF THE MOUNT FRASER AREA, PEAK HILL GOLDFIELD

by W. N. MacLeod

ABSTRACT

Five carbonatite bodies, suspected to be of magmatic origin, and associated with a distinctive type of highly acid lava, have been mapped along the axial zone of a north-plunging asymmetrical anticline in an Archaean sedimentary sequence comprising banded iron formation, shale, and quartz greywacke in the Mount Fraser area, Western Australia.

A sixth body, consisting mainly of carbonated talcose rocks, may also belong to the suite and represent an altered associated intrusion, possibly of original basic or ultrabasic character.

Preliminary geochemistry has shown anomalously high copper, nickel, cobalt, and chromium values for the carbonatites in relation to the enclosing sedimentary rocks, and subsurface testing is recommended for possible base metal ore bodies.

INTRODUCTION

A group of intrusive carbonate rocks, suspected to be of magmatic origin, was located in July, 1969 in the course of regional mapping in the eastern section of the Robinson Range 1 : 250,000 Sheet area. The area was re-examined in more detail in October, 1969 and representative material was collected for chemical and petrographic study.

Five bodies of carbonate rock, associated with a distinctive type of highly acid lava and massive quartz intrusions have been recognized. These occurrences are interpreted as diatremes discordantly cutting an Archaean sedimentary sequence. Although the term lava has been used throughout this paper to denote the fine-grained acid igneous rocks associated with the carbonate rocks it has yet to be ascertained to what extent they are intrusive or extrusive, and what the surface expression of all these rocks was during their emplacement at the levels at which they are now exposed. As such the rocks are regarded as true carbonatites as distinct from the common and widely distributed examples of carbonated basic and ultrabasic rocks elsewhere in the Archaean shield.

Apart from the intrinsic geological interest possessed by these unusual rocks, it is possible that they could be of some economic value. Preliminary geochemical studies of the carbonate rock have shown anomalously high copper, nickel, cobalt and chromium values in relation to the enclosing host rocks.

LOCATION AND GEOLOGICAL SETTING

The carbonatite intrusions occur within a restricted area between the prominent hill features of Mounts Padbury and Fraser in the south-eastern sector of the Robinson Range 1 : 250,000 Sheet area. The area is situated at approximate latitude 25° 35′S and longitude 118° 20′E, and is about 70 miles north of Meekatharra, the nearest town (see locality plan, Figure 7).

The area is readily accessible by two alternative routes from Meekatharra. The first of these is by the main station road to Mount Padbury which leaves the Great Northern Highway about five miles north of Meekatharra. From Mount Padbury Station on the Murchison River, a station track runs east for about 18 miles to the now abandoned mining centre of Mount Fraser. This track traverses the carbonatite area close to the main manganese mining area.

The alternative route is to follow the Great Northern Highway to the junction with the Horseshoe manganese mine road near the 516 mile peg. The manganese mine road is followed north for about 20 miles to the junction with the branch mining road near Murphy Well which leads to Mount Fraser. This road continues through the manganese mining area to Sleepy Hollow Well, near the south-eastern boundary of the carbonatite area (see Figure 7).

The carbonatite rocks occur as a group of small diatremes cutting an Archaean sedimentary sequence. The host sediments include banded iron formation, shale, and quartz greywacke, which form part of the extensive east-west Robinson Range belt of Archaean metasediments and lavas along the northern boundary of the Yilgarn Block.

Although strongly folded, the sediments are of low metamorphic grade and the carbonatite plugs are disposed meridionally along the axial zone of a north-plunging asymmetrical anticline. The form of this fold is defined as a consequence of the superior resistance to erosion of the banded iron formation beds in both limbs. These rocks form ridges and hills rising up to 200 feet above the surrounding plain.

The southern extension of the fold appears to be terminated by a strong east-west fault. An isolated carbonatite plug occurs close to this fault zone about three miles east of the axis of the main fold referred to above (see Figure 7). The western limb of the fold dips west at angles between 45 and 70 degrees, whereas the beds in the eastern limb are either vertical or overturned to the east. The valley floor between the limbs of the fold is flat and covered with a veneer of quartz and ironstone. Manganese deposits occur along the central section of the valley. In the past this may have been a swamp area infilled with ironstone and clay detritus from the surrounding hills. A feature of this region is the occurrence of manganese in fossil depressions and drainage channels of the older plateau surface. These deposits are now preserved as mesaform remnants and spur cappings at a slightly higher level than the present valley and river base levels.

FEATURES OF THE CARBONATITE INTRUSIONS

Five carbonatite bodies of generally similar constitution and form have been recognized. A sixth outcrop, consisting mainly of carbonated talcose rocks may also belong to the suite and represent an altered associated intrusion, possibly of original basic or ultrabasic character. The intrusions are numbered 1 to 6 on the accompanying geological sketch map and are described in that order.

No. 1

The northernmost carbonatite intrusion forms a substantial portion of an isolated hill situated about half a mile south of Mount Fraser Creek. The hill rises about 150 feet above plain level and measures about 500 yards long by 300 yards wide with the longer dimension in an east-west direction. The summit ridge and most of the southern slope is formed of carbonatite and the associated acid lava. The northern slope is mainly underlain by the country rock consisting of banded iron formation and shale.

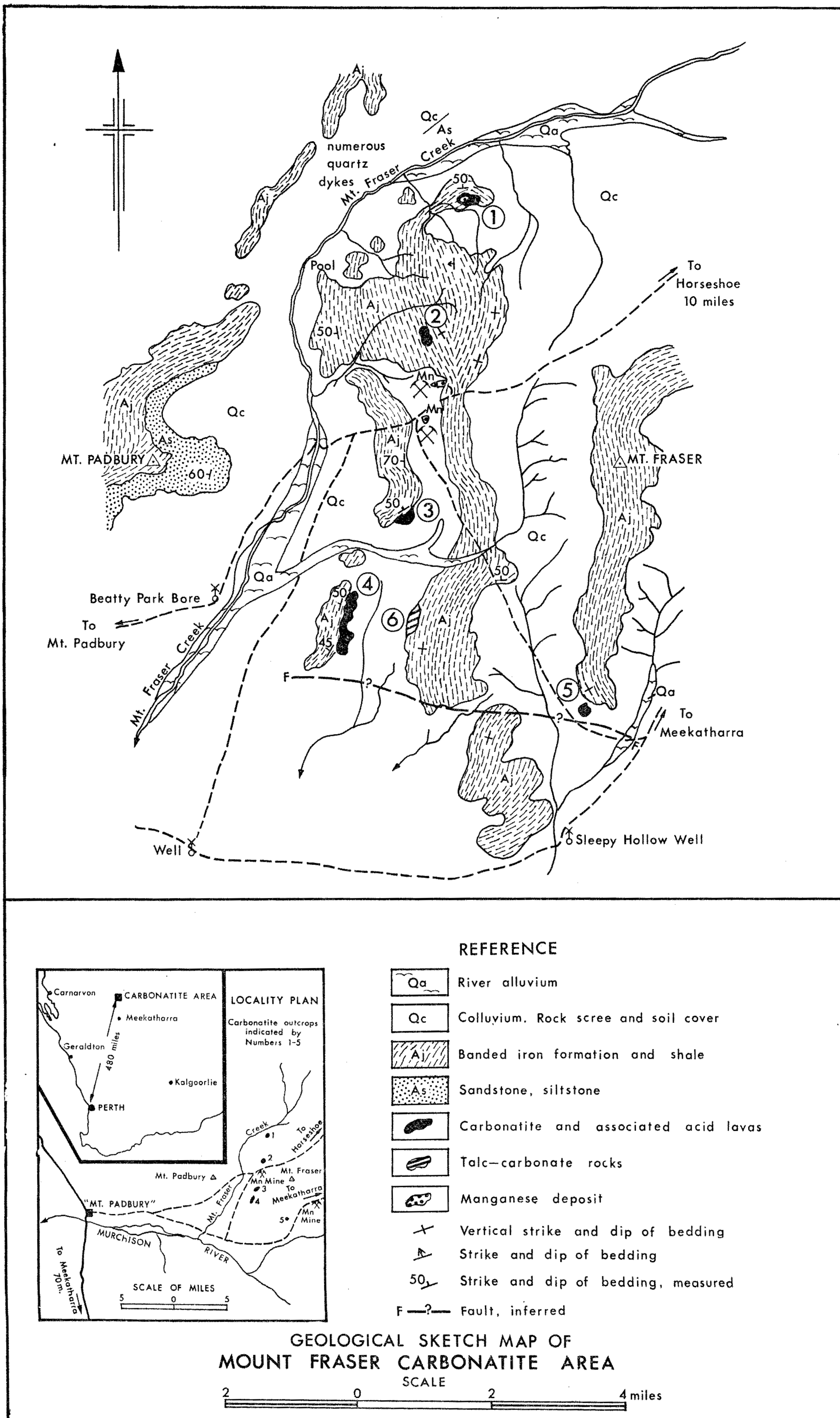
Aj
Qc
As
Qa
numerous
quartz
dykes
Mt. Fraser Creek
Qc
Pool
To
Horseshoe
10 miles
Mn
Mn
MT. PADBURY
MT. FRASER
Beatty Park Bore
To
Mt. Padbury
F
To
Meekatharra
Sleepy Hollow Well
Well
LOCALITY PLAN
Carbonatite outcrops indicated by Numbers 1-5
Carnarvon
CARBONATITE AREA
Meekatharra
Geraldton
480 miles
Kalgoorlie
PERTH
Mt. Padbury
"MT. PADBURY"
Mt. Fraser
Mn Mine
To Meekatharra
To Horseshoe
MURCHISON
RIVER
To Meekatharra 70m.
SCALE OF MILES
REFERENCE
Qa River alluvium
Qc Colluvium. Rock scree and soil cover
Aj Banded iron formation and shale
As Sandstone, siltstone
Carbonatite and associated acid lavas
Talc—carbonate rocks
Manganese deposit
Vertical strike and dip of bedding
Strike and dip of bedding
50 Strike and dip of bedding, measured
F —?— Fault, inferred
GEOLOGICAL SKETCH MAP OF
MOUNT FRASER CARBONATITE AREA
SCALE
2 0 2 4 miles

Fig. 7.

A large block of iron formation and shale, several hundreds of feet in diameter, occurs on the western slope of the hill and is completely surrounded by carbonate rock in the form of a miniature ring intrusion.

The contact between the carbonate and country rock, although sharp and well defined by the pronounced colour difference, is exceedingly complex in detail with minor tongues of carbonate surrounding and intricately veining blocks of shale.

The carbonate rock normally weathers dark brown to black and is in striking contrast to the pale brown acid lava and the reddish brown shale and banded iron formation. Almost everywhere the carbonate carries abundant included fragments of country rock and acid lava. Recognizable inclusions are shale, recrystallized rhyolite, serpentine, and quartz with a wide range in size and in both relative and total abundance. Many of the fragments are finely net-veined by carbonate and carry isolated rhombs of ankerite which weather to limonite-filled pits. Many fragments are green as a result of the development of chromiferous mica. Much of the rock appears as an intrusion breccia or agglomerate, with the content of fragments in places exceeding the volume of the carbonate base, grading through to zones composed predominantly of carbonate with occasional isolated fragments.

In No. 1, and in other occurrences, the sequence of activity appears to have been an early injection of acid lava with associated intrusions of massive quartz. The lava is flow-banded and locally auto-brecciated and in some places agglomeratic. The carbonatite has been the next major phase of injection, both veining and surrounding the acid lava, and introducing other fragmental material from deeper levels. Some sections of the carbonatite are rich in lenticles of finely crystalline serpentine. The final phase of activity is the intrusion of narrow veins of white quartz cutting both the carbonate base of the breccia and the fragments, and characterized by plates and needles of specular hematite.

The acid volcanic and quartzite fragments in the breccia have a pronounced parallel alignment in a near-vertical sense suggesting vertical flow of the magma at this level. The acid lava, where undisturbed or unbrecciated has a similar steeply oriented flow-banding.

No. 2

This intrusion is situated about half a mile north of the manganese mine road and appears as a low double conical hill rising from a valley and surrounded by higher ridges of banded iron formation. The southern cone is mainly composed of flow-banded acid lava and the northern hill consists mainly of massive quartzite. No carbonate rock was detectable in the hills but restricted outcrops occur on the valley floor immediately south of the hill through the scree cover. No accurate estimation can be made of the total extent.

No. 3

This intrusion appears as a sill-like body cropping out along the southeastern face of a prominent ridge composed of banded iron formation and shale. The enclosing sediments dip west at about 50 degrees and this relatively low dip is probably a factor in the protection of the underlying carbonate rock from erosion.

It is almost entirely composed of carbonate rock and massive quartz and the acid lava associate is either absent or unexposed. It seems likely that there are sills of carbonate in this locality separated by an interval of up to 50 feet of country rock. In the upper section the carbonate contains a higher content of fragments and much of the rock has an abundance of emerald-green chromiferous mica. A large dyke of quartzite occurs at the base of the hill and seems to be partly surrounded by carbonate. The heavy blanket of quartz scree near this dyke limits exposure of the carbonate at the base of the hill.

No. 4

The largest area of continuous exposure of the carbonate rock is found in this intrusion, which forms an elongate feature about a mile long extending along the base of the line of hills forming the western wall of the valley.

The upper contact of the carbonate body and the overlying sediments is almost continuously exposed on the spurs along the base of the hills. This contact is marked by the appearance and persistence of a narrow zone of altered acid lava pervaded by veinlets and rhombs of ankerite. The carbonate rock lower down the hill slope shows the characteristic wide ranges in texture, colour and content of fragments. Near the southern end of the body there is a spectacular intrusion breccia in which the content of included fragments commonly exceeds the volume of the carbonate base.

Like No. 3, the eastern boundary of No. 4 is largely obscured by the scree cover in the valley floor. The carbonate rock, although apparently tough and durable, is the least resistant to erosion of its associates. Exposure seems dependent on the favourable juxtaposition of more resistent associated rocks such as acid lava and quartzite or, as in the case of Nos. 3 and 4, by the protection afforded by a ridge of resistant iron formation dipping at a relatively low angle. The possibility must be borne in mind that these carbonate bodies could extend for a considerable distance below the valley floor and even represent the peropheral parts of larger or even continuous intrusive complexes.

On the opposite side of the valley there is an exposure of highly carbonated talcose rocks (No. 6) which may be derived from the weathering of an ultrabasic body, conceivably comagmatic with the carbonatite.

No. 5

This is a small isolated body almost circular in outline and about 300 yards across, situated below the southern end of the long high ridge running south from Mount Fraser. The north-western corner is occupied by fresh acid lava so highly siliceous that it resembles a quartzite and with near vertical flow-banding. This is surrounded on three sides by a cuspate carbonate zone, rich in fragments of acid lava and country rock. Blocks of acid lava up to several feet in diameter are surrounded and net-veined by carbonate. Many of the outcrops show near-vertical orientation of the long axes of included fragments.

CHEMISTRY AND PETROGRAPHY OF THE CARBONATE ROCKS

In all exposures the carbonate rock is contaminated with fragments of the associated rock suite and xenoliths of the country rock. Outcrops differ radically in appearance and, as seen in thin-section, in mineralogy, texture and degree of alteration.

A full petrographic appraisal of these rocks could be the subject of a specialized study, although for this to be meaningful it would be essential to obtain fresh rock by drilling. The surface material is obviously badly weathered, and in rocks characterized by major hydrothermal and deuteric changes only the freshest material would be of value for a true appreciation of the essential petrographic features of the suite.

In general the carbonate rocks are coarse-grained, and many show evidence of successive generation of carbonate minerals. All sections examined have a high quartz content, an abundance of iron oxides and some include a significant content of green chromiferous mica. Much of the carbonate is ankeritic but later veins and even larger intrusive masses of clear calcite are common.

Chemical analysis of an apparently ' clean ' carbonate rock specimen from intrusion No. 4 yielded 11·8 per cent calcium, 6·0 per cent magnesium and 4·6 per cent iron. On the assumption that these elements are entirely contained in carbonate minerals the mineralogical ratios can be recalculated to the following :

	per cent
$CaCO_3$	29·5
$MgCO_3$	21·1
$FeCO_3$	9·0
Total	59·6

The balance of the rock is made up of quartz, chrome mica and partly carbonated fragments of country rock.

Trace element determinations on a group of representative specimens from intrusion No. 4 yielded the values shown in the table below.

	23061	23062	23063	23064	23065	23066
Minor elements						
	parts per million					
Copper	75	80	120	170	140	45
Lead	95	110	70	80	95	95
Zinc	20	65	155	60	15	5
Nickel	725	330	120	90	1070	40
Cobalt	95	80	60	60	170	20
Chromium	700	325	35	35	700	785
Strontium	65	65	55	65	90	150
Major elements						
	per cent					
Calcium	11·8	3·6	2·0	1·9	10·9	1·8
Magnesium	6·0	2·0	1·2	0·86	6·1	0·30
Phosphorus	0·02	0·03	0·05	0·06	0·01	0·04
Iron	4·6	7·4	12·4	8·2	9·0	0·7

Analyses by Government Chemical Laboratories.

Specimens 23061 and 23065 are rocks composed predominantly of carbonate minerals. The remainder are fragmental and altered rocks within the carbonate zone. There is a strikingly wide variation in trace element content but some of the values of copper, lead, zinc, nickel, chromium and cobalt must be considered as anomalously high in relation to the sedimentary environment into which these carbonate rocks are intruded. The strontium values range between 6 and 15 times the value of strontium found normally in sedimentary carbonate rocks.

The trace element content of a striking green carbonate rock from intrusion No. 1 is as follows :

Specimen 23087

	parts per million
Copper	470
Cobalt	70
Nickel	560
Chromium	840
Manganese	6,900

This rock is mainly composed of calcite and green chromiferous mica with scattered manganese oxides and a little quartz. It is characterized by numerous inclusions of translucent green serpentine occurring as oriented lenticles generally less than an inch long.

CONCLUSIONS AND RECOMMENDATIONS

The balance of evidence available suggests that these rocks are intrusive carbonatites characteristically associated with acid volcanics. The possibility must be considered that the surface manifestations outlined above represent portions of a much more extensive, deeper seated intrusive complex with possible ultrabasic affinity as is suggested by the geochemistry.

The base metals contents are sufficiently high to justify the investigation of the economic potential of these rocks. Detailed geochemistry with correlated petrography over the exposed and adjacent zones of the carbonate rocks is required as a preliminary step combined with large-scale mapping (100 feet to the inch). Sampling by percussion drilling to depths of the order of 200 feet would appear to be essential as there is every likelihood that only a minor proportion of the carbonate rocks are exposed.

THE GEOLOGY AND GEOCHEMISTRY OF A CUPRIFEROUS AREA AT TWIN PEAKS, YALGOO GOLDFIELD, WESTERN AUSTRALIA

by J. Sofoulis and X. K. Williams

ABSTRACT

Archaean rocks of the Twin Peaks area are acid to intermediate volcanics which are intruded by ultramafic and dolerite dykes. Discrete granite bodies also intrude the sequence, mainly in tension fractures or openings caused by sinistral dragfolding. The granite bodies are arranged *en echelon* within the dragfolded zone, and have caused remobilization of copper which was originally dispersed within the volcanics, principally the pyroclastics. The more significant copper occurrences are localized at contacts between the granite and coarse pyroclastics. Minor copper occurrences are also associated with an aplite-dolerite dyke complex. The geochemical work revealed anomalous copper values over the zone of dragfolding. The two highest-order anomalies within the zone are adjacent to the Twin Peaks main shaft and they indicate the possible existence of two nearly parallel ore bodies about 300 feet apart, extending over some 800 feet of strike length. Diamond drilling is proposed to test these anomalies.

INTRODUCTION

The cupriferous area of Twin Peaks is contained within the six square miles of Ministerial Reserve 5152H, immediately adjoining Twin Peaks homestead in the Yalgoo Goldfield. Existing Prospecting Areas 2715 and 2716 within this Reserve, enclose some of the more significant copper workings. Although known since 1906 the copper occurrences of this area were worked only for brief periods and the production as reported to the Mines Department has been less than 100 tons of copper ore.

More recently the area was held by Kennecott Explorations (Australia) Pty. Ltd. as Temporary Reserve No. 3709 (relinquished in 1967).

The present study was made in May to July, 1969.

Location and access

Twin Peaks homestead is close to the junction o the Murchison and Sanford Rivers, 103 miles north of Mullewa. The road section between Mullewa and Twin Peaks is unsealed.

The station has a graded airstrip and is connected by party telephone lines to Mullewa and Yalgoo Post Offices.

The copper workings are 1½ to 2 miles northeast of the homestead and are accessible by rough bush track.

The locality is within the area of the Murgoo 1 : 250,000 Sheet, the regional geology of which is currently being compiled by the Geological Survey.

Topography, Soil, Vegetation and Climate

The Twin Peaks locality (aboriginal name Illimbirrie) is 1,100 to 1,400 feet above sea level, and comprises a number of small, moderately steep-sided valleys draining two prominent north-easterly ridges which appear as twin peaks when viewed from the southwest. The area mapped in detail covers approximately 2½ square miles and has a maximum relief of 300 feet with local relief seldom greater than 150 feet. Hill slopes are commonly rock strewn, and valleys are thinly covered by residual soil or alluvium.

The residual soil is an eroded, truncated, red earth, and shows little horizon development. In nearly all localities studied the A horizon is absent. Soil depth rarely exceeds 2 feet, and normally ranges between 6 and 12 inches. The soil is hard but porous when dry, friable when damp, and exhibits the characteristic earth fabric. The pH varies between 6·0 and 8·2, with an average of 7·3, the only exception being in one soil sample (taken from near the main shaft) where a minimum of 3·9 was recorded.

The vegetation is mainly shrub woodland and shrub steppe of *Acacia aneura* and *Eremophila fraseri*, with occasional *Eucalyptus propinque* near the major drainage channels, and a ground flora of sparse ephemerals.

The rainfall is 5 to 10 inches a year, most of which falls between March and August, and the temperature ranges from a winter low of 35°F to a summer high of 115°F.

GEOLOGY

The Archaean rocks of the area include a thick sequence of acid and basic volcanics which have been extensively intruded by ultramafics and dolerite, as well as by younger granite and minor acid dykes. The acid igneous intrusions are probably related to a large granitic mass which flanks and intrudes the preserved Archaean sequence on the southeastern side.

A younger suite of quartz dolerite dykes of east-northeast trend which cuts the Archaean rocks, is assigned to the Proterozoic.

The stratigraphy of the area is summarized in the map legend (Plate 11). The distribution of rock units is based on observations on grid line traverses on 200 feet spacing and on photoscale mapping at 1,000 feet to an inch.

Petrographic descriptions of representative samples of the various rock types appear in a report by J. D. Lewis (1970), which is also included as an Appendix in Sofoulis and Williams (1970).

ARCHAEAN

Volcanic rocks

Low-grade metamorphic rocks derived from acid lavas and tuffs are dominant in the lower part of the Archaean sequence. These include thinly and thickly banded rhyolites and dacites, banded chloritic schists, phyllites, and other rocks which are believed to be tuffs or their metamorphosed equivalents. A prominent band of fragmental rock, considered to be of pyroclastic origin, is associated with the metavolcanics. It contains angular lava and tuffaceous blocks up to 12 inches across with a lava or tuffaceous matric and commonly impregnated or veined with epidote. Other minor pyroclaseic lenses and thin clastic beds (including a prominent bed of sandstone) are also found intercalated within the volcanic sequence.

There is a thick pile of more basic metavolcanic rocks in the upper part of the sequence, and minor basic flows are locally interbedded with the acid lavas in the lower part of the sequence. Most of the metavolcanics in the upper part are fine grained, dark grey-greenish rocks commonly with elongated amygdales filled with quartz or epidote. The amygdales range from pinhead size up to one inch along their long axes.

Some minor facies variations noted in the northern part of the area include thin tuffaceous and clastic beds as well as a discontinuous hematite bed (up to 10 feet thick). This hematite bed is interpreted as an enrichment related to a banded iron formation, similar to the hematite enrichments and cappings above banded iron-rich cherts near the eastern side of the Mount Hope Hills some 10 miles north of the Twin Peaks area.

All of the volcanic and associated rocks have been affected by low-grade regional metamorphism (greenschist facies). From the absence of any defined pillow structures, it would appear that most of this sequence consists of subaerial extrusives. The presence of minor clastic beds indicates that these lavas were subject to local reworking.

Intrusive rocks

Ultramafics. Sills of metamorphosed ultramafic rocks, some of which are of considerable extent and thickness, intrude the volcanic sequence and are particularly prominent in the eastern sector. Most of these rocks are now represented by greenish-grey medium to coarse-grained tremolite-chlorite schists, sometimes with a little clino-zoisite and residual plagioclase.

Small lenses or plugs of crystalline carbonate material noted in the central part of the area might be related to these meta-ultramafic rocks. They are fine-grained, reddish-grey crystalline limestone containing a little chlorite and some talc, and their discordant relationships suggest a possible magmatic origin. However the absence of apatite and magnetite, as well as the generally low barium (80 ppm) and strontium (50 ppm) content of the carbonate rock does not support this idea.

Dolerite. Concordant and discordant bodies of dolerite intrude the metavolcanic sequence and truncate the ultramafics. They form prominent sills in the southern part of the area within the acid rocks of the lower part of the succession, and also within the more basic lavas in the eastern part of the area ; the dolerite sills have chilled margins which are commonly sheared. They are green and black rock of fine to medium grain-size, and consist of plagioclase, hornblende, sphene and augite set in a fine grained quartzofeldspathic matrix. In some specimens, pyroxene (augite) is replaced by blue-green hornblende. Feldspar phenocrysts are generally highly altered and epidotized and the rocks are best described as metadolerite, as they have all been affected by low-grade regional metamorphism. Some dykes, including porphyritic varieties, are also prominent. They trend north-northeast and were probably injected along pre-existing faults. In some instances the same faults have also been intruded by younger acid dykes which have invaded the dolerite and have produced an aplite-dolerite complex and hybrid quartz dolerite rocks. Some of these hybridised metadolerite dykes are locally copper-bearing, the most mineralized dyke being that referred to by Maitland (1919) as the ' Ringing Bell ' copper lode.

Granite and associated acid dykes. Small concordant granite intrusions with a northeasterly elongation occur within the volcanic sequence, and are arranged en echelon along northwesterly lines. They consist mainly of leucocratic, porphyritic and even-grained quartz-feldspar-chlorite rocks ranging in composition from granite to granodiorite depending on the amount of country rock assimilated. Xenoliths are common and the rock is well foliated. Porphyritic and aphanitic aplite dykes and allied acid intrusions extend outwards from the granite and transect the adjoining volcanics and dykes. Some of the narrow tongues penetrating the volcanic country rock become strongly foliated or pass into fine grained dykes of quartz porphyry. The larger dykes trend northerly. Numerous quartz veinlets also penetrate the country rocks along bedding or foliation planes or occupy tension cracks at angles to these. Some larger quartz reefs in the northeastern part of the area shed extensive quartz debris.

The granite and associated acid derivatives are probably related to, and contemporaneous with, a more extensive granite batholith which intrudes the volcanic sequence and occupies a broad area to the southeast of Twin Peaks. The border facies of this granite is finely banded, strongly foliated, and partly migmatitic. It contains numerous bands and remnants of country rock with lit-par-lit injections of granite. For the most part, it is a pale grey banded rock with a fine-grained mosaic of quartz, albite, microcline and well-formed green hornblende, together with a little sphene. Epidote is common as a secondary mineral.

PROTEROZOIC

Quartz dolerite dykes, trend east-northeast across the volcanic sequence and the granitic rocks. The three large dykes within the area are seldom more than 100 feet thick and have steep or vertical dips. They crop out as alignments of rounded blue-black boulders of 1 to 4 feet diameter, or as partly weathered pavements in valleys. These dykes are correlated with Proterozoic dykes of similar trend which cut the Archaean basement of the South West Division and the Eastern Goldfields.

Structure

The metavolcanics are in a structurally complex zone in which the folding is along northeast axes. Flow-banding and schistosity dip moderately to steeply northwesterly. Although no facing criteria were observed, it is assumed that the sequence is not overturned since the schistosity planes are steeper than bedding or banding planes.

Drag folds in the main zone of pyroclastics indicate the north limb of an anticline plunging 50 degrees to 60 degrees southwesterly, with the relative movement of beds being north side to the southwest and south side to the northeast.

The en echelon arrangement of the discrete granite bodies along the zone of drag folding normal to the main fold axes, suggests that they are occupying tension fractures and openings caused by sinistral dragfolding. Faulting of these rocks has resulted in the development of transcurrent faults of northerly trend. As in the eastern part of the area, these movements have been dextral (i.e. east block south) with lateral displacement ranging from a few feet to more than 100 feet. Dolerite and aplite dykes of this trend dip steeply east.

Other minor faults are probably related to the same tectonic movements. These may be marked by thin aplites, quartz dykes and alignments of quartz reefs which trend northwesterly or else appear as conformable intrusions of northeast trend, possibly controlled by banding or strike faulting.

COPPER MINERALIZATION

The copper workings at Twin Peaks were described briefly by Maitland (1919), Johnson (1950), and Low (1963). The deepest of the workings, and probably the main source of the copper produced from this area, is the Twin Peaks main shaft, at grid reference 8000N, 8000E (see Plate 11). This shaft is reputed to be some 100 feet deep, with a short drive southwesterly at the bottom. The copper mineralization as seen in an underlay near the main shaft is in a narrow silicified zone (up to three feet wide) forming a contact between coarse pyroclastics and a tongue of porphyritic granite which terminates close to the main shaft. This silicified zone dips steeply northwest and can be traced for a further 60 feet northeasterly from the main shaft where it then occupies the contact between dolerite and pyroclastics. Southwestwards the contact between pyroclastics and porphyritic granite has a little copper staining in poorly developed discontinuous gossanous rocks, as exposed in shallow pits over some 400 feet.

This contact zone corresponds to the high order copper anomaly detected by the geochemical work (see Plate 12). Lineations, as indicated by mineral alignments in the adjacent volcanics, plunge 50 to 60 degrees southwesterly (similar to the main drag fold), so it is anticipated that ore shoots within this anomalous zone plunge in a similar fashion.

Minor copper occurrences in shallow shafts and small pits 1,000 feet west of the main shaft are within an anomalous zone along strike from the main shaft anomaly. These holes have been sunk on poor showings of carbonate ore in spongy iron gossan associated with xenolithic blocks within the porphyritic granodiorite.

Some unprospected showings of copper carbonates were noted on the southern side of the main shaft ridge at discontinuities within the pyroclastics and at their contact with porphyritic granite. These showings correspond to a further high-order geochemical anomaly which is south of and nearly parallel to the ' main shafts ' anomaly (see Plate 12).

Copper mineralization associated with a north-trending aplite-dolerite dyke complex half a mile north of the Twin Peaks main shaft, was referred to by Maitland (1919) as the ' Ringing Bell ' copper lode. The line of lode dips steeply east and has been tested by two shafts 20 and 35 feet deep and by a series of shallow diggings and pits. There are further small copper showings in limonitic gossans adjacent to the northern extension of this dyke complex, but the absence of any significant geochemical anomaly indicates that this line of mineralization is not of economic importance. For the same reason little significance is attached to the other minor copper occurrences in the area (e.g. copper in quartz at 9,200N, 10,150E, and in dolerite at 6,550N, 6,700E), nor to any of the small isolated highs which were detected by the geochemical work (e.g. at 7,600N, 9,000E).

In all cases, the copper occurrences of the Twin Peaks area are associated with a siliceous, ferruginized, or gossanous zone ranging from a few inches to three feet thick. The copper is in the form of blue-green carbonate (malachite) and some blue chrysocolla. Chalcopyrite was noted in the old ore bin near the main shaft and it is probable that this mineral would be the principal sulphide available below the zone of oxidation.

The distribution and mode of occurrence of the copper suggests that it was initially dispersed within the volcanics, and that the intrusions of granite *en echelon* within the zone of drag folding were largely responsible for the redistribution and concentration of copper along favourable channels.

GEOCHEMISTRY

A geochemical survey of the area was conducted to determine the possible extent of the known mineralization by the trace element content of the soil, particularly the copper content.

ORIENTATION TRAVERSE

Method

An initial traverse of 5,500 feet was sampled. This extended 2,000 feet southeast, and 3,500 feet northwest of the main shaft, normal to the main strike of the country rock. Samples were collected from holes dug 50 feet apart along the traverse. Where possible, two samples were taken from each hole, one from the B horizon and one from the regolith ; at a few localities it was also possible to collect a top soil sample, but often the holes were so shallow that only one sample was obtained.

After collection, the soil samples were dried and sieved through a —200 micron plastic sieve. A 200-mg aliquot of the fine fraction was heated to 180°C in 60 per cent perchloric acid, and held at that temperature for one hour. The cooled solution was then diluted to 10 ml and analysed by atomic absorption spectroscopy.

These samples were analysed for copper, lead, zinc, nickel and cobalt, and the pH was determined. The results are plotted in Plates 12 to 14. Where only one sample was obtained from a locality it was plotted in both the B and C horizon graphs. Thus the graphs represent the results that would have been obtained if either the B or C horizon only had been collected, however it does mean that the two graphs for each element are not entirely independent.

Results

Copper. A threshold value of 350 ppm was established (Plate 13) and 15 per cent of the results are considered anomalous. Twenty-two of the 30 anomalous samples were between 7,400N and 8,150N. This area includes the main shaft (locality 8,000N) and workings on the northwest flank of a ridge trending northeasterly. The crest of the ridge is at locality 7,850N. Localities 7,850N and 7,900N are uphill from the shaft and spoil heaps, and there is no evidence of surface contamination ; nor is there much likelihood of the anomaly on the southeastern side of the ridge (localities 7,400N to 7,850N) being due to surficial contamination. This is further substantiated by the fact that most sample localities show an increase of copper content with depth. There are obvious indications of surface contamination at localities 8,000N to 8,100N and that area of the anomaly is undoubtedly due to the presence of cupriferous rubble from the workings.

Thus there is a real anomaly extending for 600 feet, from locality 7,400N to 8,000N. There is also a contamination anomaly from 8,000N to 8,150N, but soil sampling will not indicate whether or not this section of the anomaly was present before the surface was disturbed.

With the exception of localities 7,400N to 7,500N, in which the anomalies are of moderate intensity, all of the area with copper values ranging from 200 to 7,750 ppm falls within the granite and pyroclastics.

The other anomalies on the traverse occurred at localities 6,550N, 8,300N, 9,850N and 10,900N ; in granite, dolerite, ultramafics and amygdaloidal lava respectively. They were of relatively low intensity, each covered only one locality and they are not considered significant.

Lead. The lead results are all low, ranging from 4 to 24 ppm. A threshold value of 15 ppm was used, resulting in only one low intensity anomaly with values of 16 to 24 ppm. It is near the shaft, extending from localities 7,900N to 8,000N, and is undoubtedly due to the presence of some lead associated with the copper mineralization. There is no anomaly downslope from the shaft, in spite of the drop in soil pH from a mean of 7·3 to 3·9 at locality 8,050N. Lead has a low mobility, largely due to the low solubility of its sulphate and carbonates, and therefore normally forms intense, localized, anomalies. Since the highest concentration is only 24 ppm there is relatively little lead associated with the copper mineralization and less in the country rock. For this reason it was decided that lead would be a poor guide in detecting mineralization, and no lead analyses were made on the samples collected in the main survey.

The assay results from the shallower samples showed a similar variation to those from the regolith samples shown in Plate 14.

Zinc. Background zinc results range from 10 to 100 ppm with no discernible trends along the traverse (Plate 13). There is one anomaly which extends from localities 7,800N to 8,100N, covers the mine area, and appears to be related to the copper mineralization. However the zinc anomaly area is less than the area of the copper anomaly; the other copper anomalies, even that at localities 7,400N to 7,500N, are not accompanied by zinc anomalies ; and there are a number of rubbish heaps around the shaft and elsewhere in the main grid area which could give rise to contamination anomalies. For these reasons it was decided not to use zinc analyses as a general guide to the presence of copper mineralization. During the main survey many of the samples with anomalous copper concentrations were analysed for zinc, but no values greater than 100 ppm were found. This indicated that the zinc anomaly associated with the shaft may have been a contamination anomaly, and therefore not indicative of zinc mineralization associated with the cupriferous ore.

Nickel and cobalt. A threshold concentration of 250 ppm of nickel was adopted, which gave six anomalies, comprising a total of 22 samples from six locations (Plate 14). These were at localities 6,700N to 6,800N, 8,000N, 8,250N, 8,850N to 8,900N, 8,200N to 8,260N, and 9,000N to 9,050N. The results from locality 8,000N suggested the presence of traces of nickel associated with the copper. Of the other anomalies, all but that at 8,250N were over ultramafic rocks which normally have relatively high concentrations of nickel.

The cobalt results were all low, in the range 10 to 60 ppm and as with the nickel values, there was a relatively high value from the shaft sample at 8,000N. There were no clearly defined anomalies although there was a slight tendency for the higher-than-average values to be associated with ultramafics. Only the regolith results are shown in Plate 14 but the results from the shallower samples were similar.

As nickel and cobalt were associated with the ultramafics rather than with the copper, they were not determined in the main survey.

Soil acidity. Pure neutral water has a pH of 7·0. However natural ground and soil water is a dilute solution of carbonic acid, which has a pH of about 5·7, in the absence of other sources of H^+ and OH^- ions. The presence of clays and humic acids, plus other inorganic salts such as sulphates, may reduce this to four or even less. Soils vary in pH from 4 to 8, but are normally in the range 5 to 6. Thus it can be seen that the soils of this area, with a pH variation between 6 and 8, are relatively alkaline (Plate 14). The locality with the lowest pH is 8,050N where the presence of sulphides, and hence sulphates, has reduced the pH to 3·9. The majority of trace elements in the soil are in the form of acid-soluble cations, and are precipitated as hydroxides and basic salts as the pH rises. Copper, for instance, is readily soluble at a pH of less than 5·5 ; zinc at less than 7·0.

Because of the high pH in this area there has been relatively little dispersion and therefore the anomalies formed, especially by the copper mineralization, are intense and clearly defined. There is also good reason for expecting to locate the sub-outcrop of the anomaly sources close to the centres of the anomalies themselves.

MAIN SURVEY

Method

After a consideration of the average width of the different rock units, normal to the most common strike direction, a sample interval of 50 feet was chosen for the main survey. Most of the units are wider than 50 feet and this spacing means that they are all sampled at least once each time they occur along a traverse. A sample pattern of lines, parallel to the orientation traverse and 200 feet apart, was selected, to give a line-spacing to hole-spacing ratio of 4 : 1, and to allow the formation of convenient grid units of 1,000-foot squares. The grid squares were planned originally to cover geologically favourable areas, and were extended as the anomaly pattern emerged until a complete anomaly picture was obtained. Where warranted, 100-foot spaced lines were also sampled. The samples were collected from maximum depth since the orientation traverse had shown that these would give the greatest anomaly to background contrast. All samples were analysed for copper, and those with high concentrations were also analysed for zinc.

Results

The area sampled covers nearly one square mile and approximately 2,800 samples were taken along 25·5 line miles. The results are indicated in Plate 12. They fall into five distinct populations, A, B, C, D, and E, in increasing copper content (see Table 1). These are indicated by different hatchings within the contoured boundaries in Plate 12.

The samples considered anomalous contain more than 675 ppm copper and constitute 6·2 per cent of the results. They are surrounded by an area of threshold samples with 300 to 675 ppm copper (population B). Nearly 70 per cent of the samples have 0 to 300 ppm and this is considered to be the background concentration range (population A).

The anomalous samples were subsequently divided, on a statistical basis (see Williams, 1967) into populations C, D, and E.

The overall trend of the anomalies is northeasterly, approximately parallel to the foliation and banding observed in the volcanics and sills.

The most extensive anomalous area includes the main Twin Peaks shaft and associated workings. It contains three main areas of D and E intensity anomalies, and several D intensity anomalies. The two major anomalies are nearly parallel and extend over approximately 800 feet ; they are 50 to 100 feet wide, and 300 feet apart. These are divided by a ridge, the results from which are of C intensity only. However the copper mineralization may be continuous beneath the ridge, and the lower results on the ridge may have been caused by the removal of copper by leaching and drainage.

There are several other anomalies, all within the main southern area, and these coincide with areas of granite outcrop which are arranged en echelon northwesterly and correspond to the zone of the major drag fold which has affected the layered rocks. The shaft anomaly is confined to the contact between the small granitic emplacements and the area of coarse pyroclastic distribution. The anomaly south of the shaft anomaly corresponds to similar contacts and discontinuities within the coarse pyroclastic beds. The anomalies within the granite are probably due to cupriferous xenoliths.

(3)—68565

TABLE 1. DISTRIBUTION OF THE COPPER CONCENTRATIONS

ppm Range	Population	No. of samples	Percentage of samples
0–290	A	2,044	77·8
300–675	B	420	16·0
680–990	C	87	3·3
1,000–1,960	D	58	2·2
More than 1,980	E	18	0·7
Totals	....	2,627	100·0

RECOMMENDATIONS

The two high-order anomalies near the main shaft warrant testing since they indicate the possible existence of near parallel ore bodies 300 feet apart, each extending over some 800 feet in strike length.

A third high-order anomaly, localized near, and possibly representing the southwest extension of, the ‘ shaft ’ anomaly, could be a further target for prospecting.

Three diamond drill holes are therefore recommended. Two are designed to intersect the depth extensions of the sub-parallel anomalies below the zone of oxidation as well as testing the zone of lower order anomaly which separates them. The third hole is similarly sited to test the depth extension of the anomaly forming the southwest strike extension of the main shaft anomaly.

The three proposed diamond drill holes would involve a total footage of approximately 2,000 feet. These are located at the following sites :

Site 1 : At grid reference 8,320N, 7,910E ; hole to have azimuth 135 degrees, depression 45 degrees and length 700 to 800 feet.

Site 2 : At grid reference 8,250N, 7,510E ; hole to have azimuth 111 degrees, depression 45 degrees and length 700 to 800 feet.

Site 3 : At grid reference 8,320N, 7,030E ; hole to have azimuth 135 degrees, depression 45 degrees and length approximately 500 feet.

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PRELIMINARY REPORT ON TIN GRANITE IN THE PILBARA GOLDFIELD

by J. G. Blockley

ABSTRACT

In the Pilbara Goldfield, Western Australia, a distinct type of granite (‘ tin granite ’) has been recognized in eight intrusions. Pegmatite dykes associated with this granite have been the source of all the eluvial and alluvial tin produced in this area.

The tin granite is a late intrusive in the Pilbara granite complex and is seldom foliated. It is biotite adamellite in composition and forms tors and smooth exfoliation domes which rise above the flatter, mostly soil-covered areas of gneiss. In many outcrops the surface of the tin granite has a ‘ honeycomb ’ appearance.

There are three modes of occurrence of pegmatite : (a) intruding amphibolite and metasediments, (b) cutting granite gneiss and mignatite, and (c) within magmatic granite.

Tin mining in the Pilbara reached a peak of 1,238 tons in 1967 but has since declined ; recognition of the tin granite type should aid exploration for tin in this area particularly in the poorly drained parts.

INTRODUCTION

During an investigation of the tin deposits in the Pilbara Goldfield and the adjacent part of the West Pilbara Goldfield for a Mineral Resources Bulletin on Tin in Western Australia, an attempt was made to recognize and define the granite type responsible for the primary tin mineralization. Figure 8 shows the eight intrusions of ‘ tin granite ’ which have so far been identified. The information is published here to assist the prospectors and companies currently searching for new tin deposits in the region. Further work on the petrology and chemistry of the tin granites is to be carried out during 1970 in the hope that it will lead to the detection of similar granites in other parts of the State.

MINING

The first tin discovery in the Pilbara Goldfield was at Moolyella in 1898 ; later discoveries were at Eley's in 1899, Cooglegong in 1900, and Wodgina in 1902. Subsequent mining yielded 12,854 tons of tin concentrate, of which 6,100 tons came from Moolyella, 5,860 tons from the Eley's—Cooglegong field and 470 tons from Wodgina. The remainder was from small deposits at Abydos, Strelley, Tabba Tabba, Pilgangoora, Coodina and Bonnie Downs.

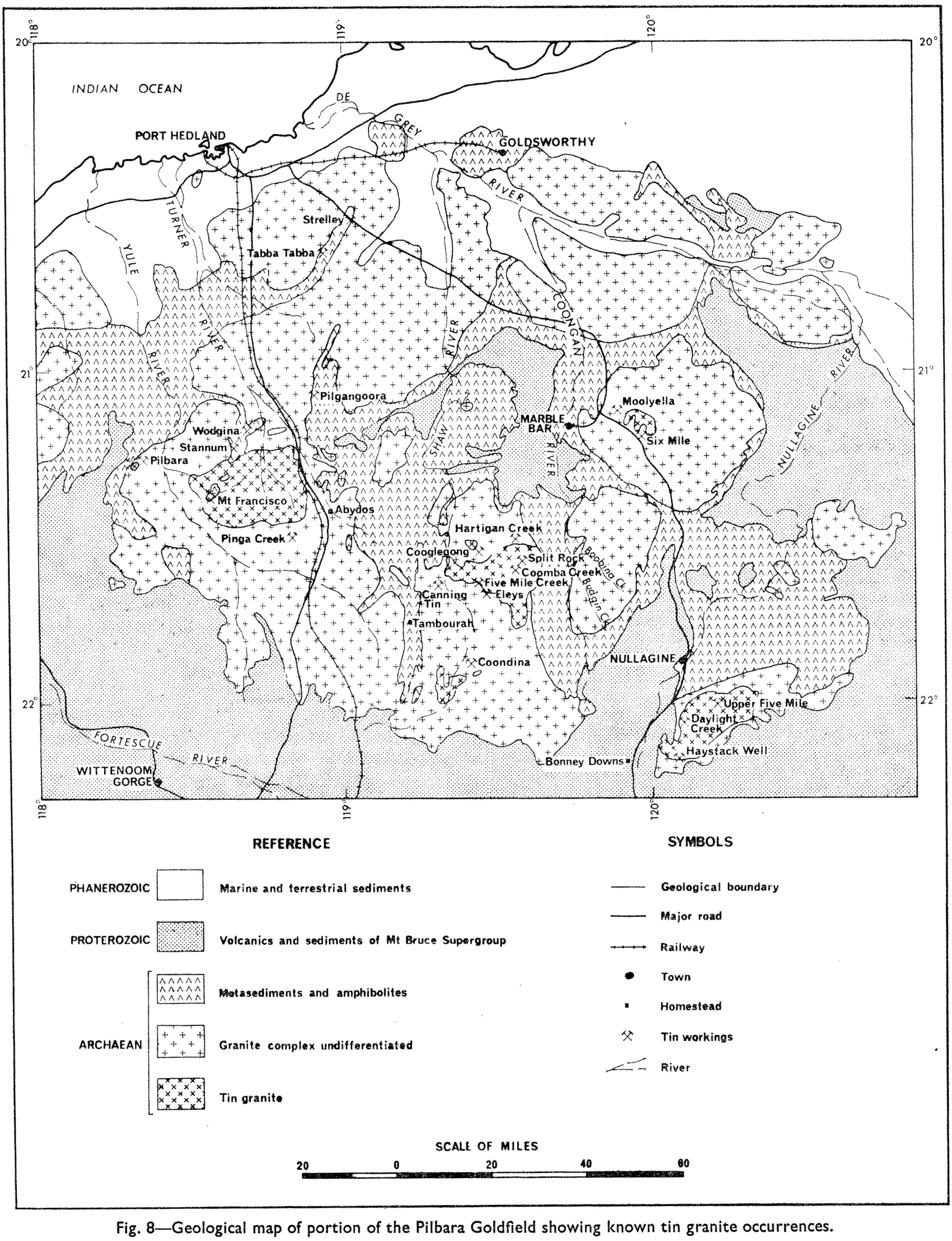

Fig. 8—Geological map of portion of the Pilbara Goldfield showing known tin granite occurrences.

After the initial period of tin mining, which lasted from about 1899 to 1914, and during which only the highest grade deposits were worked, interest in the Pilbara fields lapsed until rising tin prices brought about renewed activity in the area in 1955. Production reached a peak in 1967, when 1,238 tons of tin concentrate were mined, but has since fallen off appreciably, due to the exhaustion of payable ground.

TIN-BEARING PEGMATITES

Most of the tin mined in the Pilbara Goldfield was recovered from secondary alluvial and eluvial deposits formed close to the source areas of primary cassiterite. Apart from 350 tons of tin concentrate produced from the Mount Cassiterite mine at Wodgina, the yield from primary deposits is small when compared to that from secondary accumulations. The source of all of the tin mined has been pegmatite dykes. Earlier reports of primary tin in granites or greisens could not be substantiated during the present investigation. Frequent references to tin 'lodes' in the literature all refer to pegmatites, or to a closely related tourmaline-mica rock ; true tin lodes, of the type worked in Cornwall, New England and Tasmania, in which the tin is associated with sulphide minerals, have not been found in the Pilbara Goldfield.

There are three types of tin-bearing pegmatites in the region : (a) pegmatites intruding amphibolite and meta-sediments ; (b) pegmatites cutting granite gneiss and migmatite ; and (c) pegmatites within magmatic granite.

Type (a)

Pegmatites of type (a) are usually found at some distance from any possible source granite. Most are large, and some exceed a mile in length. Many are zoned, with a central core of blue-grey quartz surrounded by shells of pegmatitic material of varying composition. The outer shell is often found to be albite, and albite is also the most common feldspar throughout the pegmatite, although a small amount of microcline may also be present. In pegmatites of this type, tin, as cassiterite, is associated with other economic minerals such as beryl, lepidolite, zinnwaldite, spodumene, tantalite, and certain radioactive minerals. The tin production of Pilgangoora, Strelley, Tabba Tabba, and parts of the Wodgina field, has been from pegmatites of this type.

Type (b)

Pegmatites of type (b) occur in swarms close to their parent granite. They cut cleanly across the banding of their host gneiss or migmatite, and are appreciably younger. Typical pegmatites of this type range in length from a few tens to a few hundreds of feet, and in width from 2 feet to 12 feet. The thinner dykes comprise a central band of coarse grained quartz, microcline and biotite, surrounded by a marginal, fine grained aplitic rock made up of quartz, albite, green muscovite and spessartite garnet. In the thicker dykes, several alternating bands of these two rock types may be present. Most of the tin in the dykes is within the finer, albitic phase, which seems to have formed by soda metasomatism of the microcline.

Economic minerals associated with the cassiterite are tantalite, monazite (with a high content of rare earths) and gadolinite. Some fluorite is occasionally seen, but beryl and lithium minerals are absent. These pegmatites are richest in tin where they intrude the more mafic gneisses, or migmatites with an appreciable content of amphibolite and biotite rock. The placer deposits of Moolyella, Cooglegong, Eley's, Pinga Creek and Coondina were derived from pegmatites of type (b).

Type (c)

Pegmatites of type (c) resemble those of type (b), but are smaller, and contain relatively greater amounts of microcline and less albite. The cassiterite shed from these veins is finer than that from the other types of pegmatite. The tin mined at Coomba Creek, Split Rock and Gunpowder Creek, near Spear Hill, came from pegmatites of type (c).

TIN GRANITE

Previous work

The first recognition of a tin granite in the Pilbara Goldfield was made by Maitland (1919), who stated (p. 13) : ' Sections are to be seen near the tin mining centre of Wodgina, in the Pilbara Goldfield, showing an ancient intrusive granite which has been invaded by a newer (though still old) tin-bearing granite '.

Noldart and Wyatt (1962) made a study of the granite complexes in the Pilbara Goldfield during a geological survey of the Marble Bar and Nullagine 4-mile map areas. They recognized that the granitic rocks could be divided into magmatic, gneissic, and granitised types, but mapped the first two of these as one unit. They regarded some of the granite complexes as having a magmatic origin (although with marginal granitization of the invaded rocks), and others as having been formed by widespread granitization, with partial palingenetic mobilization giving rise locally to magmas.

At the completion of their survey, Noldart and Wyatt (*ibid.*, appendices 1 and 2) submitted 44 samples of granite and granite gneiss to the Government Chemical Laboratories for mineral determinations. It was hoped that some correlation would be established that would assist in identifying the ' tin granite '. No field relationships of the specimens were given, and, as both the granites and gneisses of the region have similar mineral contents, no firm correlation was found. However it was recognized that some fluorite bearing granites may be associated with the tin deposits.

General features

The tin granites are relatively late intrusions within the granite complexes of the Pilbara Goldfield. They are seldom seen to be foliated, but in places have a flaty-flow structure and broad compositional banding due mainly to variations in the content of potash feldspar. In texture they range from even-grained to porphyritic. Mostly they are medium to coarse grained rocks although some fine grained varieties occur on the margins of the intrusions. Where examined in detail they are simple rather than multiple intrusions, and the different textural varieties grade into each other. The smaller intrusions have sharp, clean-cut contacts with the gneiss, but at the edges of the larger, and presumably more deeply eroded batholiths, the contacts are irregular, with much interfingering of gneiss and granite.

In composition the tin granites are biotite adamellite made up principally of microcline, oligoclase, and quartz with minor biotite and muscovite, and accessory hornblende, apatite, fluorite, garnet, ilmenite, sphene, rutile, zircon and clinozoisite. The microcline normally forms euhedral crystals and makes up the phenocrysts of the porphyritic varieties. It is perthitic in many specimens. Oligoclase is the most common plagioclase, but the plagioclase was albite or sodic andesine in a few specimens examined. The biotite is green in thin-section, and most grains are partly altered to chlorite. The fragments of pale green hornblende in the granite are always rimmed by biotite or chlorite. Of the silica analyses of granites published by Noldart and Wyatt (1962, p. 177) three (Nos. 758, 763, 773) are of known tin granites. They contain from 69·4 to 70·8 per cent silica.

The tin granites are more resistant to erosion than the gneiss and migmatite which they intrude. Consequently they form areas of rough hilly country, marked by tors and smooth exfoliation domes, which contrast well with the flatter, often soil-covered terrain underlain typically by the gneissic rocks. Topographic expression is not, however, an infallible guide to the tin granites as other types of intrusive granite also form tors and some more resistant varieties of gneiss form rounded hills. In many outcrops of the tin granites, silicification has taken place along fine polygonal joints. Subsequent weathering hollowed out the rock between the joints, leaving the exposed surface with a characteristic ' honeycomb ' appearance.

Relationship to mineralization

The relationship of these granites to the tin mineralization is indicated by the following field evidence :

1. The main tin producing centres are all close to, or within granites of this type.

2. Pegmatites within the tin granites are similar to the tin-bearing pegmatites of type (b) in having margins composed of fine grained quartz, albite, green muscovite and garnet.

3. At Moolyella, tin-bearing pegmatites can be traced into the tin granite, and at Split Rock, Coomba Creek, Spear Hill and Eley's, tin-bearing pegmatites are found within the granite.

4. At Moolyella and Eley's, fine grained, albite-rich marginal phases of the intrusive granite contain pink garnets, similar to those in most tin-bearing pegmatites.

It is believed that the tin granites are one of the more common types of magmatic granite within the Pilbara region, at least in the area east of the Yule River. It is likely that other stocks of similar granite are present in places not seen during the present investigation, and therefore not shown on Figure 8. An examination of aerial photographs suggests that large areas of similar granite exist south of Tambourah, and in the country drained by the upper parts of Budjan and Boobina Creeks, south of Corunna Downs.

CONCLUSION

It is believed that the recognition of a tin granite type will aid exploration for tin in the Pilbara, particularly in the more poorly drained parts, where the traditional use of the prospectors panning dish is less effective in testing the potential of large areas.

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TIN-BEARING PEGMATITES IN THE NORSEMAN AREA

by J. Newton-Smith

ABSTRACT

Tin-bearing lithium pegmatites cut Archaean greenstones near Mount Deans and Mount Thirsty in the eastern part of the Yilgarn Block, Western Australia. The pegmatites are characterized by quartz, plagioclase, muscovite, biotite and lepidolite, with accessory tourmaline, garnet and cassiterite. The pegmatites were worked for tin between 1965 and 1967, during which time 15,013 lbs of tin concentrate were produced.

INTRODUCTION

Tin was produced from several lithium pegmatites in the Norseman area between 1965 and 1967, and during that period tin ore delivered to the Norseman State Battery yielded 15,013 lbs of tin concentrate. Four mineral claims cover the producing pegmatites : three in the vicinity of Mount Deans, about 8 miles south of Norseman, and one about 12 miles northwest of Norseman near Mount Thirsty (locality map Figure 9).

REGIONAL GEOLOGY

Norseman is situated close to the southern extremity of an Archaean greenstone belt which has been truncated by intrusive granites on the eastern and western margins. The tin-bearing lithium pegmatites at Mount Deans occur in basic lavas and associated intrusive rocks while at Mount Thirsty ultrabasic, basic, and acid volcanic rocks are host to the pegmatites. The granite on the western margin of the greenstone belt is considered as the source of the pneumatolitic solutions which formed the pegmatites. This granite comprises about 50 per cent quartz, 30 per cent potassium feldspar, and 15 per cent plagioclase. Accessory minerals consist mainly of muscovite with some biotite, chlorite, and epidote. Fluorite has been recorded from one specimen (Trendall, 1965). Simple quartz-feldspar pegmatites are common in the granite and greenstone, particularly where close to the intrusive contact between the granite and the greenstone belt west of Norseman. Complex lithium pegmatites however, are confined to the greenstone belt. The occurrence of tin is closely related to the presence of lithium minerals in the pegmatite ; no tin has been recorded from the granites of the simple quartz-feldspar pegmatites.

The tin-bearing pegmatite bodies occur in groups, and generally have an irregular outline and a dip of 45 to 60 degrees. They vary in width from a few inches to about 10 feet and may be traced along strike for over 500 feet. The pegmatites are complex and locally zoned. The principal minerals present are albite, commonly the platy variety called cleavelandite, quartz, locally forming graphic intergrowths with feldspar, muscovite, biotite, and lepidolite. Accessory minerals include tourmaline, garnet, and cassiterite. No potassium feldspar was noted in any of the tin-bearing pegmatites. Radiometric counts over the pegmatites are just above background. Isolated inclusions of a metamict mineral with attendant radiating cracks developed in the adjacent quartz were noted in some quartz grains from MC 95. Tantalite carrying about 70 per cent Ta_2O_5 has been recorded from the Mount Deans area (Simpson, 1952, p. 649) but no tantalite was reported by the purchasers of the tin concentrates.

MOUNT DEANS PEGMATITES

Tin-bearing pegmatites crop out within an area about two miles long (north-south) and one mile wide on the eastern flank of Mount Deans, eight miles south of Norseman. The pegmatites have invaded basic lavas and associzted basic intrusive rocks. Alteration of the adjacent wall rocks is confined to a mild bleaching.

Mineral Claim 93

Mineral Claim 93 contained the most productive tin workings in the Norseman area, having yielded 14,065 lbs of concentrate from 915½ tons of ore. A field sketch of the workings is given in Figure 9. The pegmatites are irregular in shape, and dip southwest at about 50 degrees. Zoning of the pegmatites is evident but was not studied in detail in the field. The principal pegmatite minerals are quartz and plagioclase. The plagioclase varies from albite to calcic oligoclase within the pegmatite and the albite is commonly the lamellar variety cleavelandite. Muscovite and lepidolite are also common. A compound mineral which may be white, pale lilac, or pale olive green and with a strongly developed cleavage occurs in the pegmatite. Pale lilac and pale olive green samples of this mineral were examined by the Government Chemical Laboratories. The lilac sample was found to consist of quartz, chlorite, and kaolinite ; the lilac colouration is probably caused by adsorption of manganese onto the kaolinite. The olive green mineral is formed of a mixture of quartz and a mica, possibly illite. The tin occurs in close association with the sodic plagioclase, and the nature of the workings suggests that the tin-bearing horizon is close to the upper margin of the pegmatite. The tin occurs as irregular to subhedral, commonly zoned crystals either isolated or as aggregates.

Mineral Claims 94, 136

Pegmatites on these adjacent mineral claims have yielded only small quantities of tin (Table 1). The pegmatites are exposed in a few shallow pits and one larger open cut where a dip of 45 degrees to the east was recorded on a pegmatite nine feet thick. The mineralogy of the pegmatites on MC 94 and MC 136 is similar to that described for MC 93.

TABLE 1. TIN PRODUCTION FROM PEGMATITES IN THE NORSEMAN AREA

Date	Tenement	Ore crushed (tons)	Concentrate produced (lb)
7/7/1965	MC 94	16	Not available
6/8/1965	MC 94	19	Not available
15/10/1965	MC 93	70	1673
12/11/1965	MC 94	85	480
10/12/1965	MC 93	135	3808
11/3/1966	MC 94	53½	448
18/3/1966	MC 136	23	20
20/5/1966	MC 95	48	Not available
28/9/1966	MC 93	118	1344
12/12/1966	MC 93	118	2016
20/12/1966	MC 93	84½	436
28/2/1967	MC 93	89	476
20/3/1967	MC 93	102½	1008
9/6/1967	MC 93	100	1680
6/8/1967	MC 94	57	Not available
15/9/1967	MC 93	98½	1624
27/10/1967	MC 95	27	Not available

Statistics from the State Battery, Norseman.

MOUNT THIRSTY PEGMATITES

Pegmatites have been emplaced into acid volcanic rocks, amphibolite, and tremolite-actinolite rock which crop out about four miles southwest of Mount Thirsty. The tremolite-actinolite rock has undergone contact metamorphism close to the margin of the pegmatite where it has been altered to biotite-tremolite-actinolite rock which locally contains quartz.

Mineral Claim 95

Seventy-five tons of ore have been extracted from pegmatites on MC 95 but there is no available record of the quantity of tin concentrates produced. Two areas have been worked on this mineral claim and are here referred to as the western workings and the eastern workings (Figure 9).

The principal minerals present in the western workings are quartz and plagioclase but the most characteristic is muscovite in books over nine inches long and two inches thick. The muscovite commonly contains needles of dark blue tourmaline over three inches long. Tourmaline is common throughout the pegmatite and may be dark blue, greyish-blue, greenish-blue, or more rarely pink. Lepidolite, and a black mica with a radial structure (probably zinnwaldite) are present.

The eastern workings are better exposed than the western workings and show a complex zoning of the pegmatite. The principal pegmatite minerals are quartz and plagioclase ; the plagioclase varies from albite to calcic oligoclase and the platy form of albite, cleavelandite, is common. The accessory minerals recognized are garnet, bluish-green, pink, and black tourmaline, muscovite, biotite, and a black mica with a radial structure, probably zinnwaldite. A metamict mineral occurs as isolated inclusions in some quartz grains and the adjacent quartz contains small cracks radiating from the inclusions.

FUTURE PROSPECTS

The irregular nature of the pegmatite bodies and the localized occurrence of the tin within these bodies renders prospecting difficult. The most promising area for further investigation is the eastern flank of Mount Deans which has been the most productive area and is where the pegmatites are most extensive. Prospectors have been active in this area but no further tin shows have been located. Many of the pegmatites in this area lie beneath a thin cover of colluvium but their approximate position can be traced by pegmatite float. Many of the pegmatites in the Mount Deans area are either barren or contain only very minor amounts of tin, and extensive pitting is necessary to determine the tin content of the pegmatites.

The prospects of discovering alluvial tin, notably in the valleys east of Mount Deans and the alluvial areas on the western shore of Lake Dundas, must not be discounted. In particular the north-south valley developed along the contact of the basic rocks and banded iron formation east of MC 93 may be worth investigating for alluvial tin.

The close association of tin with complex lithium pegmatites and the apparent absence of significant tin deposits in the simple quartz-feldspar pegmatites suggests that broader based prospecting should be orientated to the search for further lithium pegmatites within the Norseman greenstone belt.

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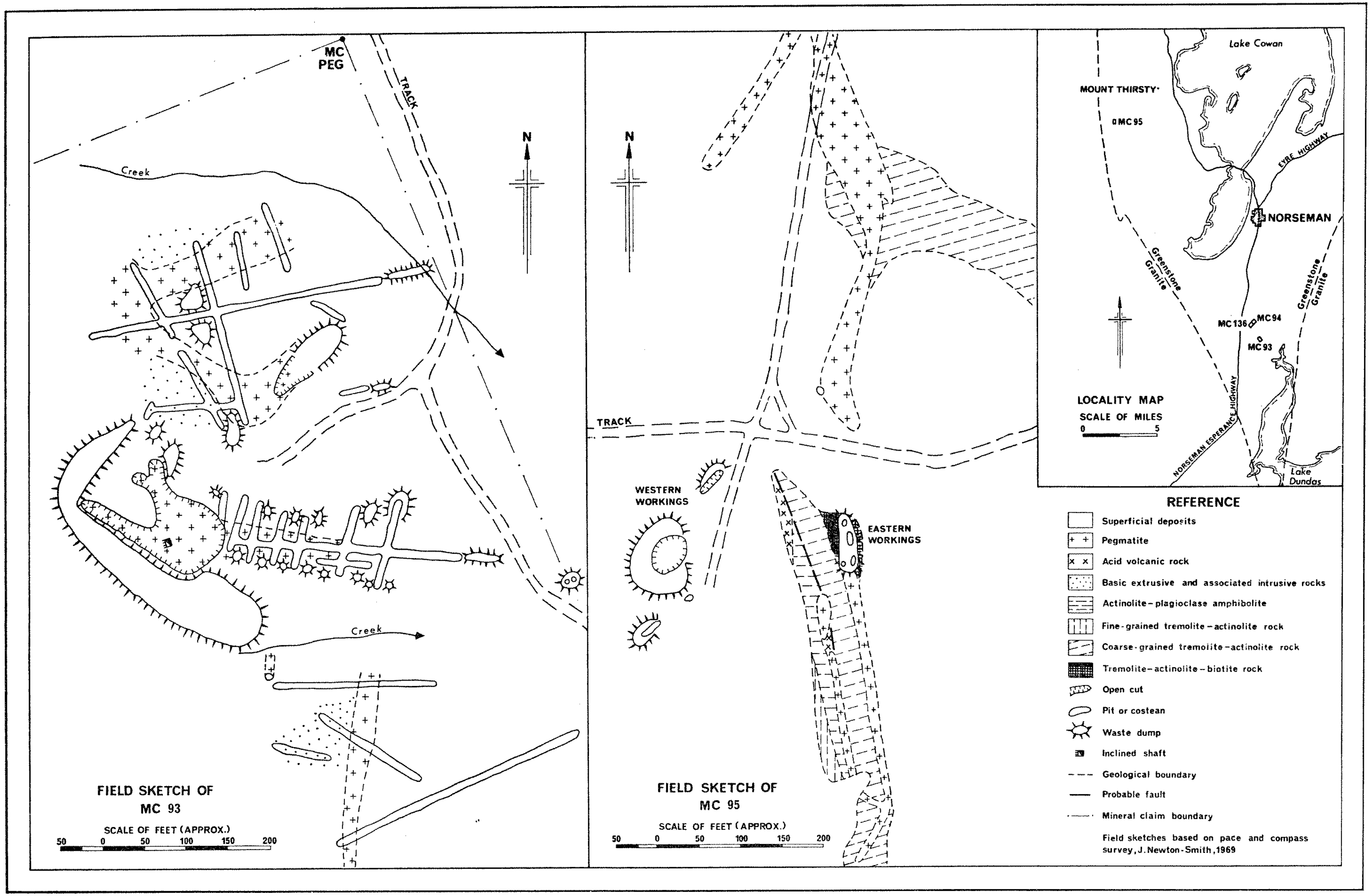

Fig. 9—Field sketches of some tin workings in the Norseman area.

FORAMINIFERA FROM THE PLANTAGENET GROUP EAST OF ESPERANCE, WESTERN AUSTRALIA

by J. Backhouse

ABSTRACT

A distinctive foraminiferal fauna was obtained from rocks belonging to the Werillup Formation of the Plantagenet Group, which was penetrated in boreholes drilled for water on several locations east of Esperance. The fauna is Upper Eocene, confirming previous age estimates for the Plantagenet Group. Comparison is made with other Upper Eocene foraminiferal faunas in Western Australia, South Australia, Victoria and New Zealand.

INTRODUCTION

The Plantagenet Group crops out in discontinuous areas in the southern part of Western Australia. Sediments belonging to this group were encountered by bores on Neridup Locations 14, 118 and 159 (see Figure 10). Sludge samples from the bores yielded diverse faunas including foraminifers, ostracods, bryozoans, molluscs and echinoids. Dasycladacean algae from two of the bores have already been recorded and mention made of the foraminifers by Cockbain (1969).

On Neridup Location 118, a single borehole, Brookman 1, encountered calcareous grey siltstones, which yielded a rich fauna, at a depth of 85 feet. Four boreholes on Neridup Location 159, Neridup 20, 21, 22 and 23, encountered similar grey siltstones at depths of 90, 75, 75 and 55 feet respectively. These beds are associated with dark carbonaceous siltstones, which, together with the calcareous grey siltstones, are referable to the Werillup Formation. The three bores Neridup 13, 14 and 25 are on Neridup Location 14. The deepest bore, Neridup 14 (see Figure 11), penetrated sandy bryozoan limestone between 105 and 107 feet, below which were unfossiliferous grey siltstones. This limestone was encountered at 65 and 85 feet in Neridup 13 and 25 respectively.

Foraminiferal faunas from the calcareous grey siltstones and from the bryozoan limestone are basically the same, although foraminifers are less abundant and less diverse in the limestone. The bryozoan limestone is lithologically similar to the Nanarup Limestone which crops out near Albany and is considered to be a member of the Werillup Formation (Cockbain, 1968b).

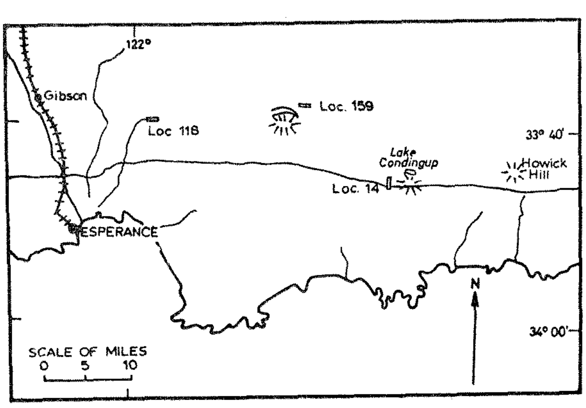

Fig. 10—Map showing Neridup Locations 14, 118 and 159.

FORAMINIFERA FROM THE NERIDUP LOCALITIES

Where more than one fossiliferous sample was recovered from a borehole, all the samples recovered yielded assemblages similar in diversity and abundance of species. A few species are relatively common in almost every sample examined, and may be regarded as characteristic of the Werillup Formation in the Esperance area. They are *Cibicides perforatus*, *C. vortex*, *Eponides lornensis*, *Maslinella chapmani*, and *Sherbornina atkinsoni*. Another characteristic form, *Bolivinella* sp., was recorded by Ludbrook (1961) and figured by Quilty (1968, unpubl.). Some specimens at present assigned to *E. lornensis* may belong to the species *E. repandus*. *Maslinella chapmani* occurs extensively but is only abundant in samples from bores on Neridup Location 159. This large species with a strong bilamellar test is extremely abundant in the Nanarup Limestone (Quilty, 1968, unpubl.).

Elphidium sp., *Discorbis balcombensis*, and *Linderina* sp. are also particularly common in the bores on Location 159. *Asterocyclina* sp. and *Carpenteria* cf. *hamiltonensis* are almost entirely restricted to Neridup 20.

A few planktonic forms have been recovered, *Globigerapsis index* and *Globigerina linaperta* from Neridup 25, and *Globigerina* cf. *offocinalis* and *Globorotalia* cf. *centralis* from Neridup 22.

ENVIRONMENT

The overall fauna from the Neridup area suggests shallow-water conditions for the deposition of the Werillup Formation. There is an abundance of large robust forms such as *Maslinella chapmani*, *Elphidium*, *Carpentaria* cf. *hamiltonensis* and *Asterocyclina*. Smaller species are frequently strongly ornamented and heavily calcified, an indication of shallow-water conditions. Further evidence for a shallow-water environment is found in the low proportion of planktonic forms in the fauna (less than 1 per cent) and in the presence of dasycladacean algae, on the basis of which Cockbain (1969) suggests a depth of not more than 10 metres.

The presence of Asterocyclina has been mentioned by Cockbain (1967) and comment made on its significance as a tropical genus occurring so far south during the Eocene.

There is some variation in lithology and foraminiferal assemblages between the bores. The foraminiferal fauna of Neridup 20 represents a very shallow-water assemblage, of probably less than 10 metres depth. In samples from this borehole robust species predominate. The remaining boreholes on Neridup Location 159 and Brookman 1 borehole contain fossiliferous beds similar in lithology to those of Neridup 20, but with faunas less predominantly shallow-water in aspect.

TABLE A

Species	Neridup							Brookman 1
	Bore 13	Bore 14	Bore 25	Bore 20	Bore 21	Bore 22	Bore 23	
Angulogerina cf. *australis* Heron-Allen and Earland	R	....	....	R	....	C	....	R
Anomalina nonionoides Parr	R	R	....	F	....	C	F	C
Anomalinoides pinguiglabrus (Finlay)	....	F	....	....	....	F	F	F
Asterigerina cf. *cyclops* Dorreen	A	A	....	F	....	R	A	A
Asterocyclina sp.	....	....	....	A	....	R	....	....
Astrononion parki Hornibrook	....	....	....	....	....	F	....	....
Bolivina sp.	....	....	....	....	....	F	....	....
Bolivinella sp.	A	A	....	C	F	A	A	A
Buliminella madagascariensis (d'Orbigny)	R	....	....	F	....	F	F	F
B. sp. A.	F	R	....	C	....	C	C	A
B. sp. B.	R	....	....	....	....	R	R	....
Carpenteria cf. *hamiltonensis* Glaessner and Wade	....	....	....	C	....	....	....	....
Cassidulina subglobosa Brady	F	....	A	F	....	C	....	R
C. laevigata d'Orbigny	....	....	....	....	....	F	....	R
Cibicides mediocris Finlay	....	R	R	R	....	F	....	F
C. perforatus (Karrer)	A	F	A	C	F	C	C	A
C. vortex Dorreen	F	....	R	C	R	C	F	F
Cribrorotalia lornensis Hornibrook	....	....	....	R	R	F	R	R
C. tainuia Dorreen	F	....	F	R	R	F	....	....
Dentalina sp.	....	....	....	....	....	R	....	R
Discorbis balcombensis Chapman, Parr and Collins	R	R	R	C	F	....	C	F
Elphidium sp.	F	F	R	A	F	F	C	F
Eponides lornensis Finlay	F	F	C	F	R	F	C	C
Fissurina laevigata Reuss	....	....	....	R	....	F	R	F
Glabratella crassa Dorreen	....	....	....	F	....	R	....	R
Globulina gibba d'Orbigny	....	....	F	R	....	R	....	R
Guttulina problema (d'Orbigny)	F	R	F	F	R	F	R	F
Gyroidinoides zelandica (Finlay)	....	....	F	....	....	F	....	F
Hanzawaia sp.	....	R	....	F	....	F	F	C
Lagena hexagona (Williamson)	....	....	....	R	....	F	R	R
Lamarckina airensis Carter	....	....	....	....	....	F	F	C
Lenticulina sp.	....	....	A	F	....	R	....	R
Linderina sp.	....	F	....	C	R	F	A	....
Maslinella chapmani Glaessner and Wade	....	F	F	A	C	R	C	R
Missiissppina concentrica (Parker and Jones)	R	F	....	C	F	F	F	F
Operculina sp.	....	....	....	C	....	F	F	....
Pullenia bulloides (d'Orbigny)	....	R	....	....	....	R	....	....
P. quinqueloba (Reuss)	....	....	....	....	....	F	....	....
Planorbulina mediterranensis d'Orbigny	....	....	R	F	....	F	F	....
Pseudopolymorphina sp.	....	....	R	....	....	R	....	....
Reussella finlayi Dorreen	....	....	....	C	R	C	F	....
Rosalina turbinata (Terquem)	F	R	....	C	R	F	F	F
Schackoinella sp.	R	....	....	F	R	F	F	C
Sherbornina atkinsoni Chapman	F	F	R	C	R	F	A	A
Triloculina sp.	....	....	....	....	....	....	F	R
Uvigerina sp	....	....	....	R	....	F	....	....

KEY: A, abundant; C, common; F, few; R, rare

All fossiliferous beds from the Werillup Formation of Neridup Location 14 are white bryozoan limestones. This limestone has produced a poorer foraminiferal fauna than the grey beds of the other boreholes. The bryozoan limestone is a distinct facies in the Werillup Formation representing either deeper water, or more open conditions or both. Quilty (1969) records planktonic forms as constituting 10 per cent of the foraminifers in the Nanarup Limestone, which he considers was deposited at a depth of 120 feet ± 60 feet.

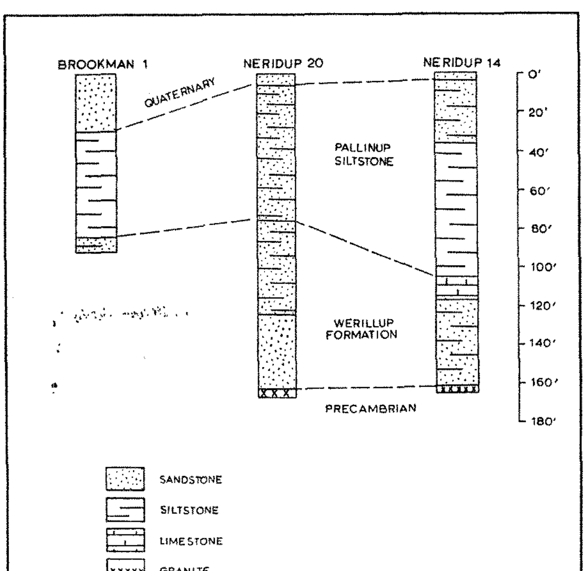

Fig. 11—Correlation of Brookman 1, Neridup 20 and Neridup 14 boreholes.

COMPARISON WITH OTHER UPPER EOCENE FORAMINIFERAL FAUNAS

The benthonic fauna compares closely with that recorded by Quilty from the Nanarup Limestone. The planktonic assemblage from the Nanarup Limestone has been dated as Upper Eocene, a dating extended to the Plantagenet beds occurring east of Esperance. A similar fauna has been recorded from the Wilson Bluff Limestone and Toolinna Limestone of the Eucla Basin, and Cockbain (1968a) described a closely comparable fauna from the Norseman Limestone at Lake Cowan.

In the Murray Basin in South Australia the Upper Eocene fauna of the Buccleuch Group includes *Linderina*, *Maslinella chapmani*, *Bolivinella* and *Sherbornina atkinsoni* as well as Upper Eocene planktonic forms. The fauna of the Tortachilla Limestone of the St. Vincent Basin is very similar to the Werillup fauna but occurs below the zone of *Hantkenina alabamensis*. This zone forms Carter's Faunal Unit 1, which is characterized by the occurrence of *H. alabamensis* together with *Globigerapsis index*. The Plantagenet Group corresponds with Carter's Faunal Unit 2, which is younger than Faunal Unit 1 and is characterized by the occurrence of *G. index* without *H. alabamensis*. The Faunal Units were first erected in the Tertiary of the Aire district of Victoria, where Faunal Unit 2 includes the Upper Browns Creek Clays and the lower part of the Castle Cove Limestone. In the Gippsland Basin the Tertiary strata are all younger than Faunal Unit 2, which is the highest to include Eocene beds.

The Carnarvon Basin in northwest Western Australia contains beds considered to be Middle to Upper Eocene. This dating is based partly on the smaller foraminifers but mainly on the larger foraminifers including species of *Asterocyclina*, a genus restricted to the Middle and Upper Eocene, which is recorded from the Giralia Calcarenite (Edgell, 1952).

In New Zealand a very similar benthonic fauna occurs in the Upper Eocene outcrop in Ethel Creek near Greymouth on the north coast of South Island. Dorreen (1948) regarded this as a tropical fauna and it contains several species which are common in the Werillup fauna.

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PETROGRAPHY AND DEPOSITIONAL ENVIRONMENT OF SOME PRECAMBRIAN SEDIMENTARY ROCKS FROM THADUNA, WESTERN AUSTRALIA

by A. F. Trendall

ABSTRACT

Eight core samples of Precambrian Bangemall Group sedimentary rocks (about 1,000 m.y. old) were examined in support of a reappraisal of the copper occurrence at Thaduna. Six of the samples range from coarse breccia with mixed sodic lava and siltstone fragments, through similar rocks of smaller grain-size to laminated siltstones comparable with those of the breccia fragments. Epidote and amphibole are partly clastic and partly products of final diagenesis. The purple colouration of the fine rocks is due to very fine cementing hematite. The remaining two samples are of rocks close to the lode. They differ only in having little hematite but abundant secondary chlorite and epidote ; as a consequence they are green. From petrographic evidence, regional geology, and two examples of widely different environments which have led to the existence of similar rocks, a depositional environment is suggested; this involves the possibility that the Bangemall Group rocks at Thaduna, together with their folding, faulting, and mineralization, may all be related to a single tectono-volcanic event along the southern unstable margin of the developing Bangemall Group basin.

INTRODUCTION

During a recent reappraisal of the Thaduna copper occurrence (Blockley, 1968) brief descriptions were requested of some core samples chosen to reflect the range of lithological types present in the host rocks. The paucity of available information on these rocks, which hold great interest for Precambrian palaeogeography, warrants the publication of these descriptions, together with notes on the regional geological environment and a brief discussion of their significance.

REGIONAL GEOLOGICAL ENVIRONMENT

Mapping in progress on the Peak Hill 1 : 250,000 Sheet, indicates that the rocks at Thaduna belong to the Bangemall Group (W. N. MacLeod, personal communication). This group was defined as such by Halligan and Daniels (1964) on the basis of the earlier Bangemall Series of Maitland (1909). Its outcrop area extends at least over a crudely triangular area of some 40,000 square miles ; Thaduna lies roughly centrally along the southern side of the triangle. The rocks of the Bangemall Group were formerly considered to be part of the 'Nullagine Series' (e.g. Talbot, 1926). De la Hunty (1964) first appreciated the importance of the unconformity between the correlative Manganese Group of the Balfour Downs Sheet and the underlying older rocks, equivalent to the traditional Nullagine of the type area. The Bangemall Group rocks have been studied in most detail on the Edmund 1 : 250,000 Sheet, near the west apex of the triangular outcrop (Daniels, 1966). Daniels recorded several thousands of feet of shale, sandstone, chert, and dolomite laid down in a basin with a northwest to southeast elongation, but of uncertain extent.

Daniels (1968) subsequently recognized volcanic rocks in the Bangemall Group of the Edmund Sheet, while Horwitz and Daniels (1967, p. 51) referred to volcanic rocks north of Wiluna and on the Glengarry, Peak Hill, and Nabberu Sheets ; these extend in a general easterly direction from Thaduna, and are correlatives of the Bangemall Group. Acid volcanic rocks were also collected by geologists of Westfield Minerals N.L. during mapping in the Mt. Augustus area, some 200 miles west-northwest of Thaduna and to the south of the Edmund Sheet. Compston and Arriens (1968) carried out Rb-Sr isotope analyses on these rocks, and found weak support for their earlier determination of an isochron age of 1,080 ± 80 m.y. for Bangemall Group black shales from the Edmund area. There are no descriptions yet published of any of these volcanic rocks reported in the Bangemall Group.

The current mapping of MacLeod (pers. comm.) on the Peak Hill Sheet indicates that the Thaduna volcanic rocks and associated sediments occur within a sub-basin separated from the main Bangemall Group basin by a horst of Archaean granite and metasediments. The rocks along the northern margin of this sub-basin, which include the Thaduna volcanic assemblage, are tectonically disturbed, suggesting that this zone may have been an unstable hinge line during the initial stages of sedimentation. The volcanic rocks appear to be confined to a limited zone on this unstable shelf and have no great lateral extension. To the west they are replaced by schistose psammitic and pelitic clastic sediments which have been intruded by dolerite sills. To the east and south the Thaduna rocks are overlain disconformably by relatively undisturbed quartz sandstone deposited when the basin margin was more quiescent.

PETROGRAPHY

Eight small pieces of core were received. Two of them (R2680 and R2681*) are green sediments whose colour is characteristic of those close to the lode. The other six (R2674–R2679) are representative of the more usual reddish purple sedimentary host rocks, and range, in their numbered sequence, from the coarsest variety of greywacke to stiltstone. A note on colour is appropriate here. The colour just referred to as ' reddish purple ', and by Blockley (1968) as ' purple ', is very close to 5RP4/2 of the Munsell system, for which the preferred name of the American Rock-Color Chart Committee is ' grayish red purple '. For brevity, this colour is referred to as purple in the succeeding text. Similarly the green sediments near the lode are close to 5F5/1 which is between greenish grey and dark greenish grey.

R2674 is a coarse rock which could with equal propriety be called a greywacke, a breccia, or a tuff. The most conspicuous fragments are of purple siltstone, variously elongate (up to 35 x 1 mm) or nearly equant (up to about 10 x 15 mm). Most have some internal stratification, which is parallel to the longest dimension of the elongate pieces. There is a strong sub-parallel arrangement of the long axes, in spite of the fact that they all appear to be more or less plastically deformed ; this is assumed to be the bedding direction. The larger siltstone pieces are markedly angular, but the smaller ones, which are still recognisable down to a diameter of about a millimetre, are increasingly rounded. Interspersed with the siltstone fragments, and forming about an equal volume of the rock, are smaller (up to 10 mm) white, pale green, or grey fragments in which no structure is visible to the naked eye. All are firmly cemented to form a compact rock of strikingly particoloured appearance.

In thin-section most of the purple siltstones have angular quartz and feldspar fragments up to 0·02 mm scattered in a matrix which probably consists of fine quartz and feldspar, but whose confident optical identification is rendered impossible by variably dense clouds of hematite ' dust ', made up of grains $1/\mu$ or less across. These hematite clouds sometimes form a crudely reticulate meshwork with an elongation parallel to that of the fragments. A few of the siltstones are slightly coarser, and there appears to be a relationship between the grain-size of the sediment and that of the staining hematite, the coarser silts having granular and platy hematite up to 5 μ. That the hematite is to some extent a redistributed staining material, at least in part, is shown by the presence in many shale fragments of a dark hematite-rich rim formed after fragmentation ; but the wide variation in hematite content of different siltstone fragments suggests that a process of variable staining or replacement of these rocks by mobile iron was similarly active before fragmentation.

The larger individuals of the (macroscopically) paler fragments appear in thin-section to be highly variable in shape. They range from sharply angular, as if freshly broken, through subangular to rounded many of these last seem corroded, and a few are very clearly embayed by diagenetic corrosion. Those appearing palest in core consist variously of clear quartz (up to 5 mm across), alkali feldspar, quartz mosaic of a wide grain-size range, quartz-feldspar mosaic, or the same two minerals in graphic intergrowth. The grey and green fragments tend to be more commonly rounded. They consist of a great variety of lava types, most of which consist of albite or potassic feldspar laths, either along or intergrown with quartz, arranged in variants of felted, pilotaxitic, feathery, or spherulitic textures. There are almost as many textural varieties as there are fragments, and it is quite difficult even in a large thin-section to select two lava grains which, although compositionally very close, are not distinguishable by some subtle textural criterion. Most have a little finegrained chlorite, with or without epidote, emphasizing the outlines of the laths, and wispy colourless amphibole and chlorite never seem to co-exist within a single grain. The lava grains exhibit all the classical textural varieties usually listed for acid and intermediate lavas, except that perlitic cracking is apparently absent, and that glass is represented by chlorite. This assumption derives from the existence of a continuous gradation, in selected grains of lesser abundance, between grains which consist solely of chlorite and those of the common sort with very little chlorite that are in a textural position frequently occupied by glass in fresh lavas.

Subhedral epidote crystals up to 0·2 mm across are common amongst the other grains, and it is difficult from their appearance to judge confidently whether they are detrital or of later growth (diagenetic or metamorphic). However, in at least one rounded lava grain the epidote is arranged circumferentially just within the grain boundary ; this seems clear evidence for post-fragmentation growth. Another grain has coarse sieved albite arranged in a similar textural position. Calcite often occurs, on the contrary, as a core to lava grains, also suggesting replacement in response to factors controlled by the grain boundary, and therefore post-fragmentation.

All these types of fragment occur in smaller pieces down to a diameter of about 0·05 mm, but below this there appears to be no finer material, and in particular, most of the lava grains appear to have mutually accommodated their shapes in such a way as to fill all the available space ; the grains are consequently not separated by interstitial spaces or by finer material, but are cemented together by a thin skin of dusty hematite, possibly mixed with some other cementing material.

* Numbers prefixed by R are in the registered rock collection of the Geological Survey of Western Australia.

R2675 has a sharply defined bedding plane separating a breccia similar to that already described from a laminated purple siltstone. In the thin-section the breccia has all the features of that already described, except that the siltstone fragments are smaller (5 mm maximum). It is particularly noticeable in many fragments of this rock that chlorite and epidote are usually restricted to different grains. One rounded polycrystalline grain of epidote, if it is not to be interpreted as a clast, must be supposed to have replaced a pre-existing grain with unusual precision. A single elongate subhedral prism of pale green amphibole 0·4 mm long in the breccia is centrally fractured, with one end strained and rotated through an angle of about 10°. Although some finer amphibole present in lava fragments appears to be secondary, this piece, which seems optically indistinguishable, either grew within the rock early and was later fractured by compaction, slumping, or folding, or it is a clast.

The siltstone in this sample is coarser than that of most of the breccia fragments, although otherwise closely similar. Feathery laths of colourless amphibole about 0·05 mm long, lying along the stratification, are abundant. Within the siltstone there is a lenticle (6 x 2 mm) of coarser sediment similar to that of R2676, which is described below.

R2676 is of an even-grained speckled purple greywacke with most grains equant and less than a millimetre across, but some flat fragments of purple siltstone reach a length of 3 mm.

The largest grains are all quartz and feldspar. Quartz grains vary between well rounded and sharply angular. There is usually some strain extinction, and this is often related to contact with other grains. The feldspars are all angular to subangular and almost all are of clear albite ; the remainder are of potassic feldspar. Some grains of feldspar mosaic or of quartz-feldspar mosaic are present. Apart from quartz and feldspar grains there is about an equal volume of subangular lava grains up to 0·5 mm long. Most are elongate along the bedding and show feathery albite laths forming a variety of fan-like textures ; a little granular chlorite helps to outline the laths and define the textures.

The larger grains of both kinds lie among smaller grains of the same materials down to a diameter of about 0·1 mm. As in the breccia of sample No. 1 there is no indeterminate fine matrix filling the interstices between the grains ; all such space is apparently filled by slight distortion of the lava grains, which are firmly cemented by a thin skin of dusty hematite.

It is necessary to described only those features of special interest in samples R2677–2679, since in most respects they differ only in grain-size from the coarser rocks already described ; the purple siltstone of R2678 and R2679, especially, is exactly like that of the siltstone fragments of R2674, and is in these samples interlaminated with paler and coarser sediment like that of the coarser lenticle within the purple siltstone in R2675. R2678 has an average grain diameter of about 0·1 mm and is of interest in having, macroscopically conspicuous in the core, vaguely defined darker purple spots 1 to 3 mm across ; they are arranged very roughly in rows along the bedding, and have little expression in the thin-section apart from a greater concentration of intergranular hematite. Also in this slide much of the epidote appears detrital, because rounded grains, sometimes polycrystalline, always have much the same size range as the surrounding material, although this varies somewhat across the slide. There are two good examples of fractured amphibole prisms, in one of which the two parts are rotated about 30°. Elsewhere, the feathery terminations of similar amphibole cut across the boundaries of lava grains, indicating diagenetic or metamorphic growth.

R8026 is the coarser of the two pieces of green sediment from close to the lode. Its largest grains are about 0·5 mm across, and consist of angular to subangular quartz, alkali feldspar, a variety of lava types exactly like those of the rocks already described, and reddish material consisting of hematite stained cryptocrystalline quartz-feldspar aggregate. Grains of these materials, down to a diameter of about 0·05 mm, make up about a quarter of the volume of the rock. The remainder consists mainly of epidote and pale green chlorite whose textural arrangement suggests clastic grain shapes : that is, the epidote crystals and crystal aggregates, and the chlorite aggregates, form discrete grain-like bodies with the same shapes and size distribution of the undoubted clasts. Under high power, though, the boundaries of these apparent grains are vaguely defined, and all are cemented by a pervasive matrix of almost isotropic chlorite. However, the chlorite of many apparently clastic chlorite grains is often distinctive in textural arrangement and in composition, as expressed by wide variation in anomalous birefringence colour. A few chlorite ' grains ' have skeletal amphibole cores. Thin veins crossing the rock have calcite, epidote, and chlorite.

It is impossible to assess whether the relative abundance of chlorite in this rock is due to compositional differences of this sediment from the samples already described, or whether differently composed lava grains have been selectively replaced by chlorites of different composition. Certainly much of the epidote and calcite here is secondary, but exactly how much is uncertain.

R2681 is of a finely laminated green siltstone in which the bedding is crossed at high angle by a cleavage assumed to be parallel to the axial planes of the folds, but possibly in the direction of a lode shear. Two thin veins of quartz and chlorite also follow this direction, and act as small faults, one reversed and one normal, across which the bedding is shifted about a millimetre. The larger grains in the coarser siltstone layers are about 0·05 mm across, and are of angular quartz, subhedral albite, and chlorite. They are set in an effectively isotropic matrix of very pale green chlorite. The cleavage is defined in the slide by a general shape orientation of the larger grains, by thin parallel streaks of dusty material, possibly epidote, and by less abundant flakes of chlorite about 0·02 mm long. The chlorite of the larger grains is mostly strained and in places bent along the cleavage direction.

DISCUSSION

Nomenclature and origin of lava clasts

Almost without exception the lavas of the clasts in the sediments described are fine-grained albite-chlorite rocks, with or without quartz. Both the naming and the origin of these rocks present problems. While they clearly belong petrographically to the ' spilite keratophyre association ' of Turner and Verhoogen (1960, p. 258–272) these authors partly use general geological environment in their definition. It therefore seems wrong to use either term for unprejudiced environmental interpretation. Hatch, Wells, and Wells (1965, p. 343) also emphasize the environmental significance of both names, in these terms : " To be entitled, so to speak, to the name

' keratophyre ', an albite-trachyte must be associated with other members of the Spilitic Suite in the right kind of environment ". The lavas under discussion are close to the ' weilburgites ' of Lehmann (1952), but it is preferred here to avoid the nomenclatural problem by referring to them as sodic intermediate lavas.

The problems of the origin of such rocks are well summarised by Turner and Verhoogen. These authors conclude that sodic lavas in orogenic regions generally acquire their soda from saline water with which the magma comes into contact at some stage, but that the exact mechanism is complex, and likely to be of different kinds. The association of the Thaduna lavas with clearly subaqueous sediments, and the absence of any lava fragments of ' normal ' types makes such an origin acceptable here, but without any implication of tectonic environment. Known flows of such lavas are mainly intercalated with subaqueous sediments, and it is inferred that extrusion was subaqueous ; there are no grounds for supposing the Thaduna lavas to be exceptional in this respect, although the range of genetic processes which Turner and Verhoogen consider to be feasible admits the possibility of their subaerial extrusion.

Continuity of diagenetic processes

Examples were described, in several of the samples, of the presence of the same minerals, in optically indistinguishable forms, as both clastic grains and secondary growths. Epidote and amphibole are the best examples. These minerals do not appear to occur as phenocrysts within lava fragments. It is concluded that there are two stages of diagenesis, before and after the latest fragmentation ; and that some or all of the breccia material previously existed elsewhere, in a fragmental but aggregated form, in a similar physico-chemical environment to that obtaining during final diagenesis.

One of several phases of fragmentation?

There is no unequivocal evidence as to whether the lava and siltstone fragments of the breccias were simultaneously broken and mixed or whether the history of the rock is more complex. However, the general roundness of the large quartz fragments, coupled with the extreme elongation of fragile and plastic pieces of siltstone strongly suggests that the mixing of siltstone and lava fragments was preceded by earlier fragmentation and attrition of the igneous debris. Flow textures of the lavas are truncated by the grain boundaries, and it is therefore likely that the lavas existed as flows rather than that the pieces were disintegrated by and during explosive ejection from the centre of vulcanicity. The indicated sequence of events is therefore extrusion, fragmentation of lava, and final mixture with fragmented siltstone.

Significance of the hematite colouration

The purple colour of these rocks, which is due to the cement of hematite dust, qualifies them for designation as ' red beds ', many of which they resemble in other petrographic features (Van Houten, 1961). The environmental significance of red beds is currently controversial (Van Houten, 1961 and 1964). Walker (1967) has recently suggested six critical factors for the formation of red beds by breakdown of detrital iron-bearing minerals during diagenesis, and has emphasized that red beds are not reliable paleo-climatic indicators. In summary, he regards internal availability of iron during suitable diagenetic conditions as the main factor in red bed formation, and if his views are accepted a red colour is likely in any volcanoclastic rocks in which diagenetic conditions have been favourable.

Other instances of volcanic-pelitic clastic association

It may be useful to note two instances, from the author's own geological experience, where clasts of volcanic and pelitic material are associated ; the examples are from widely differing environments. Firstly, in the Cumberland Bay Series of South Georgia, a sequence of Mesozoic tuffaceous greywackes some 10 kilometres thick, pellets of fine-grained black tuff commonly occur within the coarser grades (Trendall, 1953, p. 16–17). This mixture probably took place during turbidity current flow down the slope of a trench adjacent to a volcanic island arc ; the clastic tuffaceous material derived from the islands accumulated offshore as an unstable shelf which periodically collapsed to produce a single turbidite unit (Trendall, 1958, p. 43–45). Secondly, on the flanks of the subaerial central Miocene volcanoes of East Africa local irregularities led to the accumulation of fine-grained lacustrine or fluviatile tuffs. Later paroxysmal eruption led to simultaneous outward collapse of these tuffs, and their intimate mixture with coarse volcanic debris, to give stratigraphically complex mélanges. A good example of this is Rusinga Island (Shackleton, 1951), marginal to the Rangwa volcano of Kenya.

These two examples help to give general guidance for the geological acceptability of any of the various possible genetic hypotheses which could accommodate the purely petrographic evidence.

CONCLUSIONS

It remains now to suggest a hypothesis which synthesizes the inferences already drawn separately in the preceding discussion from the various discrete pieces of evidence. Such a hypothesis must allow for the local occurrence of rainpits and for the other sedimentary structures reported by Blockley (1968). A suggested sequence of events follows :

1. Onset of local vulcanicity within the shallow marginal part of the depositional basin of the Bangemall Group ; the marginal strip is assumed to be a tectonically and volcanically active hinge zone associated with the development of the basin.

2. Slight (tectonic?) emergence of the volcanics shortly afterwards, with consequent rapid erosion, and deposition of coarse lava conglomerates. Slight changes in environment led to alternation with finer silts, which were locally exposed to give rain-pits.

3. Continued deposition, with burial causing diagenetic growth of epidote and amphibole, possibly accelerated by hot water associated with the vulcanicity.

4. Further depression of the basin, causing local tilting and slumping of the sediments already deposited ; at this stage some adjacent siltstone and clastic lava beds became mixed as complex breccia during flow.

5. Further growth of epidote and amphibole ; cementation by interstitial hematite.

This sequence appears to account for all observed features of the petrography, to be acceptably related to the regional geology, and to be credible in terms of comparative geology ; it remains to be seen whether further field studies of the whole Bangemall Group basin, which are urgently needed, lend support to it or give grounds for modification. It is not possible to say from petrographic evidence where the faulting and mineralization fit into this reconstruction, but it is relevant to draw attention finally to a recent study of a similar association in the Kurile Islands (Sergeyev, 1963). Here it appears that faulting, with associated sulphide introduction, took place within an almost continuous sequence of sedimentation associated with spilite-keratophyre vulcanicity. In view of the occurrence of axial plane chlorite in sample R2681, there is no reason to discard the possibility that the folding, faulting, and mineralisation at Thaduna are all parts of the same tectono-volcanic event which caused and controlled the deposition of the host rocks.

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PETROGRAPHY AND SIGNIFICANCE OF SOME XENOLITH-BEARING BASIC DYKES OF THE MECKERING DISTRICT, WESTERN AUSTRALIA

by J. D. Lewis

ABSTRACT

Basic dykes, containing many xenoliths of granite, form part of a northeast-southwest dykeswarm, of unknown age, emplaced in Archaean granites. The dykes were probably intruded along shear faults, with the xenoliths representing crushed country rock caught up in the advancing magma. Petrographically the dykes show the mixing of basic magma and a micropegmatite extract from the xenoliths, leading eventually to a hornblende granophyre. In the xenoliths an initial destruction of mafic minerals and development of a granophyre zone along the crystal boundaries is followed by the complete assimilation of the K-feldspar and the development of melt channels along the cleavages of the plagioclase. Finally the xenoliths break down to give xenocrysts of plagioclase and quartz. Chemically the matrix consists of two end members, a quartz-dolerite, and a granitic fraction approximating to the low melting point fraction of the system, quartz-albite-anorthite-silica. The basic magma is shown to have assimilated from 25 to 60 per cent of micropegmatite. The composition of the liquid assimilated compares well with that previously found for assimilation of acid material by basic magma.

INTRODUCTION

During regional mapping of the Meckering district, about 80 miles east of Perth, part of a dyke swarm was mapped. Some of the dykes, most commonly quartz dolerites, were crowded with partly digested xenoliths of granitic material. Nine such dykes were mapped between Meckering and Cunderdin, about 15 per cent of the total. Further examples of such dykes have been brought to my notice near Northam (A. F. Trendall, pers. comm.) and near Mangaroon Homestead in the Edmund 1 : 250,000 Sheet area (J. L. Daniels, 1968). Both of these dykes are northerly trending.

The purpose of this paper is to record the presence of these peculiar dykes in Western Australia, to examine their mode of formation, and to discuss the information they give on the assimilation of granitic material by basic magma.

FIELD RELATIONSHIPS

The principal dyke trend in the Meckering area is northeast-southwest, approximately at right angles to the general structural trend of the Archaean basement (Wilson, 1958 ; Lewis, 1969). A few dykes are intruded parallel to the Archaean structures. The dykes range from about 1 foot to 60 feet wide and a few can be traced for several miles. About 60 dykes were noted in the area mapped (Plate 15), and in general they have the characteristics of basic dykes elsewhere ; they are vertical or nearly so, have sharp straight margins, and have only a very few xenoliths of country rock. The dykes are usually quartz dolerites with a basaltic chilled margin, although a few, south of Cunderdin, have glassy tachylitic margins. There is no noticeable metamorphism of the country rock at the dyke wall.

The nine xenolithic dykes found in the area all trend northeast-southeast and appear to form a component of the main dyke swarm. Apart from the presence of numerous granitic xenoliths some also differ from other dykes in that there is considerable metamorphism of the wall rock, and an association with a shear zone. The xenolithic dykes range in width from about 15 feet upwards.

The Beeberring dyke (Plate 15 (1)), which forms a prominent feature at the northeast end of the Beeberring Hills, north of Meckering, illustrates both metamorphism of the country rock and a wide shear zone (Figure 12). Much of the feature is formed of a dark baked granite which is more resistant to weathering than the surrounding granite or the dyke itself. The darkened marginal granite is about three feet wide and similar to that reported by Peers (1966) for the xenolithic dyke near Mangaroon Homestead. The margin of the dyke is sharp and vertical but the outermost six feet of the dyke contains no xenoliths, although in thin-section there is evidence that considerable amounts of granitic material have been assimilated (Plate 16A). The central portion of the dyke, some 60 feet wide, is crowded with granitic xenoliths showing all stages of assimilation. To the southeast the dyke margin is obscured by an intense epidotized shear zone several feet wide.

The appearance, distribution and size of the xenoliths in each dyke is very variable. In appearance they range from little-altered angular fragments of a coarse grained granite, with sharp margins towards the enclosing basaltic material, to streaked-out or rounded pale patches with diffuse margins. In dyke No. 4, southeast of Meckering the xenoliths are usually small and angular, ranging from a half inch to one inch across ; they are granitic and set in a dark grey dolerite that appears to be unaffected by assimilation. In contrast, dyke No. 2, south of Meckering, shows the greatest degree of assimilation, with xenoliths so diffuse, crowded and streaked-out as to give the rock the appearance of a migmatite. In parts of this dyke where xenoliths are less crowded, they are about six inches to nine inches across and unidentifiable as a normal granitic rock. The matrix of this dyke is a very pale grey in colour, having assimilated sufficient granitic material to be an intermediate rather than a basic rock.

The size of xenoliths varies within each dyke, the usual range being from a half inch to nine inches across. Exceptionally a xenolith of one foot to two feet across is found. Similarly the total concentration of xenoliths varies from less than 10 per cent of the rock, in parts of dyke No. 4, to greater than 50 per cent in dyke No. 2. Xenoliths are usually

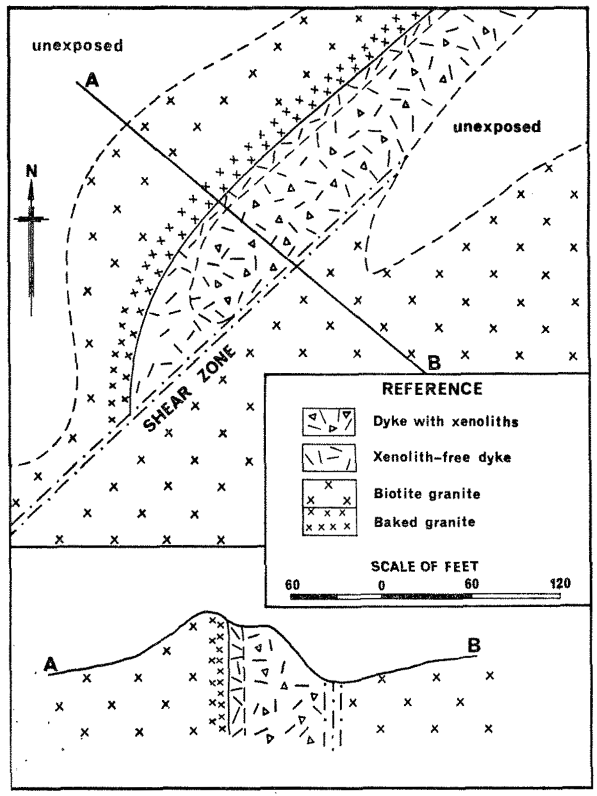

Fig. 12—Sketch map and section of xenolithic basic dyke Beeberring Hills Meckering, W.A.

distributed uniformly within a dyke but two variations from this are seen. In the Beeberring dyke (Plate 15, (1)) there is a zone about six feet wide along the northwest margin which contains no xenoliths. Xenolith-free material also occupies the first 30 yards of the dyke from its southwesterly termination (Figure 12). This lack of xenoliths could be due to a separate intrusion of basic magma, probably later than the main dyke, or it could be interpreted as a marginal zone where flow of the intruding magma caused the breakup and complete assimilation of the xenoliths. No distinct internal contacts within the dyke are exposed, and thin-sections indicate that considerable amounts of granitic material have been assimilated, both of which support the latter interpretation. In dyke No. 4 the northeasterly exposures show a uniform distribution of xenoliths but at the southwestern end xenolithic material is found to occupy distinct lenses within the dyke. Large areas are xenolith-free dolerite while others are crowded with small angular xenoliths. As exposures are traced southwestward the dyke becomes progressively more xenolith-free. There is no evidence of internal boundaries within the dyke, so that it is possible that the present distribution of the xenoliths reflects some form of turbulence in the magma resulting in incomplete mixing of the xenoliths into the magma.

PETROGRAPHY

The majority of dykes in the northeast-southwest swarm are normal quartz dolerites, some of which are porphyritic. In fresh specimens subophitic augite enclosing laths of labradorite comprises most of the rock, the remainder being a little opaque iron oxide (probably ilmenite) and interstitial quartz or micropegmatite. Most specimens, however, show some alteration and augite is often completely replaced by green hornblende. In extreme cases epidotization has reduced the rock to oligoclase and epidote with a little leucoxene. Porphyritic varieties carry phenocrysts of labradorite that show oscillatory zoning to andesine.

A coarse grained biotite granite which is presumed to form the majority of xenoliths and will serve as a model for the unaltered xenolith has the following description. Microcline and microcline perthite are the commonest minerals and together with oligoclase (An_{15-17}) and quartz forms a coarse-grained equigranular aggregate with granitic texture. Brown biotite occurs as interstitial flakes and is often associated with a little opaque iron oxide, zircon, and prismatic apatite. A little muscovite is also present as a secondary mineral after biotite or feldspar. The mafic content of the rock is variable and some specimens have a considerable proportion of biotite and apatite. Apart from the sericitization of the feldspars a little epidote is often present as an alteration product.

A generalized description of the petrology of the xenolithic dykes is made difficult by the varying amount of assimilation of granitic material that has taken place. A complete series of rock types can be found : from a dolerite which appears to be little altered ; to a hornblende granophyre with few of the characteristics of a rock with basic affinities. Between the extreme types the only common factor is the presence of granitic xenoliths and xenocrysts of quartz and plagioclase.

Dyke No. 4 (Plate 15) provides an example of a dyke affected relatively little by contamination. In thin-sections of specimens 15006 and 15035 (these numbers refer to specimens in the rock collection of the Geological Survey of Western Australia) the rock is essentially basaltic, consisting of plagioclase laths about 0·4 mm long, augite, and a little ilmenite. The plagioclase is continuously zoned from a core of labradorite (An_{60}) to andesine (An_{38}) and sometimes there is a very narrow rim of fresh oligoclase (about An_{20}). Augite occurs as pale green subhedral prismatic crystals up to 0·7 mm long and in 15006 is usually strongly uralitized or replaced by green hornblende. In 15035 this uralitization and replacement is most pronounced in the vicinity of granitic xenoliths. Interstitial to the main minerals are areas of quartz and micropegmatite which make up about 15 per cent of the rock (cf. Plate 16A). It is usually accepted that a tholeiitic magma, on differentiation, will yield about 5 per cent of micropegmatite (see Turner and Verhoogen, 1960, p. 211) so that in this particular rock the amount of granitic material assimilated would be at least 10 per cent and be present predominantly in the form of interstitial micropegmatite. A few small flakes of biotite, dleochroic from olive green to pale green, also appear to be the result of assimilation. Alteration products present include a little epidote, patches of chlorite, and hematite. Amygdales in 15006 are filled by calcite.

Progressive assimilation of larger amounts of granitic material is illustrated by consideration of specimens 15005 from the Beeberring dyke and 15031 and 15032 from dyke No. 2 (Plate 15). In the Beeberring dyke stumpy prismatic andesine (An_{42}) is the commonest mineral and usually forms a focal point from which a fine grained granophyric intergrowth radiates. The granophyre constitutes about 20 per cent of the rock. Specimen 15031 from dyke No. 2 is similar but the granophyre is coarser and the plagioclase is strongly zoned from a core of andesine (An_{49}) to oligoclase (An_{20}). Specimen 15032 is taken from a part of the same dyke which appears to be migmatitic in the field, and in thin-section it is almost entirely granophyric with very little original plagioclase remaining. All three specimens contain a brown hornblende which in part is being replaced by pale green actinolite and chlorite, but 15005, and to a lesser extent 15031, also contain corroded remnants of a pale green clinopyroxene which is mantled by the brown hornblende. Small subhedral crystals of ilmenite scattered throughout 15005 show progressive alteration in 15031 and 15032 to leucoxene and sphene, and in addition small hexagonal plates of menatite are found in 15032. A little green biotite, partly altered to chlorite, occurs in 15005 and 15031, especially in the vicinity of granitic xenoliths.

Dykes 3 and 5 (15011 and 15034) exhibit a slightly different pattern of contamination with euhedral laths of plagioclase up to 0·5 mm long and subhedral prisms of pale green augite set in a fine grained felsitic matrix (Plate 16B) in which granophyric texture is only sparsely developed. The plagioclase ranges from labradorite (An_{54}) to oligoclase (An_{28}) and is often zoned. The augite is sometimes uralitized but is often mantled by tremolite. The brown hornblende common in other specimens is only poorly developed, but small flakes of dark red-brown biotite are common. Ilmenite grains are scattered throughout the rock and are partially altered to leucoxene and sphene. Small hexagonal plates of hematite are common.

Granitic xenoliths and xenocrysts of quartz and plagioclase throughout the dykes show many signs of disequilibrium with, and progressive assimilation by, the enclosing basic magma. A feature common to all xenoliths is the almost complete destruction of the mafic constituents to leave a completely leucocratic rock. This step is followed by the gradual breakdown of the granitic texture of the xenoliths, leading eventually to the separation of xenocrysts of quartz and plagioclase.

The first stage of reaction between granite and basic magma is illustrated by 15028, taken from the wall rock of the Beeberring dyke ; the rock is still recognizably granitic in texture but the original perthite has been replaced by a granophyric intergrowth and the plagioclase shows signs of melting along cleavage planes. Original mafic minerals have been replaced by aggregates of chlorite and magnetite grains and there are a few secondary aggregates of small brown biotite flakes and subhedral actinolite. Another noticeable feature is the slight pink colour of the apatite. Specimen 15030 is taken from a large xenolith within the Beeberring dyke and shows the almost complete removal of mafic components except for a little chlorite, actinolite and ilmenite, and the breakdown of the granitic texture. Melting seems first to take place along crystal boundaries, the mutual reaction of quartz and feldspar resulting in the formation of a granophyric intergrowth (Plate 16C, D). Perthite has been almost completely eliminated to give large patches of granophyre. Between oligoclase and quartz a wide granophyric zone has developed. The granophyric intergrowth between plagioclase and quartz is demonstrably metasomatic in that ghost albite twinning can be traced from unaltered plagioclase into the granophyric intergrowth (Plate 16D). Another feature is that the formation of the granophyre appears to have depleted the central plagioclase in the albite molecule. The plagioclase of the biotite granite is usually oligoclase (An_{18-20}), but in this xenolith the core is andesine (An_{33}), while plagioclase in the outer zones of the granophyric intergrowth is oligoclase (An_{10}). This anorthite enrichment is not noticed in other specimens and is not supported generally by the analyses reported in Table 1 ; nowhere does it approach the enrichment from An_{30} to An_{90} recorded by Sigurdsson (1968) for xenoliths from Iceland. The growth of the granophyre zone has necessitated the incorporation of quartz, with the result that large embayments, filled by granophyre, occur in the quartz. Around some of the embayments the quartz has been recrystallized.

In the early stages of assimilation the granitic xenoliths are surrounded by a reaction rim of small biotite flakes. This is seen very well on xenoliths from dyke No. 4. At a later stage the biotite is dispersed throughout the rock.

As assimilation proceeds, the formation of granophyre within the xenolith becomes less marked and instead the plagioclase becomes traversed by remelt channels along the principal cleavages. Usually the channels are filled by untwinned feldspar, probably albite, but occasionally opaque iron oxide or even hornblende forms a network along the cleavages (Plate 16F). The cleavage fragments of plagioclase resulting from this process remain in optical continuity. The final stage is reached when the remelted quartz and feldspar forming along the crystal boundaries has reached sufficient proportion that the xenolith begins to disintegrate, releasing xenocrysts of quartz and plagioclase into the magma. Zircon also survives to this stage and is found as xenocrysts in specimen 15020 from dyke No. 6. The embayed xenocrysts of quartz have a similar appearance to quartz phenocrysts in a quartz-feldspar-porphyry ; the plagioclase xenocrysts progressively disintegrate as the melt channels within it widen.

The final cooling of the magma with its xenoliths has preserved all the stages of disintegration and assimilation of the xenoliths, and in several instances what would appear to have been a liquid pool within or marginal to a xenolith has been chilled and recrystallized as sheafs of poorly twinned plagioclase with small pools of quartz (Plate 16E). In dyke No. 2 a plagioclase is preserved in its final state of disintegration ; small rounded cleavage fragments are found which have been disorientated but not completely separated.

CHEMISTRY

Three dykes were chosen for chemical analysis (Nos. 1, 4 and 5, of Plate 15) and analyses of both matrix and xenoliths are given in Table 1. In addition non-xenolithic material from dyke No. 4 and a porphyritic quartz dolerite from Cunderdin have also been analysed. From Wilson (1958) analyses have been used to obtain an average quartz dolerite (Table 1 F) and an average biotite adamellite (Table 1 J) for Western Australia.

TABLE 1. CHEMICAL ANALYSES OF CONTAMINATED DOLERITE DYKES AND OTHER DOLERITES AND GRANITES

	A	B	C	D	E	F	G	H	I	J
SiO_2	66·49	63·78	54·00	55·75	52·45	49·54	80·16	75·07	81·29	74·12
Al_2O_3	13·94	13·95	14·61	14·52	16·29	14·31	10·66	13·94	9·92	13·91
Fe_2O_3	2·31	2·17	4·01	3·22	2·29	2·71	0·71	0·63	0·73	0·73
FeO	3·59	4·80	6·57	8·70	8·63	10·60	0·08	0·04	0·10	0·74
MgO	2·04	2·54	3·93	4·58	4·67	6·10	0·12	0·05	0·15	0·43
CaO	3·52	4·79	7·38	5·82	8·71	10·68	1·51	1·98	1·92	1·22
Na_2O	3·25	3·19	2·87	2·88	2·80	2·02	3·59	4·83	3·61	3·43
K_2O	2·84	2·64	0·55	0·55	0·43	0·49	2·64	2·89	1·25	4·69
H_2O^+	0·90	0·95	2·59	1·89	1·40	1·37	0·38	0·37	0·60	0·38
H_2O^-	0·05	0·13	0·40	0·13	0·07	0·33	0·08	0·21	0·23	0·08
CO_2	0·073	0·09	1·22	0·53	0·80	....	0·06	0·07	0·09	....
TiO_2	0·47	1·01	1·63	0·94	1·44	1·50	0·09	0·09	0·21	0·10
P_2O_5	0·10	0·12	0·09	0·12	0·11	0·15	0·02	0·02	0·03	0·09
FeS_2	0·09	0·15	0·25	0·18	0·20	0·14	0·03	0·02	....	0·07
MnO	0·07	0·07	0·12	0·15	0·14	0·25	....	....	....	0·08
Li_2O	....	0·09	0·05	....	0·02	....	0·08	0·09	0·05	....
Total	99·73	100·47	100·27	99·96	100·45	100·19	100·21	100·30	100·18	100·10

NORMS

	A	B	C	D	E	F	G	H	I	J
Quartz	25·05	20·55	14·89	13·89	7·47	2·56	46·37	32·15	51·84	32·84
Corundum	....	....	....	0·12	....	....	....	....	....	1·19
Orthoclase	16·78	15·60	3·25	3·25	2·54	2·99	15·60	17·07	7·38	27·69
Albite	24·79	26·99	24·28	24·36	23·69	16·93	30·37	40·86	30·54	29·06
Anorthite	15·06	15·95	25·36	24·73	30·61	28·50	5·17	7·82	7·17	5·42
Di. Wo.	0·54	2·69	1·23	....	2·84	9·82	0·34	0·14	0·43	....
Di. En.	0·29	1·40	0·71	....	1·38	4·95	0·29	0·12	0·37	....
Di. Fs.	0·23	1·21	0·45	....	1·41	4·65	....	....	....	....
Wollastonite	....	....	....	....	....	....	0·40	0·38	0·08	....
Hyp. En.	4·78	4·92	9·07	11·40	10·24	10·27	....	....	....	1·07
Hyp. Fs.	3·80	4·26	5·82	12·04	10·42	10·52	....	....	....	0·78
Magnetite	3·34	3·14	5·81	4·66	3·32	3·90	....	....	....	0·92
Hematite	....	....	....	....	....	....	0·70	0·62	0.72	....
Ilmenite	0·89	1·91	3·09	1·78	2·73	2·85	0·16	0·08	0·21	0·24
Titania	....	....	....	....	....	....	....	0·11	0·24	....
Pyrite	0·09	0·15	0·25	0·10	0·20	0·14	0·03	0·02	....	0·07
Apatite	0·23	0·28	0·21	0·28	0·26	0·38	....	0·04	0·07	0·23
Calcite	0·15	0·20	2·77	1·20	1·81	....	0·13	0·15	0·20	0·04

A 15005A. Matrix of xenolithic basic dyke, Beeberring Hills, north of Meckering (Analyst : F. R. W. Lindsey).
B 15034A. Matrix of xenolithic basic dyke, 2 miles south of Cunderdin (Analyst : J. R. Gamble).
C 15037A. Matrix of xenolithic basic dyke, 8 miles southeast of Meckering (Analyst : J. R. Gamble).
D 15036. Non-xenolithic basic material associated with 15037A (Analyst : F. R. W. Lindsey).
E 15010. Porphyritic quartz dolerite dyke, 1 mile southeast of Cunderdin (Analyst : P. Hewson).
F Average of five quartz dolerites from Western Australia (Wilson, 1958, p. 76, specimens Nos. 52, 53, 54, 55 and 57).
G 15005B. Granitic xenolith from basic dyke, Beeberring Hills, north of Meckering (Analyst : J. R. Gamble).
H 15034B. Granitic xenolith from basic dyke, 2 miles south of Cunderdin (Analyst : J. R. Gamble).
I 15037B. Granitic xenolith from basic dyke, 8 miles southeast of Meckering (Analyst : J. R. Gamble).
J Average of four biotite adamellites from Western Australia (Wilson, 1958, p. 67, specimens Nos. 10, 13, 16, 17).
Analyses 1–5 and 7–9 by staff of the Government Chemical Laboratories of Western Australia.

PLATE 16 (opposite)
Description of photomicrographs

A 15029. Xenolith-free material from the north-west margin of the Beeberring dyke (Plate 15 (1)). Andesine (An_{45-50}), augite and opaque iron oxide with a granophyric matrix. Crossed polarizers ×47. (FN 1379.)

B 15034. A large embayment in a quartz xenocryst from dyke No. 5. Small crystals of plagioclase, now strongly sericitized, and chlorite, set in a fine-grained felsitic matrix. Crossed polarizers ×47. (FN 1380)

C 15032. The development of a granophyric zone between quartz and plagioclase from a xenolith in dyke No. 2. The plagioclase shows a strong development of melt channels along cleavage planes and the mutual reaction of feldspar and quartz has led to the embayment fo the quartz and the formation of a granophyric intergrowth. Crossed polarizers ×47. (FN 1381.)

D 15030. Part of a large xenolith in the Beeberring dyke showing the growth of a granophyre zone by metasomatism. The upper crystal of plagioclase shows ghost albite twinning extending into the granophyre zone and outlining the original limits of the plagioclase. The lower crystal of plagioclase shows albite twinning of the feldspar of the granophyric zone. The central plagioclase has been enriched in lime and is now andesine (An_{33}) while the grnaophyre zone contains oligoclase (An_{10}). Crossed polarizers ×64. (FN 1382.)

E 15037. A xenolith from dyke No. 4, showing sheafs of poorly twinned plagioclase recrystallized in an embayment in quartz. Crossed polarizers ×47. (FN 1383.)

F 15037. Part of a xenolith from dyke No. 4, showing marginal melting of plagioclase. The remelt channels are mainly filled by untwinned feldspar but some hornblende and biotite is also present. Crossed polarizers ×47. (FN 1384.)

Turner and Verhoogen (1960, p. 148) discuss the assimilation of acid igneous rocks by a basaltic magma and conclude that the bulk of the material assimilated will be of a similar composition to the residual fraction of a crystallizing granite melt. Tuttle and Bowen (1958) have investigated experimentally the approximate granite system SiO_2–$NaAlSi_3O_8$–$KAlSi_3O_8$–H_2O and more recently von Platen (*in* Winkler, 1965) has extended the investigation to include the anorthite component, $CaAl_2Si_2O_8$. Von Platen was able to show that in addition to water pressure the presence of other volatile components and the albite-anorthite ratio of the original rock affect the composition of the eutectic mixture. From the work of von Platen (Winkler, 1965, pp. 188, 190) it appears that a plausible composition for the micropegmatite melt extracted by the basic magma from granitic xenoliths would be, at PH_2O = 2000 bars, Q = 39, Ab = 34, An = 3, Or = 24, which gives the chemical composition noted in Table 2 B.

TABLE 2. PARTIAL CHEMICAL ANALYSES OF QUARTZ DOLERITE AND MICROPEGMATITE

	A	B
SiO_2	50·9	76·8
Al_2O_3	14·9	13·5
Fe_2O_3 + FeO	13·1	....
MgO	6·0	....
CaO	10·5	0·6
Na_2O	2·2	4·5
K_2O	0·5	4·6

A Selected oxides from the average of six quartz dolerite dykes in Western Australia (E and F of Table 1), recalculated volatile free.
B Hypothetical micropegmatite melt at PH_2O = 2,000 bars.

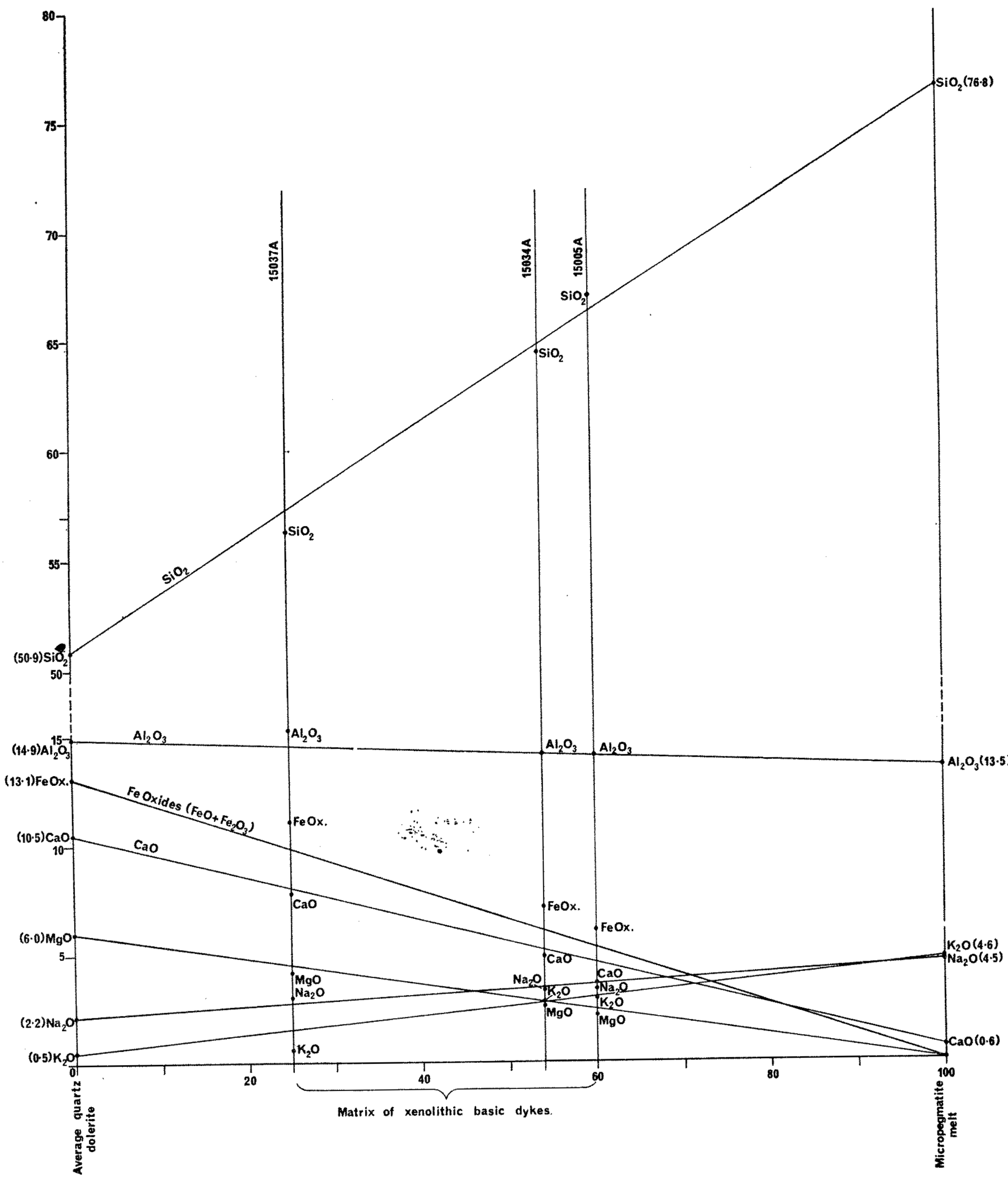

Fig. 13—Graphical representation of the assimilation of a hypothetical micropegmatite melt by a tholeiitic magma (all analyses recalculated volatile free).

Figure 13 is an attempt to correlate the composition of the micropegmatite melt, the average quartz dolerite magma of dykes in Western Australia and the hybrid rocks found as a matrix of the xenolithic dykes. Assuming that the hybrid rocks are mixtures of the two end members it is possible to fit the analysed specimens of xenolithic rock into intermediate positions to indicate the relative proportion of quartz dolerite magma and assimilated micropegmatite. From Figure 13 it will be seen that the hybrid rocks fit this hypothetical model with fair accuracy and that assimilation has varied from about 25 per cent in dyke No. 4 to about 60 per cent in dyke No. 1. Other conclusions that can be drawn from Figure 13 are that the original basic magma probably contained slightly less MgO and CaO than that calculated from the available analyses and the (Fe_2O_3 + FeO) content was probably higher. From the slopes of the graph it is also seen that the micropegmatite melt must have included a little (Fe_2O_3 + FeO).

The analysed specimen 15036 (Table 1 D), which was taken from an apparently uncontaminated portion of dyke No. 4 does not fit well into Figure 13 but has nevertheless probably assimilated a small proportion of granitic material.

The xenoliths separated from the matrix (Table 1, analyses G, H and I) probably represent quartz-rich patches of granite that would be more resistant to assimilation than average. The analyses show two things : firstly that although the Fe_2O_3 content has remained constant the FeO has been notably reduced ; and secondly a considerable reduction in the components of orthoclase. The FeO extracted from the granite is probably represented by the zone of biotite surrounding some xenoliths. For the matrix a proportionate change can be noted in the analyses related to the degree of assimilation but for the xenoliths the only consistent change that can be noted is the decrease of the anorthite-albite ratio from $An_{19.0}$ in dyke No. 4 (15037B) to $An_{14.5}$ in dyke No. 1 (15005B).

DISCUSSION

Other published examples

According to Frankel (1967) " xenoliths are relatively uncommon in dykes, sills and larger bodies (of basic rock) " ; nevertheless, several authors have discussed the assimilation of acid material by basic magma and presented estimates of the composition of the material extracted from the xenoliths and absorbed by the matrix.

Xenolith-rich basic dykes, similar to those of the Meckering district have been described from the Singhbum granite of Orissa State, India, by Raha and Saha (1963). Originally described as syenodioritic differentiates of a basic magma Saha and Guha (1968) reinterpreted them as normal dolerites that had assimilated granitic material from the xenoliths. A similar mechanism has also been invoked by Cogné (1962) to account for dykes of sizunite, a lamprophyre rich in potassium and phosphorous, from Cap Finistère, France. In Western Australia Kriewaldt (1964) briefly mentions a dyke stretching for about 50 miles southeast of Dampier and describes it as a granophyre with many xenoliths of granite and quartzite, and from California Knopf (1938) describes the assimilation of granodiorite xenoliths by a dolerite sill.

The mobilization and assimilation of sedimentary xenoliths by sills and dykes of the Karoo dolerites, from South Africa is described by several authors (e.g. Moore, 1965) and Wyllie (1961) has studied the fusion of xenoliths of Torridonian sandstone by a picrite sill in the island of Soay, Scotland.

Granitic xenoliths ejected by the volcano Surtsey, and their pyrometamorphism is described by Sigurdsson (1968) and a general account of the assimilation of granitic material by basic magma is given by Turner and Verhoogen (1960).

Despite the variety of xenoliths and geological environment many of the above authors describe a basically similar sequence of events, including the initial formation of a liquid rich in SiO_2 and K_2O and the penetration of veins of glass along the cleavages of the plagioclase, leading to their eventual disintegration. The liquid extracted from the xenoliths has been estimated by several methods including the analysis of glasses, all authors agreeing that tı approximates to the experimentally determined low-melting fraction of the granite system.

Origin of the xenoliths

The mechanism usually invoked for the intrusion of basic dykes is the extension of a fissure by a wedge of magma (Anderson, 1951). For this mechanism to operate the magma must be under a pressure at least equal to the hydrostatic pressure in the rock. At the tip of the wedge there will be a horizontal tension sufficient to fracture the rock and extend the fissure. Assuming an isotropic country rock the magma wedge would produce a clean fracture and a minimum of xenoliths. This is in agreement with the commonly observed lack of xenoliths in basic dykes (Frankel, 1967) and the sharp nature of their margins. Dykes emplaced by magmatic stoping however, could be expected to contain many xenoliths of country rock, but equally, sharp linear margins would be the exception. The presence of both xenoliths and sharp margins in the dykes under discussion argues that other factors must be involved in their emplacement.

The basic pattern of dyke intrusion in the Meckering area is of two swarms approximately at right angles to one another, with the northeast-southwest swarm predominating (Plate 15). In addition, in several areas the granites are slightly sheared parallel to the dykes (Lewis, 1969) indicating the possibility that the dykes are intruded along shear zones. The majority of shear zones observed were narrow zones less than an inch wide, and showed no lateral displacement. Dykes could be expected to take advantage of such lines of weakness but the number and size of xenoliths carried forward by the magma would be very small. Larger shear zones or even faults would be expected to be an easier passage for basic magma and could contain numerous blocks of country rock to form the xenoliths. The hypothesis that the xenolithic dykes were intruded along faults is supported by the wide epidotized crush zone seen along the southwest margin of the Beeberring dyke (Plate 15) and the discovery by F. R. Gordon (pers. comm.) of an old fault (a few hundred yards northwest of, and parallel to, dyke No. 2) that had been reactivated during the Meckering earthquake of October 14, 1968.

If the xenolithic dykes are emplaced along wide shear zones then it is to be expected that the xenoliths will be of the country rock into which the dykes are intruded. In the Meckering district the dykes are emplaced exclusively in granite and although, because of metamorphism, the xenoliths cannot be accurately matched to a particular granite, they all appear to be of granitic origin. Most of the xenolithic dykes are intruded into a fairly coarse grained biotite granite which matches the xenoliths fairly well, while dyke No. 2, which contains many fine grained xenoliths is intruded into a fine grained adamellite. A local origin for the xenoliths is supported by evidence from the Northam and Mangaroon dykes. At Northam the dyke is intruded into granite gneiss and contains xenoliths of gneiss, while at Mangaroon the xenoliths can be correlated with the granites and high grade metamorphics into which the dyke is intruded.

Basaltic magma and solid granite have a similar density (Holmes, 1944) so that it is unlikely that the concentration of xenoliths found in some dykes represents an accumulation of xenoliths that have either sunk through the basic magma or have floated to the top. A more probable cause of the concentration is that the advancing magma swept the xenoliths before it. The streaking out of xenoliths, especially in dyke No. 2, shows that the xenoliths have been moved by the magma up the plane of the dyke and the irregular distribution of xenoliths in dyke No. 4 probably indicates that the flow was not laminar. A single xenolith of sandstone in the Mangaroon dyke, probably derived from Bangemall Group sediments that once overlaid the area, shows that magma could also move downward.

Assimilation of the xenoliths

The ultimate product of the assimilation of granitic xenoliths by a basic magma, assuming a sufficient supply of heat, would be the complete homogenization of the magma with the production of a rock type intermediate between the xenoliths and the invading magma. The dykes under discussion represent an intermediate stage in the process and the petrographic and chemical evidence can be discussed under two headings. Firstly there is the melting effect of granite being immersed in a basic magma with which it is not in equilibrium, resulting in the selective fusion and extraction of certain ions and their incorporation in the magma, and secondly there is the ' mechanical ' effect, whereby xenoliths are progressively reduced in size until they are more easily absorbed and their presence more difficult to detect.

Sigurdsson (1968) noted that the first product of fusion of granitic xenoliths brought up by the volcano Surtsey was a brown glass, and concluded that this explained the removal of Fe, Mg, and Ti from the rock and the early breakdown of the hydrous ferromagnesian minerals in the xenolith. Knopf (1938) also states that early-formed melt has dissolved some biotite in granodiorite xenoliths caught up in a dolerite sill. In the Meckering dykes no glass is seen but few of the xenoliths contain mafic minerals and some are surrounded by fringes of small biotite flakes which possibly represent the migration of iron from the xenolith. In the wall rock of the Beeberring dyke the mafic minerals have been attacked and reduced to aggregates of magnetite grains. Evidently, as with the Icelandic and North American examples, the mafic minerals have been the first to be metamorphosed and, along with a K-rich liquid, the first to be removed from the xenolith and absorbed by the magma. Unlike the Icelandic examples the Ti has not been affected in the Meckering xenolithic dykes.

Both Knopf and Sigurdsson describe the early attack on alkali feldspars and the formation of a liquid rich in alkalis and silica. Knopf describes a situation exactly similar to that seen in the larger xenoliths from the Meckering dykes, namely " that the glass was produced by the mutual reaction between the quartz and adjacent feldspar, forming a relatively low melting liquid ". (Knopf, 1938, p. 376) In the Meckering dykes a granophyric intergrowth takes the place of glass (Plate 16C). The removal of a liquid rich in alkalis and silica should leave the xenolith impoverished in those constituents and enriched in the more refractory constituents CaO and MgO. Sigurdsson reports that in pyrometamorphic xenoliths thrown up by Surtsey the plagioclase is An_{85-95} while less altered granitic xenoliths contain An_{20-30}. In the Meckering examples the change noted is not so dramatic ; 15030 shows oligoclase (An_{20}) being enriched with lime to give andesine (An_{33}) and the analyses of Table 1 indicate a variation from $An_{14.5}$ to $An_{19.0}$, the latter being from a rock where the effects of assimilation are slight. It would seem, in the examples under discussion, that, although initially the extracted liquid was rich in soda and the xenolith thereby enriched in lime, as assimilation proceeded the temperature was sufficient to extract a liquid with lime and soda in similar proportion to the original rock. The corrosion and embayment of quartz xenocrysts and the disintegration of plagioclase by penetration of the melt along the cleavages, is described by Knopf and Sigurdsson in a manner similar to that found in the Meckering dykes.

The composition of the liquid extracted has been calculated for Figure 13 assuming that the work of von Platen (Winkler, 1965) relating to the system SiO_2–$NaAlSi_3O_8$–$CaAl_2Si_2O_8$–$KAlSi_3O_8$–H_2O gives a reasonable estimate of the lowest melting fraction of a granite. An estimate of the actual composition of the liquid can be made by taking those figures which give the best fit to the data available. Alternatively assuming the proportions of basic magma and granitic material given by Figure 13, and the composition of the basic magma (Table 2 A), the composition of the liquid can be calculated. Two estimates of the composition of the assimilated material are given in Table 3 (F and G) along with similar estimates by Sigurdsson (1968) ; Saha and Guha (1968), Wyllie (1961) and analyses of actual glasses by Frankel and Switzer (*in* Wyllie, 1961). Apart from the introduction of about 2 per cent Fe_2O_3 or (Fe_2O_3+FeO) it will be noted that the estimates agree fairly well with that calculated from von Platen's data (Table 2 B) and with the analyses of actual glasses by Frankel and Switzer from remelted xenoliths. The reversal of the proportions of Na_2O and K_2O compared with the other analyses is the only significant difference but the validity of this for the Meckering dykes is borne out by the almost complete removal of K-feldspar early in the assimilative process.

The xenoliths thrown out during the eruption of Surtsey are often surrounded by a layer of basaltic glass (Sigurdsson, 1968, p. 443) which would protect them from mechanical breakdown. In the situation of an intrusive dyke the xenoliths will be constantly brought into contact with fresh magma, the movement of which will lead to a mechanical breakup of the xenolith.

In the earliest stages of assimilation, a fringe of biotite is present around the xenolith but later becomes dispersed throughout the rock. This is followed by mutual reaction along crystal boundaries, giving rise to a low-temperature melt. As the proportion of this melt increases, the bond between the crystals (and hence the mechanical strength of the xenolith) diminishes. This is shown in many xeno-

TABLE 3. COMPOSITION OF LIQUID FRACTION EXTRACTED FROM XENOLITHS DURING ASSIMILATION

	A	B	C	D	E	F	G	H
SiO_2	71·90	69·72	72·57	71·29	75·70	76·00	75·84	77·00
Al_2O_3	12·45	14·80	13·08	12·69	10·30	13·50	13·23	13·50
Fe_2O_3	....	0·55	0·94	0·69	6·10	2·00	1·90	....
FeO	....	1·36	0·50	0·41	....	....	....	....
MgO	....	0·40	0·08	0·41	....	....	....	....
CaO	1·89	1·42	1·12	0·77	....	0·50	....	1·00
Na_2O	4·18	3·87	3·75	4·19	4·60	3·90	4·00	4·50
K_2O	1·91	2·75	2·33	3·54	1·80	4·20	4·43	4·00
H_2O^+	6·32	4·33	5·21	4·57	....	....	....	....
H_2O^-	....	0·15	0·17	....	....	....	....	....
TiO_2	....	0·48	0·18	0·29	....	....	0·28	....
P_2O_5	1·35	0·21	0·23	....	....	....	0·08	....
Fe_2S	....	....	....	....	....	....	0·10	....
Total	100·00	100·22	100·26	99·66	98·50	100·00	99·86	100·00

A Calculated composition of the glass in a fused xenolith from a picrite sill, Soay, Scotland (Analyst : W. H. Herdsman).
B Calculated composition of the glass in a fused xenolith of feldspathic sandstone in dolerite, South Africa (Analyst : J. J. Frankel).
C Glass separated from fused xenolith of feldspathic sandstone in dolerite, South Africa (Analyst : J. J. Frankel).
D Glass separated from a fused xenolith of tonalite (Analyst : G. Switzer).
E Hypothetical liquid extracted from granitic xenoliths by a basic magma, Surtsey, Iceland ; calculated graphically by H. Sigurdsson (1968, p. 449).
F Composition of the liquid extracted from granitic xenoliths by basic magma ; Meckering xenolithic dykes. Estimated graphically.
G Composition of the liquid extracted from granitic xenoliths by basic magma ; Meckering xenolithic dykes. Calculated from analyses A and B of Table 1.
H Hypothetical micropegmatite melt, Saha and Guha (1968).
Analyses A to D are taken from Wyllie (1961), Table 2, p. 14.

liths where all trace of granitic texture has been lost and the xenolith now consists of an agglomerate of xenocrysts with narrow zones of hybrid material between them. The final stage is the dispersion of the xenocrysts into the surrounding magma, and ultimately their total absorption.

The assimilation of granitic material cannot be considered exclusively as the diffusion of ions out of a xenolith into the magma as if a semi-permeable membrane surrounded the xenolith. The effect of mechanical breakdown will be to increase the surface area exposed to reaction with the magma, and to increase it differentially. Quartz, which tends to form large xenocrysts, will react slower than feldspar which breaks up into small cleavage fragments and presents a large surface area to the magma. These factors could account for the consistently low silica analyses recorded in Table 3 for glass and liquid extracted from xenoliths when compared with the theoretical work of von Platen, and the high figures for lime and iron.

Mechanical factors may account for the fact that although the SiO_2 content of the extracted liquid (Table 3, F, G) appears to be higher than that of the original granite (Table 1, J), the SiO_2 content of the xenoliths is higher than both (Table 1, G, H, I). The xenoliths are possibly those parts of the granite which were more quartz-rich, the feldspar-rich parts having been more susceptible to mechanical breakdown and easy assimilation.

CONCLUSIONS

The xenolithic dykes which have been described from the Meckering district are a relatively uncommon feature of basic dyke swarms ; they present problems of the mechanics of intrusion, and provide a good opportunity to study the assimilation of acidic xenoliths by basic magma. It has been shown that :

1. The dykes were probably intruded along faults or shear zones and the xenoliths are from the local country rock.

2. The original magma intruded was similar to the average quartz-dolerite magma found in basic dykes throughout the Archaean of Western Australia.

3. Chemical and petrographic differences between the matrix of the xenolithic dykes and a normal quartz-dolerite can be accounted for by the assimilation of a low melting-point fraction extracted from the granitic xenoliths.

4. The composition of the low melting-point fraction (Table 3, F, G) is comparable to that which has been obtained for synthetic systems by Tuttle and Bowen (1958) and von Platen (Winkler, 1965).

NOTE

Since writing this article Laitakari (1969) has published an account of a Finnish dyke swarm trending west-northwest which contains several xenolithic dykes. The author proposes that the dyke trend was controlled by major faults in the area, and several have marginal breccia zones containing a matrix of prehnite. Unlike the Meckering xenolithic dykes the xenoliths are predominantly quartzite of sedimentary origin and probably originate from a deeper level than at present exposed in the country rock. The few xenoliths of granodiorite show melting and assimilation similar to the Meckering examples.

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THE AGE OF THE COPPER HILLS PORPHYRY

by J. R. De Laeter and A. F. Trendall

ABSTRACT

The Copper Hills Porphyry is a small elongate porphyry intrusion at the margin of a broad granite dome in the Archaean Pilbara Block, in the northwest of Western Australia. Previous Rb-Sr results indicated an age about 3,000 m.y. for the granite, and available geological mapping suggested that the porphyry was intruded, before folding, as a sill in the sediments which now dip steeply adjacent to the porphyry. The Rb-Sr results on core samples of the porphyry give an isochron of 2,880 $\pm$ 66 m.y. with an initial Sr^{87}/Sr^{86} ratio of 0·7303. The porphyry is more likely to have been intruded after folding, as an irregular steeply dipping sheet, between the granite and the formerly adjacent metasediments, although it is uncertain what event in the development of the porphyry is represented by the isochron.

INTRODUCTION

Isotope geochronology was initiated in Western Australia at the Physics Department of the University of Western Australia in the late 1950's, and particularly important results were obtained from Precambrian rocks by the Rb-Sr method (Wilson and others, 1960). This work was later discontinued locally, and taken up at the Geophysics Department of the Australian National University, with which the Geological Survey has maintained an active liaison in this field. In 1968 it was agreed to re-establish Rb-Sr geochronological work in Perth as a cooperative project of the Physics Department of the Western Australian Institute of Technology and the Geological Survey, broadly contributing laboratory and field work respectively. To test the feasibility of the liaison, eight initial projects were conceived, conforming with the following requirements :

1. Each project to involve relatively few analyses, and to be self-contained and geologically simple.

2. Analytical work to be initially confined to material with a Rb-Sr ratio suitable for a combination of unspiked Sr mass spectrometry and X-ray fluorescence analysis (no isotope dilution required).

3. Projects to avoid overlap with continuing Australian National University work.

We report here the results of the first of these projects ; a determination of the age of a small intrusive body of porphyry in the Archaean rocks of the Pilbara Block.

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GEOLOGY

Regional setting

The Pilbara Block (Prider, 1965 ; Daniels and Horwitz, 1969), is an irregularly shaped area of Archaean rocks in the northwest part of Western Australia, approximately between the latitudes 20° and 22°S and longitudes 118° and 121°E. It is bounded to the south and east by the basal unconformity of the overlying Proterozoic Fortescue Group, to the north by the edge of the Phanerozoic Canning Basin, and to the northwest by the Indian Ocean.

The component rocks of the block are typical of those of similar Archaean areas both in Western Australia and in the ancient shields of other continents. Sinuous belts of low-grade metasedimentary and metavolcanic rocks are disposed around broad domes of granite (Ryan, 1964 ; Horwitz, 1966). These encircling belts are steeply synclinal, so that on a regional scale the granite margins are broadly concordant with the adjacent stratified rocks, although in detail the granites are invariably intrusive and mildly discordant. There is usually a gneissose or migmatitic margin within the boundary of the granite and a narrow aureole of thermal metamorphism immediately outside it.

Initial descriptions of the metasedimentary and metavolcanic rocks of this area (Maitland, 1904) differentiated between the older Warrawoona Beds, with a predominance of metavolcanics, and the younger Mosquito Creek Beds, consisting mainly of clastic sediments. These terms, which were current for some sixty years, are not now in common use, but have not been satisfactorily replaced ; the two lithologies are now seen as distinct but coeval facies of a complex depositional environment (Ryan, 1964).

Copper Hills Porphyry

The most recent description of the area of occurrence of the Copper Hills Porphyry is that of Noldart and Wyatt (1963), who mapped the Marble Bar and Nallagine 1 : 250,000 map sheet areas (a total of 16,500 square miles) in the eastern part of the Pilbara Block. Figure 14 is taken directly from their maps, and shows the outcrop area of the porphyry along the southeastern edge of a granite dome. In surface exposures the porphyry is a tough, aphanitic, white, cream or pale-green rock with a variable content of quartz and weathered feldspar phenocrysts up to 5 mm in diameter. Noldart believes the porphyry to be a sill intrusive into the steeply dipping metasediments adjacent to the granite. Its outcrop area is closely associated with that of a coarse-grained feldspar porphyry whose appearance varies from granitic to almost black, due to the fine-grained matrix.

Previous age estimates

Noldart (*in* Noldart and Wyatt, 1963, p. 192–4) regards the Copper Hills Porphyry as older than the adjacent granite, and this in turn as older than the coarse-grained feldspar porphyry. This latter relationship is described as tentative, and is based on the absence of shearing in the coarse porphyry. The intrusion of the Copper Hills Porphyry is seen as associated with the earliest fold movements, which intensified to produce shearing before the intrusion of the granites. Noldart and Wyatt (1963) record no contact relationships between the granite and the two porphyry types sufficiently well displayed to make their age relationships unequivocal.

Compston and Arriens (1968, p. 566) have summarized the isotopic data from the Pilbara Block available at the time of our study. Twelve granites from various domes of the Pilbara Block, including that with which the Copper Hills Porphyry is associated, give a Rb-Sr isochron of 3,050 $\pm$ 180 m.y. A single granite previously reported by Leggo and others (1965) gave a maximum age of 3,040 m.y. Acid lavas intruded by granite also gave a 3,000 m.y. age, " suggesting either that emplacement of the granite followed not long after eruption of the lavas or alternatively, that the Rb-Sr age of the acid lavas was reset during emplacement of the granite " (Compston and Arriens, 1968, p. 566). Age determinations of pegmatite minerals, by the Rb-Sr, K-Ar and U-Pb methods, give variable younger ages.

COPPER MINERALIZATION

The total copper production from the Copper Hills Mine between 1952 and 1960 was 464·71 long tons of copper ore (average 25·6 per cent Cu) and 13,255·15 long tons of cupreous ore (Low, 1962). A little ore was produced also from smaller nearby deposits, including Kellys Copper (Figure 14). Noldart (*in* Noldart and Wyatt, 1963, p. 194) describes the mineralization as associated with shears with a trend of 290° to 310° in the northern part of the porphyry, swinging to 310° to 330° in the southern part. He found mineralization in shears in the adjacent metasedimentary rocks as well as in the Copper Hills Porphyry and coarse-grained feldspar porphyries.

A report on drilling by Lord (1957) notes that although the main copper mineralization in the porphyry is confined to fractures and veins, there is disseminated copper throughout the porphyry.

MATERIAL USED

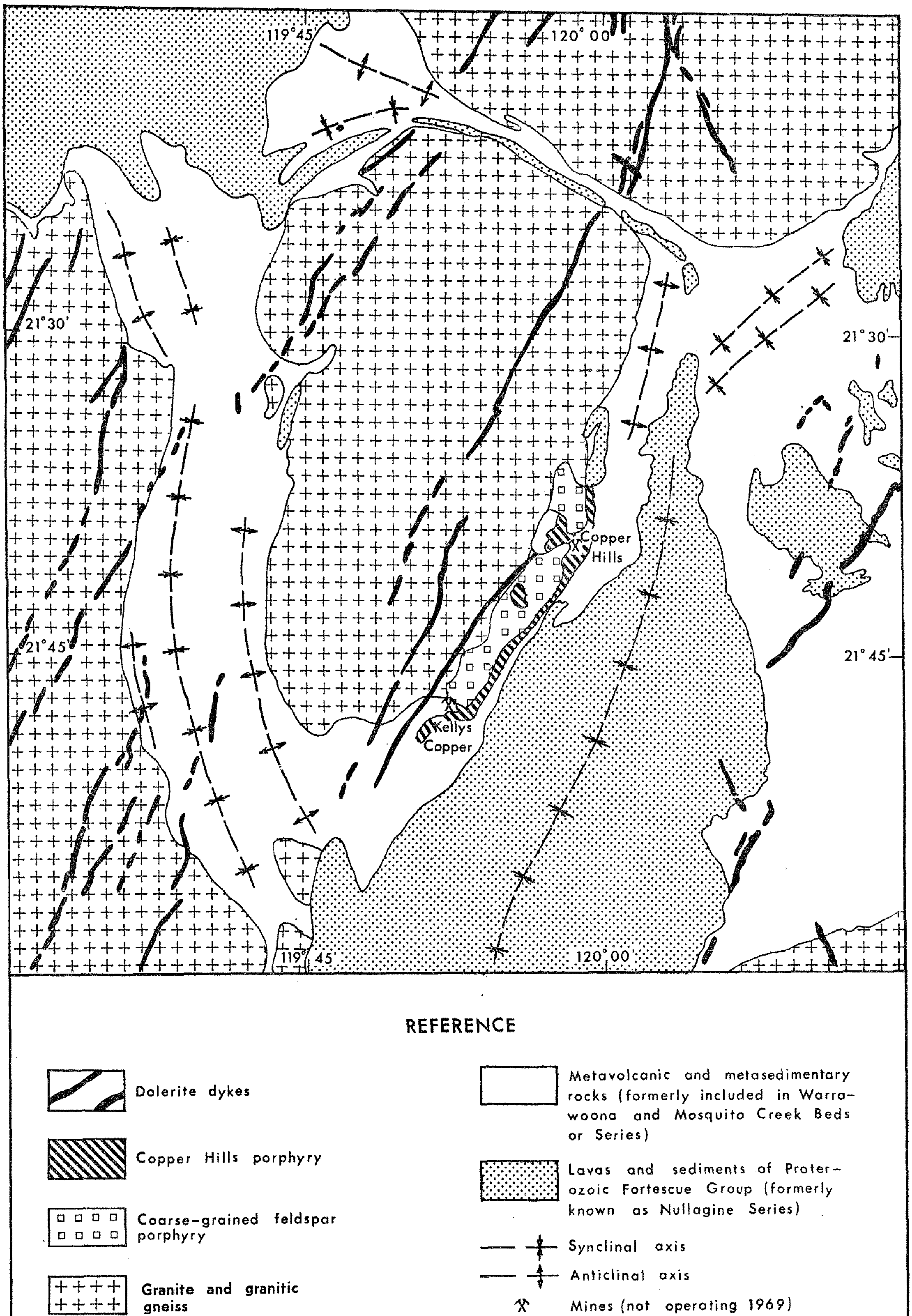
One of us (A.F.T.) visited Copper Hills in 1964, and collected representative samples of core remaining at the site from drilling carried out by New Consolidated Goldfields (Australasia) Pty. Ltd. in 1957. The core was in disarray, and neither the hole number nor the depth is known, but as all the drillholes were well inside the indicated outcrop of the Copper Hills Porphyry, and collared at a maximum distance of 518 feet from the mine portal, there is no doubt of the rock type which they represent. The six small lengths of core collected were numbered 12753A–F.

Considering that the six pieces were initially selected to embrace a wide range of porphyry type there is remarkably little variation within them. All are pale cream or pale green porphyritic rocks with abundant quartz and feldspar phenocrysts, forming between about 30 and 50 per cent of the total rock volume.

In thin-section they fall naturally into two groups : 12753 B, C, and F, in which feldspar phenocrysts are comparatively unaltered, and 12753 A, D, and E, in which the (assumed) feldspar phenocrysts are completely replaced by secondary minerals. In the following description these are referred to as the fresh and altered groups respectively.

In the fresh group B and C have evenly distributed quartz phenocrysts up to about 3 mm in diameter. Most are subhedral, with smoothly rounded edges, and many are deeply embayed. The feldspar phenocrysts are less abundant, are anhedral, and are of the same average size as the quartz phenocrysts, although the size range is greater. They are all of albite, either clear or cloudy with fine (less than 1μ) indeterminate dust, and most have irregular internal patches of carbonate or fine sericite. Combined albite/carlsbad twinning is general, and many of the phenocrysts are formed of a coarse mosaic of several separate crystals. There is no zoning, but a few phenocrysts have thin internal shells of chlorite mimetic of the external boundaries. The matrix is notable for its non-uniformity, but usually consists of a quartz mosaic of average grain diameter between 0·02 and 0·1 mm, with a variable proportion of finely flaky sericite and subordinate chlorite and carbonate. Sharply defined angular patches of finely crystalline chlorite are probably pseudomorphous after a ferromagnesian parent, possibly amphibole. F is a closely similar rock, but the albite phenocrysts in it are cloudy with sericite flakes, and there is an irregular distribution of the phenocrysts, as though the rock were a welded breccia of pieces of phenocryst-free matrix and of normal porphyry.

The rocks of the altered group, A, D, and E, closely resemble those of the fresh group, except that albite phenocrysts are absent, and are presumably represented by the areas of equivalent size and shape which are clearly defined by their lighter colour within the matrix, although they are composed of similar material. The light colour is related partly to a higher sericite/quartz ratio and partly to an absence of chlorite. In this group there are scattered, well formed rectangular chlorites about 0·02 mm across. They consist essentially of single crystals, although they have suffered some late alteration, and probably have an origin different from the areas of finely crystalline chlorite. In these rocks there are also small scattered grains of undetermined opaque minerals.



MAP SHOWING
THE REGIONAL GEOLOGICAL RELATIONSHIP OF THE
COPPER HILLS PORPHYRY

SCALE

8 0 8 16 miles

(Geology from Noldart and Wyatt, 1963)

Fig. 14.

Although no chemical analyses of these rocks were made, their mineralogy suggests their chemical equivalence with quartz-rich adamellite, since the low potassium content indicated by the restriction of feldspar content to albite is probably at least counterbalanced by the general abundance of sericite.

EXPERIMENTAL PROCEDURE

Sample preparation

About 100g of each sample (equivalent to about 3 inches of BX core) were reduced to —100 mesh using a jaw crusher and a Kurt Resch hammer mill. After splitting, about 10g were further ground for about 15 minutes in a Kurt Resch automatic mortar grinder.

Chemistry

An accurately weighed sample of each rock selected for analysis was placed in a teflon dish. For an 0·5g sample approximately 10 mls of 48 per cent HF and 1·5 mls of 70 per cent $HClO_4$ were required for the disolution, the mixture finally being taken to dryness on a hotplate. The residue was then dissolved in 30 mls of 2·5N HCl and the solution taken to dryness. Approximately 10 mls of 2·5N HCl were then added and the solution transferred to a quartz ion exchange column containing 20g of wet Dowex 50W-X8, 200–400 mesh cation exchange resin. Strontium was eluted using 2·5N HCl, the cut being taken between 40 mls and 50 mls. The eluted sample was taken to dryness, redissolved in a minimum of 2·5N HCl, and placed on a micro column containing lg of cation resin. The strontium was then eluted as before and the eluant taken to dryness ready for mass spectrometric analysis.

Mass spectrometry

Isotopic analyses were carried out on a 12-inch radius, 90° magnetic sector, solid source mass spectrometer. The source and collector slits were set to 0·004 in. and 0·020 in. respectively to provide a resolution of approximately 400. The sample was mounted as the chloride on the side filament of a conventional triple filament surface ionization source. Rhenium filaments, which were outgassed prior to use, were employed throughout. No evidence of rubidium or strontium contamination from the filaments or ion source could be detected. New filament buttons were used for each sample and the source was cleaned between successive analyses.

The usual operating currents for strontium, loaded as the chloride, are 4·0 amps for the centre, ionizing filament, and approximately 1·0 amps for the side filaments. For rubidium chloride, slightly lower currents were used. For a strontium analysis the filaments currents were initially adjusted to a value where strontium emission is minimal. These conditions were retained for about one hour to enable the alkali beam, which was invariably present, to be reduced to a level where it no longer has a serious suppressing effect on the production of strontium ions. After the rubidium beam was reduced to a negligible size, the side filament temperature was gradually increased until an Sr^{88} ion beam of the order of 10^{-12} amps was obtained. For a $5\mu g$ sample this beam could be maintained over several hours of operation without a marked decrease in intensity.

An electron multiplier with a gain of about 10^4 was used as the ion detector, after which the signals were amplified by a vibrating reed electrometer. A voltage to frequency converter, followed by an electronic counter, allowed digital presentation of the data. The ion currents were also displayed on a recorder chart. The peaks were magnetically scanned from the lowest mass to the highest mass and then back again, this operation constituting one sweep. The digital read-out system was adjusted so that integrated voltages of one second integration time were recorded in succession through sweeps of the mass spectrum. The sweep speed was adjusted so that four to five such numbers were recorded across the top of a peak, whilst a minimum of time was spent between peaks.

Replicate analysis of the M. I. T. standard strontium carbonate were made over a period of time to give a mean value of Sr^{88}/Sr^{86} of 8·2850 rather than 8·3752 as determined by other authors (Faure and Hurley, 1963). The difference is largely due to the influence of electron multiplier-induced mass discrimination. However for the data contained in Table 1 the Sr^{87}/Sr^{86} ratios have been normalized to $Sr^{88}/Sr^{86} = 8{\cdot}3752$.

X-ray fluorescence

This technique was used to select rocks with favourable Rb-Sr ratios for mass spectrometric analysis and also to determine precise values of the Rb-Sr ratio for the selected samples. A Siemen's SRSI fluorescence spectrometer, equipped with a tungsten tube, a lithium fluoride (200) crystal, and a scintillation detector, was used for the Rb-Sr analyses. Finely ground samples (—200 mesh) were pressed with a boric acid backing (Norrish and Chappell, 1967) and were then in a form suitable for X-ray fluorescence analysis.

Rubidium was read at a 2θ position of 26·56° and strontium at a 2θ position of 25·09°. Before selecting the background positions consideration was given to possible interference effects and the profile of the background in the vicinity of the $RbK\alpha$ and $SrK\alpha$ peaks was carefully observed. The most satisfactory background positions for this spectrometer were found to be at 2α positions of 27·06° and 25·81° for rubidium and 25·59° and 24·59° for strontium.

A preset count of 2×10^5 was used for each position and a dead-time correction was then made. Each sample was measured a number of times depending on the concentrations of rubidium and strontium in the particular sample. The final accuracy given in Table 1 has been assessed at the 95 per cent confidence level.

A conversion factor from intensity to weight ratios was determined by analysing a number of standard rocks, with a wide range in Rb-Sr ratio, in which the concentration of rubidium and strontium was accurately known. This calibration curve allowed for matrix effects and the variable fluorescent response between rubidium and strontium. Machine drift during an analysis was obviated by analysing a reference sample between each run. In addition an appropriate standard rock was analysed with each suite of samples.

For each isochron the Rb-Sr ratio in at least one sample was determined by isotope dilution. This enabled a minor adjustment for differences in matrix between the standard and the rocks analysed to be made, if necessary, using the isotope dilution value.

Isotope dilution

The elemental abundance of strontium in a sample was determined using a strontium nitrate tracer enriched to approximately 76 per cent in Sr^{84}. The rubidium content was likewise determined using a rubidium chloride tracer enriched to approximately 97 per cent in Rb^{87}.

Known quantities of the tracers were added to accurately weighed aliquots of the sample after it had been taken into solution in 2·5N HCl. The spiked aliquots were then taken to dryness and the residues re-dissolved in a minimum of HCl and transferred to cation exchange columns. The ion exchange chemistry was carried out as before except that rubidium was eluted with 1N HCl. The final eluants were then taken to dryness and mounted as the chloride in the mass spectrometer ion source.

Blank determinations showed that strontium contamination introduced by the reagents and containers was less than 10^{-7}g. The corresponding rubidium contamination was less than 10^{-8}g for the complete extraction procedure.

Treatment of data

The Rb^{87}/Sr^{86} ratio for each sample was determined from the measured Sr^{87}/Sr^{86} ratio and the corresponding Rb-Sr value using the relation :

$$\frac{Rb^{87}}{Sr^{86}} = \frac{Rb}{Sr}\left[\frac{827\cdot 70 + 87\left(\frac{Sr^{87}}{Sr^{86}}\right)}{308\cdot 0}\right]$$

as discussed by White and others (1967).

TABLE 1. ANALYTICAL DATA FOR SAMPLES OF THE COPPER HILLS PORPHYRY

Sample		Rb/Sr	Rb^{87}/Sr^{86}	Sr^{87}/Sr^{86}
12753C	....	2·67 ± 0·05	7·98 ± 0·16	1·0690 ± 0·0012
12753B	....	2·80 ± 0·06	8·36 ± 0·17	1·0605 ± 0·0017
12753F	....	4·74 ± 0·09	14·49 ± 0·29	1·3093 ± 0·0007
12753E	....	5·54 ± 0·11	17·1 ± 0·3	1·4328 ± 0·0027
12753A	....	15·6 ± 0·60	54·5 ± 2·6	2·8555 ± 0·0036
12753D	....	27·2 ± 1·1	117·1 ± 4·7	5·728 ± 0·010

RESULTS

The measured Rb-Sr and Sr^{87}/Sr^{86} ratios, as well as the Rb^{87}/Sr^{86} ratio calculated from these, are given, with errors at the 95 per cent confidence level, in Table 1, for each of the six samples used. An isochron derived by the method of Williamson (1968), which minimises the weighted sum of squared residuals, appears in Figure 15. Age calculations are based on a Rb^{87} decay constant of $1\cdot 39 \times 10^{-11}$ year $^{-1}$. The errors associated with the age and initial Sr^{87}/Sr^{86} ratio are calculated from the standard deviation of the slope and intercept respectively.

The computed age from the six samples is 2,880 ± 66 m.y., with an initial Sr^{87}/Sr^{86} ratio of 0·7303 ± 0·0119.

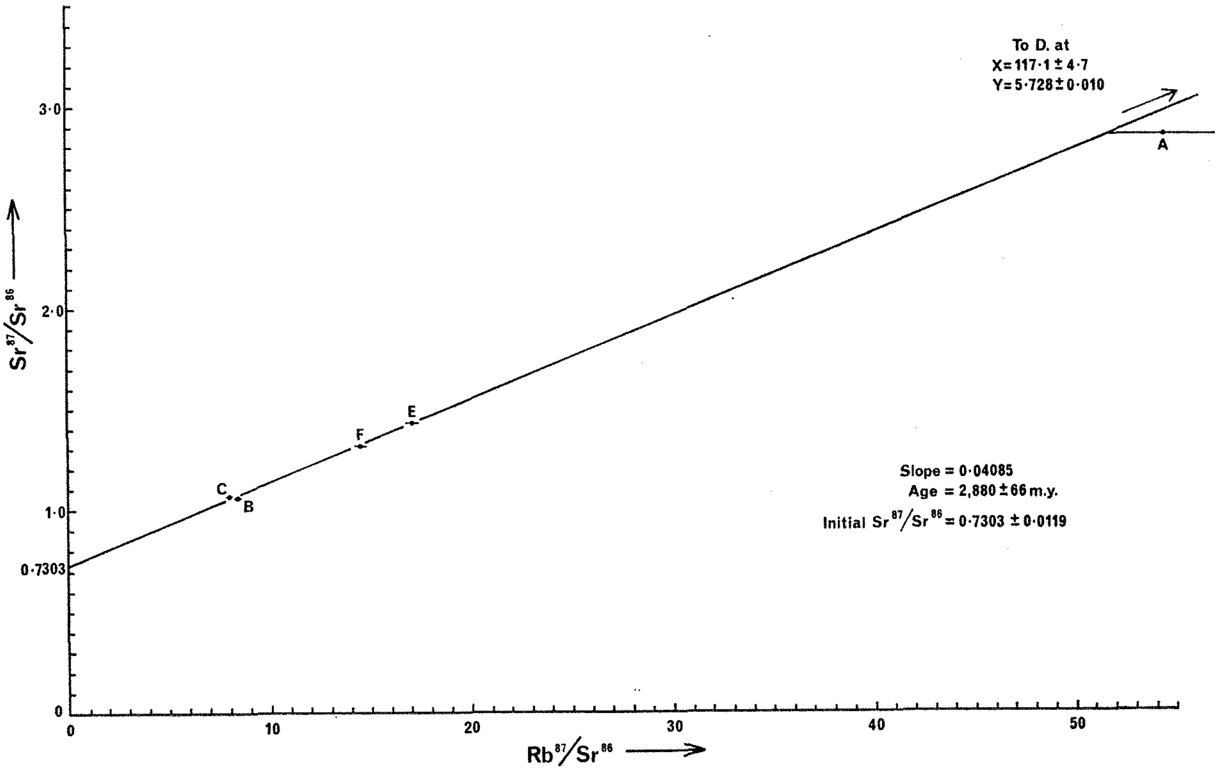


Fig. 15—Isochron plot for the data of Table 1. The horizontal bars show the errors as given in that table. The errors for Sr^{87}/Sr^{86} are within line thickness.

DISCUSSION

Our reported age may be associated with any one of three major events in the life of the material now constituting the Copper Hills Porphyry : its generation as magma, its emplacement as the presently defined porphyry body (which in the scale of time dealt with may be thought of as synchronous with crystallization for a body of this size), or the metasomatic event responsible for much replacement of feldspar by sericite.

However, the unusually high initial Sr^{87}/Sr^{86} ratio for an isochron of this age does place limits on the time range within which these events could have occurred. If the mean Rb-Sr ratio for the six samples analysed (about 9·8) represents that of the total porphyry body, then the Sr^{87}/Sr^{86} ratio would rise by about 0·052 every 100 m.y. Thus, assuming chemical closure, a period of only about 60 m.y. separates the initial ratio of our isochron from any possible earlier stage when the total Sr^{87}/Sr^{86} ratio could have been as low as 0·70, the approximate expected ratio for magma generation from basic material.

Extreme interpretations of our data are therefore :

1. The porphyry magma was generated from mantle material about 60 m.y. before the isochron age, and the isochron represents an isotopic homogenization connected with either crystallization or internal metasomatic adjustment.

2. The porphyry magma was generated from older crustal material at the isochron age, and internal differences of Rb-Sr ratio at the total rock scale have persisted through all subsequent events.

In either case our data suggest a younger age of emplacement than the 3,050 m.y. reported by Compston and Arriens (1968) for granites of the Pilbara Block, and a re-examination of the geological evidence for its previously supposed pre-granite age becomes necessary.

We have already noted the apparent absence of clearly displayed contact relationships between the granite northwest of Copper Hills and either of the two types of porphyry described from the area by Noldart. The pre-granite age of the Copper Hills Porphyry thus rests largely on the premise that shearing in this porphyry is related to the folding of the host sediments, and that this folding is pre-granite. Current concepts of the development of the components of a structurally typical section of Archaean crust, such as the Pilbara Block, envisage contemporaneous sedimentation, folding, and intervening diapiric ascent of the granite domes, all taking place over a relatively long period. Thus the development of a gneissose granite margin is seen as contemporaneous with the folding of the adjacent sediments and both events may occupy a sufficiently long period for a later marginal porphyry intruded towards their close to suffer some shearing as a result of the continuing causative stress.

In conformity with these concepts we suggest that the magma of the Copper Hills Porphyry was essentially cogenetic with that of the adjacent granite, and that it was intruded as an irregular steeply dipping sheet, between the granite and the adjacent metasedimentary and metavolcanic rocks, as a late phase of a continuous and protracted Archaean episode of crustal generation.

In this discussion we have avoided interpretations which do not require chemical closure. A complete review of such speculative possibilities is hardly justified by our data, but the linearity of the analytical results, in the grab sample used, does suggest that the distribution of rubidium and radiogenic strontium have not been modified from outside the body at a late stage, as might be expected if the sericitization of the feldspars had been caused by late potassium metasomatism.

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GRAVITY EVALUATION OF A MANGANESE DEPOSIT AT WOODIE WOODIE, WESTERN AUSTRALIA

by I. R. Nowak

ABSTRACT

A gravity survey, using a Worden gravimeter, was carried out over a manganese deposit located in rough terrain on Mineral Claim 431 at Woodie Woodie in the Pilbara Manganese Province, Western Australia. The survey was conducted to define the sub-surface configuration of the ore body and to test the validity with which reserves of manganiferous material may be assessed by the gravity method in rough terrain, following earlier successful application in low relief country. It was successful in both respects and 187,000 to 246,000 tons of manganiferous material are estimated to lie below the surveyed (gridded) area. The wide tonnage range reflects uncertainty in the average density for the body. The optimum estimate is around 213,000 tons. This figure agrees very closely with ore reserves proved later by drilling.

INTRODUCTION

In August, 1969, the Geological Survey of Western Australia was approached by Longreach Manganese Pty. Ltd. to carry out a gravity survey over a manganese deposit in Mineral Claim 431 in the Woodie Woodie area of the Pilbara Goldfield in the North West Division of Western Australia (Plate 17). The ore body had already been close-pattern drilled and the extent and estimated tonnage of reserves determined by this means. It was proposed that the gravity survey should be made prior to open-cut mining as a test of the ability of this method to arrive at a distribution of manganiferous material and a reserves estimate similar to that obtained by drilling.

Evaluation of the economic potential of a particular manganese deposit in the area at present requires extensive drilling, as the greater portion of many of the ore bodies is concealed and there is only minor associated outcrop. The high density contrast between the manganese and country rocks suggested that the gravity method may prove to be a rapid and relatively inexpensive means of detecting and assessing bodies of commercial interest.

Previous work in the Woodie Woodie area (Rowston, 1964) has demonstrated the efficacy of the gravity survey in low relief country. However, as the present survey was conducted in rough terrain, a more rigorous test of the versatility of the method is provided.

GEOLOGY OF THE AREA INVESTIGATED

In the deposit investigated in M.C. 431 the manganese ore occurs in steeply dipping fissures and cavities in impure dolomite associated with chert breccia. The ore is probably a secondary body which has been deposited from descending solutions (de la Hunty, 1963). The main ore minerals of this and related deposits are braunite, cryptomelane, and pyrolusite.

THE GRAVITY METHOD

The gravimeter used in prospecting is designed to measure minute differences in the force due to gravity at selected points on the Earth's surface. Differences occur due to a number of influences such as latitude, topographic relief, and deep crustal structures, or they may result in part from local rock density variations at a relatively shallow depth.

The latter are of particular interest in mineral prospecting. If the sought mineral is concentrated into a body of sufficient size and has a density which contrasts significantly with that of the host rock, then its detection is feasible by the gravity method. Manganese occurrences often satisfy these conditions and on M.C. 431 the density contrast is around 0·9 to 1·3 gm/cc. The ore body however must be large enough to appear as a distinct gravity anomaly after the initial gravity readings have been corrected for other influences.

Topographic relief in the survey area should preferably be slight so that the terrain corrections required are not of a greater magnitude than the anomaly due to the manganese body. If the body is small and superficial, or large but deeply buried, the method is not practicable in rough country. The terrain encountered in the present survey is considered to be rougher than would be desirable for a confident evaluation of the deposit.

FIELD PROCEDURE

The area surveyed for the proposed gravity work measured approximately 700 feet by 400 to 500 feet and was gridded and pegged at 25 feet intervals with each peg levelled to 0·01 foot.

However the form of the gravity survey was slightly adjusted for two reasons : (a) the peg spacing was unnecessarily small over the deposit, and (b) the grid did not extend a suitable distance from the assumed manganese zone. To rectify the situation, instrument readings were taken at all pegs of every second line and also at 50-foot intervals along selected lines 200 to 300 feet apart extending from the prepared grid. The latter readings were required to provide some control, for future corrections, over ground below which manganese was thought to be absent.

A base station was established at peg No. 401 and this was re-occupied at approximately hourly intervals to determine the drift rate of the gravimeter.

The gravimeter used on this survey was a Worden, Serial No. W70, on loan from the Department of Geology, University of Western Australia. Whilst this instrument may be read to an accuracy of 0·01 milligal in ideal conditions, it is probable that read ings with an error of about $\pm$ 0·02 milligal were obtained during the present survey when moderately strong winds prevailed.

The total period of meter reading for two men was 1½ days. Pegging and levelling was done by the company.

DENSITY FACTOR

There are three principal types of material in the surveyed area ; dolomite, chert breccia, and manganese ore. Density determinations for these were made in the course of earlier gravity work (Rowston, 1964) and gave the following mean densities :

Dolomite : 2·84 gm/cc

Chert breccia : 2·64 gm/cc

Manganese ore : 4·0 gm/cc

The densities of both the breccia and the dolomite fell within narrow limits and are considered valid for the present survey area. However, the density of manganese ore varies with grade and 4·0 gm/cc appeared to be slightly high for the average material encountered on M.C. 431. For reasons considered later a figure of 3·8 gm/cc was adopted for mass anomaly calculations.

For all stations a factor of 0·0600 has been used in calculating the combined free-air and Bouguer corrections. This corresponds to a density of 2·69 gm/cc for all non-manganiferous material. This figure may be expected to be the most appropriate as it was employed in the reductions of the previous gravity work in the Woodie Woodie area. However, the same factor was obtained independently for the M.C. 431 tenement along an extended line over chert breccia by Nettleton's (1940) method of least correlation between topography and measured gravity. The subsequent elimination of topographic effects justified the use of this factor throughout the ductions.

CORRECTIONS

Latitude. At the latitude of M.C. 431 readings along a north-south direction would normally be corrected at the rate of 0·016 milligal per 100 feet. However the degree of uncertainty associated with the far greater terrain corrections for the survey renders latitude corrections insignificant by comparison, and these were not applied.

Terrain. The topographic relief of the surveyed and surrounding areas is considerable and a further complication was the presence of a cliff some 40 feet high which had been produced by preliminary open-cut mining of the deposit. Investigations indicated that the effect of such irregular terrain upon the gravity results was profound and that it was essential to apply corrections. The anomalies produced by topography alone were of an order similar to those due to the ore body. Consequently the accuracy of the ultimate result may be viewed with some reservations. However as levelling of the grip was precise to within 0·01 foot it is considered that the laborious process of applying terrain corrections was fully warranted and that this assisted substantially in achieving a reasonably authentic final anomaly.

Plates 17 and 18 show the contrasting forms of the Bouguer anomalies before and after their correction for terrain effects.

Regional. The limited regional gravity data available for the Woodie Woodie area precluded the application of standard regional corrections. A regional gravity level over the deposit was assumed from a visual inspection of the contour maps and was taken into account when calculating the mass anomaly. Deeper gravity trends in the area would be expected to exert little influence upon the anomaly due to the shallow depth of the manganese body.

INTERPRETATION

Interpretation of the results has been directed solely towards obtaining a mass anomaly for the deposit which may be expressed as an estimate of reserves of manganiferous material. All gravity readings and peg levels were reduced to the level at a common base, in this case peg No. 401.

The combined free-air and Bouguer correction factor was then applied and the results have been presented in the form of a contoured Bouguer anomaly map (Plate 17). By means of a Hammer zone chart, used in conjunction with standard tables, a further correction for the effect of topographic relief within a radius of 175 feet of each station was added to all station values. Plate 18 shows the contoured map of the terrain—corrected Bouguer anomalies from which the anomalous mass has been calculated.

By a visual inspection of both the terrain-corrected Bouguer anomaly map and selected profiles the 0·00 milligal contour was taken as the background gravity level for the area. The summation of the reduced gravity values for each station was related to this level for the purpose of mass anomaly calculation.

The actual mass of the body causing the anomaly (presumably manganiferous material) has been determined from the formula (Parasnis, 1962) :

$$\text{Mass} = 2.22 \frac{p_1}{p_1 - p_2} \Sigma \Delta g \Delta s \quad \text{tons}$$

where : p_1 = density of manganiferous material (gm/cc)

p_2 = density of host rock (gm/cc)

Δg = gravity anomaly at a point (milligals)

Δs = areal element, in square feet,

enclosed by any four gravity values utilized in the calculations (here 50 feet x 50 feet).

No attempt was made to arrive at a theoretically probable shape or form of the body from the data as this does not fall within the scope of the report. It should also be noted that whilst gravity measurements alone cannot uniquely determine the distribution of anomalous masses, they do provide a unique estimate of the total anomalous mass.

DISCUSSION OF RESULTS

As stated above, for the present survey the standard Bouguer anomaly does not represent a sufficient degree of data reduction upon which to base quantitative interpretation. Terrain corrections have therefore been added to emphasise further the true nature of the anomaly due to the manganese body. The necessity of such corrections is apparent from a visual comparison of the two appended contour maps. On the normal Bouguer map (Plate 17) there are shown several isolated gravity ' highs ' and ' lows ' which are almost certainly not related solely to the distribution of manganese. Again, the establishment of valid contour continuity over the open-cut cliff appears impracticable. The terrain-corrected Bouguer map (Plate 18) obviously gives a more coherent and correct picture of gravity variations due to the ore body alone. It is therefore this map which is discussed.

The ' highs ' (shown thus : +) may be taken to represent the greatest concentrations of manganiferous material. There are four such ' highs ' over the pegged area with three of these lying on a north-northwest to south-southeast trend as expected from geological considerations. The centre ' high ' is the largest and probably indicates that the greatest single concentration of ore is in this area. A depression of the order of 0·10 milligal occurs in the centre of this gravity structure which expresses a possible local reduction in quantity and/or grade of manganese. The ' high ' to the north on the same trend, although small in areal expression, is relatively large in magnitude (0·50 milligal maximum) and suggests a possible fissure filling of higher grade ore of some vertical extent. The persistence of the anomaly into the open-cut area reinforces the impression that ore continues below the present level of mining.

Superimposed upon the gravity contours on Plate 18 is a line delineating the approximate limits of material containing more than 40 per cent manganese as determined from drilling data. This is a composite boundary drawn from information at several different levels and is included to indicate the degree of coincidence between the known deposit and the gravity anomaly. Although there is a considerable broad similarity between the known form of the body and its gravity expression, it is apparent that the gravity anomaly is displaced some 50 feet to the east of the better quality ore as determined by drilling.

A maximum allowable regional correction applied to the Bouguer anomaly was found to be insufficient to correct the discrepancy which may result from two further possible causes :

1. There could exist a substantial but undetermined quantity of low grade material to the east of the main body.

2. A geometrical shift of the position of the anomaly occurred during reduction of the original data to the corrected form.

To the west of the gridded area a few tentative contours have been sketched on the basis of readings made along lines extended in that direction. Terrain information is not precise in this area and topographic corrections may not be reliable. However the high gravity values recorded suggest that further investigations in this locality would be justified.

The prime objective of the survey was to arrive at an estimate of the reserves of manganiferous material in the area of detailed gravity information. Material of all grades contributes to the gravity pattern and as stated previously there is some doubt as to the average ore density which should be assumed for mass anomaly calculations. Although a figure of 4·0 gm/cc as determined from other deposits in the Woodie Woodie area was assumed by Rowston (1964), a sample collected from M.C. 431 and containing 45·5 per cent manganese had a density of 3·84 gm/cc. It is known that the grade of ore material in the deposits is variable and that a manganese content less than 40 per cent is quite common. The main impurity which lessens the grade is known to be silica and an increase in silica at the expense of manganese would lower the ore density. Thus, an assumed average density of 3·8 gm/cc is probably close to the optimum value for mass anomaly calculations. For this density reserves are estimated to be 213,000 tons.

Following the derivation of this value, Longreach Manganese Pty. Ltd. was requested to furnish for comparison a reserves estimate based upon the results of detailed drilling. This more conventional means of assessment produced a figure of 240,000 tons. When it is considered that this prediction was made prior to the removal of some 15,000 tons or ore in the open cut area, agreement between the estimates based upon gravity and drilling results is seen to be very close.

If more precise density information becomes available in the future, reference may be made to the following table. This gives the calculated tonnages which correspond to the range of average densities from 3·6 to 4·0 gm/cc.

Density (gm/cc)	Estimated Reserves (tons)
3·6	246,000
3·7	228,000
3·8	213,000
3·9	200,000
4·0	187,000

These estimates are based upon the mass anomaly for the gridded area only and do not include possible reserves associated with the tentative gravity ' high ' to the west of the grid. Again, the mass of material removed by mining prior to the survey is excluded from the figures given.

CONCLUSIONS AND RECOMMENDATIONS

It has been established previously (Rowston, 1964) that the gravity method is an effective means of detecting and delineating manganese deposits of the type found in the Pilbara region. The basis for the application of the method is the high density contrast between ore and host rock. The results of the present work confirm that the use of gravity can provide a relatively economical method of obtaining a preliminary estimate of ore reserves, and further, that it is applicable to rough terrains provided adequate levelling is carried out.

The gravity method should not be regarded as a substitute for more expensive detailed testing since the magnitudes of gravity anomalies give no definite information about grade and the economic potential of a deposit cannot be positively established. However much unnecessary and unproductive drilling can be eliminated by initial prospecting and surveying with gravity. A rapid assessment may be made of the anomalies which appear worthy of close attention.

Future employment of the gravity method for evaluating manganese prospects should prove rewarding. It is suggested that consideration of the following points would result in more confident interpretations :

1. Small-scale gravity surveys to be accompanied by systematic density sampling of ore and host rocks (where these are available) over the area of interest.

2. The establishment in a given area of some relationship between gravity effects and grade of ore.

3. The consultation of available regional gravity data to facilitate an accurate determination of the extent to which a certain anomaly is a measure of gravity effects due solely to the ore body.

4. A judicious selection of traverse lines and grid network to minimise where possible the effects of terrain. Surveys to be completed if possible prior to any earth moving or dumping operations.

ACKNOWLEDGMENTS

Thanks are due to Professor R. T. Prider of the Department of Geology, University of Western Australia, who made available the gravimeter used on the survey.

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GEOCHEMICAL PROSPECTING FOR COPPER, LEAD AND ZINC IN THE NORTHAMPTON MINERAL FIELD

by X. K. Williams

ABSTRACT

Geochemical surveys were made of two areas, each approximately 2,000 square feet, and along five line traverses in the Northampton Mineral Field. Soil samples were analysed for copper, lead, and zinc by atomic absorption spectroscopy. The trace element content of the soil is directly related to the metal content of the underlying rock ; there has been limited dispersion, so that the anomalies are relatively intense. Two new anomalies were discovered and warrant further investigation. One is at Martins Spring, and the other is close to Northampton on the road to Horrocks Beach. Geochemical prospecting is a suitable method of exploration for base metals where the soil is residual over granitic rocks and dykes, but not over sandplain, laterite, or transported soils.

INTRODUCTION

GENERAL

The geochemical surveys in the Northampton Mineral Field were undertaken with a threefold aim. (1) to study the dispersion patterns of the base metals in the soils of the area, in particular the anomalies around known occurrences of copper, lead, and zinc ; (2) to determine the possible differences of dispersion east and west of a granite boundary ; and (3) to investigate the feasibility of using geochemical methods for broad-scale exploration in the Northampton Mineral Field, for instance to explore the hypothesis that the better mineral deposits occur in the eastern part of the region where the sheet-intrusive granite is thickest.

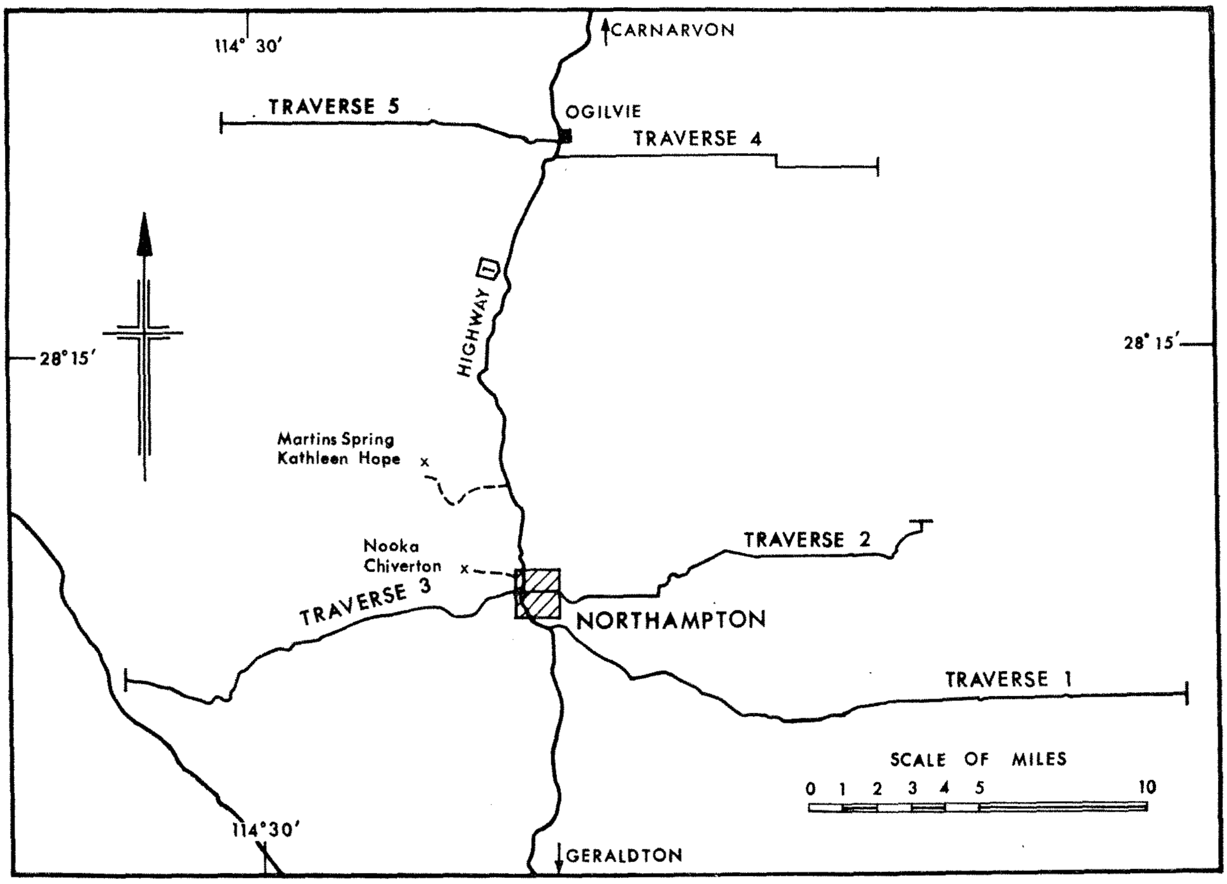

Fig. 16—Locality map showing the two grid areas and five road traverses, Northampton Mineral Field.

Two areas, each of approximately 2,000 square feet, and containing old base-metal workings, were close-sampled, and studied in detail. They are the Nooka—Chiverton and Martins Spring—Kathleen Hope areas (Figure 16). Soil samples were also collected from five east-west traverses over a total distance of 77 miles.

ENVIRONMENT

The rainfall over the area varies from 5 to 10 inches a year, and most of it falls between May and October. The mean annual temperature ranges from 65 to 70 degrees F, and the humidity is low. The main vegetation is Acacia with a low scrub of Grevillia and Dodonaea. The Nooka—Chiverton area has several moderate to steep-sided small valleys. The Martins Spring—Kathleen Hope area is relatively flat, the highest land being near the centre of the area. The soil is a red podzolic on the ridges and slopes, altering to a gleyed podzolic in the valleys. At Nooka—Chiverton the pH of the soil varies from 5 to 7 (excluding the mine area where the pH drops to 4) ; at Martins Spring—Kathleen Hope it is slightly more alkaline, varying from 5·2 to 7·7 (pH values determined at Government Chemical Laboratories).

GEOLOGY (by R. C. Horwitz)

The rocks of the Northampton Block are high-grade metamorphic rocks of sedimentary and basic igneous origin which have been intruded by granite, producing areas of migmatite, then folded, then intruded by a swarm of parallel dolerite dykes. All these rocks have been described in part by Maitland (1903), Prider (1958), Jones and Moldart (1962), Blockley (in prep.) and Peers (1969).

The granite is concordant and is a feature of the eastern part of the block, but it does not persist everywhere. It is a valuable marker horizon in a broad stratigraphic sequence and has also led to the recognition of some regional controls to the metal distribution in the area.

The chronology of geological events for the rocks older than the dolerite dyke swarm is believed to be as follows : deposition of littoral sediments, intrusion of small basic sheets in soft well-layered rocks, metamorphism concomitant with granite sheet intrusion which preferred the soft well-layered rocks, then folding.

MINERALIZATION (by R. C. Horwitz)

Lead, copper, zinc and silver have been produced from the Northampton Block. Low (1963) gave accounts of the copper production in the region, and Blockley (in prep.) described each lead mine systematically and gave a comprehensive account of the geological and economic aspects of the mines in the region. He pointed out that early workers, such as Maitland (1903), were impressed by the association of the ore bodies with the dolerite dykes. Low also noted the association of copper ore bodies with the dolerite dykes. Blockley concluded that the various lead, zinc, and silver deposits of the Northampton Mineral Field are either hydrothermal fissure veins or tectonic breccia fillings, and that the ore controls are mostly the northeast fractures parallel to the dolerite dykes, although some follow other fracture directions or the gneissic banding.

Some regional controls can be added. The mineralization of the Northampton region greatly favours the coarse-grained rocks of the lower part of the sequence which contain relict cross-bedding. Throughout the Geraldton Sheet area, with the exception of the Lady Samson Mine, the mines are west of the granite sheets, and hence are lower in structural level than the granite or its apophyses. The mines are generally clustered in areas where the lower parts of the granite sheet are present, such as at Northampton and Nabawa.

A model is proposed in which metallic sulphides were present, possibly disseminated, in the stratigraphic sequence. Thermal increase, which caused metamorphism, could also have caused migration and concentration of the sulphides in more porous horizons where they were then sealed off by overlying granite and migmatite. The present ore bodies could then have been formed by later migration into fractures, and remobilization by the dolerite dykes.

It is therefore possible that better mineral deposits occur, in depth, in the eastern part of the region where the granite is thicker and might have formed a better seal. They would be at shallower depths on the anticlines.

NOOKA—CHIVERTON AREA

Nooka mine is approximately three miles west of Northampton townsite and is reached by a dirt road from the town. Chiverton mine is close to, and south of, Nooka. The area studied lies within Mineral Leases 284, 286 and 293.

MINERALIZATION AND WORKINGS

Nooka Mine was worked for lead from the late 1870's until recently. Mining operations, including an open cut 300 feet long, have been carried out over a considerable area and this source of surface contamination must be considered in the interpretation of the geochemical data.

According to Blockley (1968), " The ore-body is a fissure vein along a northerly striking, west-dipping fault which cuts Precambrian granulite and quartsite. The fault can be traced on the surface for about half a mile, and is seen to curve to the west at the southern end. The Nooka mine is about midway along the traced extent of the fault, and two shafts have been sunk on a copper prospect at the south end of the fault line. Unlike many mines in the Northampton area, the lode is not closely associated with dolerite, although dykes of this rock are seen 300 feet east and 1,200 feet west of the mine . . ."

" Where mined, the lode is a body of quartz and siliceous breccia 2 feet to 4 feet wide. Lead is present as the mineral galena which, along with the other sulphide minerals, forms a discrete vein normally situated at the edge of the lode. The width of the sulphide vein ranges from a few inches to 3 feet. On the sub-level at 228 feet, the average width was about 12 inches. Other sulphide minerals in the ore are sphalerite, pyrite and chalcopyrite. Quartz is the principal gangue material. Vugs lined with crystals of quartz, galena, and pyrite (in that order of deposition) are common. Sphalerite is most abundant at the northern end of the ore body, and the copper content of the lode increases towards the south. Typical of the Northampton area, the ore is coarse-grained and the galena has a low silver content. The sphalerite contains a high proportion of cadmium, one sample having assayed 5·78 per cent Cd."

SAMPLING AND ANALYSIS

A base line was established bearing 045 degrees from the terminal, high-voltage, power line post immediately to the east of the shaft and main working area at Nooka mine. This base line was marked off at 200-foot intervals and sampling lines, bearing 135 degrees and 315 degrees started from these points. Soil samples were collected from these lines at 50-foot intervals. The area sampled was uncultivated grassland, but there were crops north and south of the grid. The grid is bounded on the southwest by a steep-sided valley and extensive diggings and excavations (Lucky Lou prospect). It covers the main Nooka mine area, the Chiverton extension to the south, a cluster of small diggings 1,200 feet northwest of the mine area (Nooka West), and a number of smaller scattered diggings and costeans.

Samples were collected from immediately above bedrock or a depth of 18 inches whichever was the least.

The samples were air-dried and sieved through a minus 200-micron nylon sieve in a plastic frame. They were heated at 180°C in 60 per cent perchloric acid for one hour, and the copper, lead, and zinc contents of the resulting solutions were determined by atomic absorption spectroscopy.

RESULTS

Statistical Treatment

The statistical treatment used is that described by Williams (1967). The results for each element are logarithmically distributed, and the cumulative frequency curves have been plotted on logarithmic probability paper. The points of inflection are the best estimates of the boundaries between the different populations of results that are present. These boundaries have been used as contour concentrations in Figure 17, where the results for each element are plotted on the appropriate grid positions. Table 1 shows the frequency distribution of each population and the boundary contours. Four populations have been extracted for each element. Of these the first is considered to be background, the second threshold, and the upper two anomalous. The anomaly centres indicate the location of the anomaly source.

TABLE 1. FREQUENCY DISTRIBUTIONS OF THE RESULTS OF COPPER, LEAD, AND ZINC ANALYSES OF SOIL SAMPLES FROM NOOKA—CHIVERTON AND MARTINS SPRING—KATHLEEN HOPE AREAS

	Nooka-Chiverton		Martins Spring-Kathleen Hope	
	p.p.m.	Percentage of results	p.p.m.	Percentage of results
Cu	0–130	84·2	0·110	91·7
	140–270	8·8	120–160	4·9
	280–590	5·7	170–250	2·1
	More than 600	1·3	250–990	1·0 } 1·3
			> 1000	0·3 }
Pb	0–170	70·8	0–110	89·7
	180–390	14·3	120–330	6·0
	400–980	8·8	340–840	2·4
	More than 1,000	6·1	More than 840	1·9
Zn	0–170	71·6	0–170	94·5
	180–440	20·1	180–270	3·9
	450–710	3·7	280–450	1·4
	More than 720	4·6	More than 450	0·2

Discussion

For all three elements there is an anomaly overlying the mine area and following the drainage direction southwest from it. There is also a second anomaly to the southwest of the mine. These areas have been disturbed by mining activities and there are several heaps of rubble. These activities will have caused considerable contamination that could be the main source of the second anomaly. It is also possible that the lode continues in that direction, but the problem cannot be solved by further study of the surface geochemistry. The two small copper and lead anomalies on the southern edge of the grid, plus other surface indications of mineralization, suggest that the lode continues southward from the mine, with only a slight swing to the west, and that the copper content increases southward as reported by Blockley.

There is a low-intensity copper anomaly associated with the dolerite dyke that underlies the ridge along the northwestern edge of the grid. It is continuous across the grid, except for a break in the northern corner caused by dispersion of copper by surface drainage.

There is an intense lead-zinc anomaly at the Nooka West Mine and another at the Lucky Lou Prospect. These areas and the intense zinc anomaly northeast of Nooka West are surrounded by low-intensity anomalies and connected by a band of threshold concentrations. The results suggest that there may possibly be continuous mineralization connecting all these localities. The dispersion effect of the surface drainage is clearly shown by the continuation of the threshold area which extends eastward and downslope from Lucky Lou to the Nooka anomalies (Figure 17).

A second dolerite dyke crosses the grid on the eastern edge beneath the two threshold areas on the copper map. There is a small lead and zinc anomaly within this area.

MARTINS SPRING—KATHLEEN HOPE AREA

Martins Spring and Scott and Gales are freehold properties included in Location 312, and Mineral Lease 263 covers Kathleen Hope. These adjacent areas lie 4 miles north of Northampton and 2½ miles west of Highway No. 1. There is a dirt road and then a farm track between the highway and the area studied.

MINERALIZATION AND WORKINGS

There are two collapsed shafts at the northern end of the area (Martins Spring : A, Figure 18). They are 45 feet apart and were originally 42 feet and 50 feet deep. One contained lead, and up to 50 ounces of silver per ton (Maitland, 1903). The Scott and Gales area (B, Figure 18), includes a collapsed shaft from which some lead was recovered, and the dump material was copper stained (Low, 1963).

The Kathleen Hope mine in the south, produced 23 tons of lead and 26 ounces of silver to 1967, and has been described by Blockley : " The lode strikes 025 degrees and dips easterly at 75 to 80 degrees. Within the lode two shoots 500 feet apart have been worked, and the line between them has been tested by numerous pits and costeans ".

" On the southern shoot the lode is opened up on the surface over a length of 120 feet. At the northern end it is 12 feet wide and contains lead throughout the whole width. Here the edges of the lode consist of siliceous veins, each 1 to 1½ feet thick, while the central part is made up of brecciated gneiss. Underground mining was carried out from a vertical shaft sunk to the east of the outcrop. The shaft is now 44 feet deep but is probably partly filled ".

" The northern shoot was worked over a distance of 75 feet from three shafts. The southern shaft is on the lode and leads to stopes 2 to 3 feet wide. The other shafts are 50 and 75 feet respectively from the southern shaft on a bearing of 50 degrees, and seem to have been sunk in country rock."

SAMPLING AND ANALYSIS

The base line was established bearing due north from the high ground in the centre of the area and the grid was tied in to the shafts which can be accurately relocated. Soil samples were collected at 50-foot intervals from lines at right angles to the base line and 200 feet apart. The sampled area forms an oblong of uncultivated ground, 3,000 feet by 2,100 feet, surrounded by cultivated farmland. Samples were collected from bedrock, or a depth of 18 inches, whichever was the shallower, and treated as previously described.

RESULTS

Statistical Treatment

The results were cumulated and plotted as described for Nooka—Chiverton (see Figure 18 and Table 1).

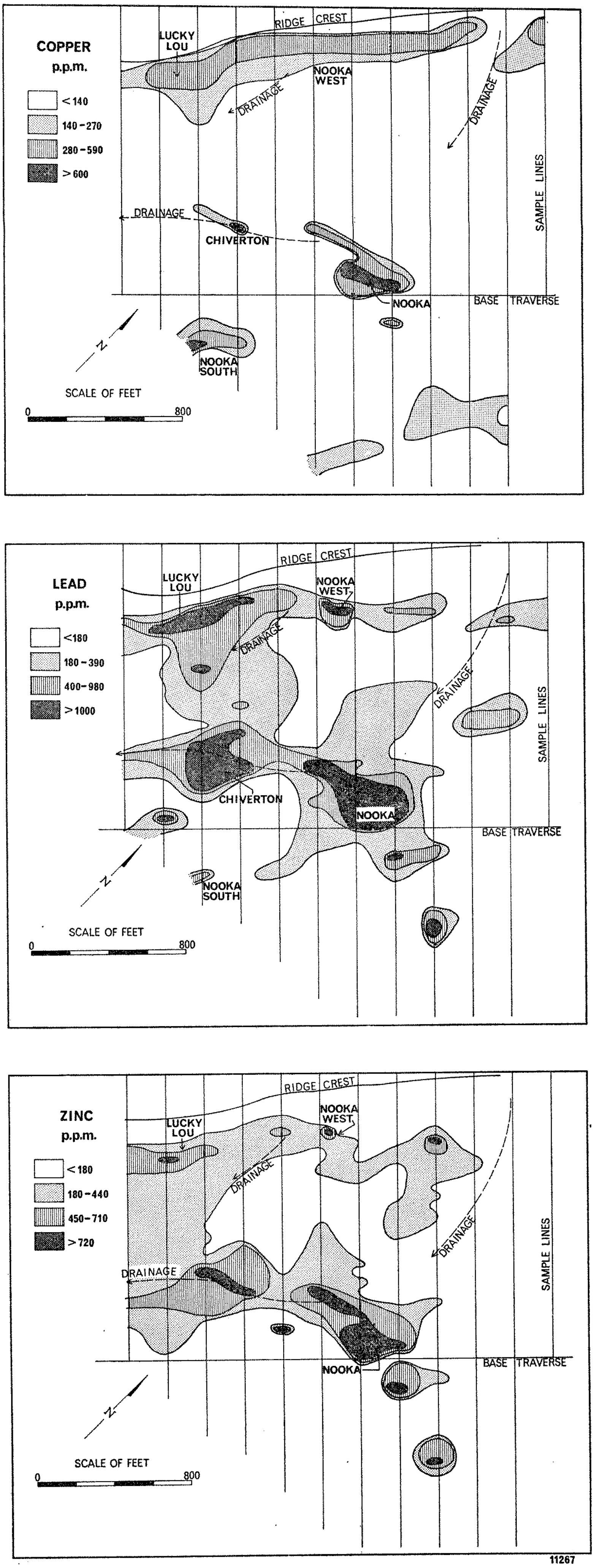

Fig. 17—Results of soil analyses for copper, lead and zinc from Nooka-Chiverton area, Northampton Mineral Field.

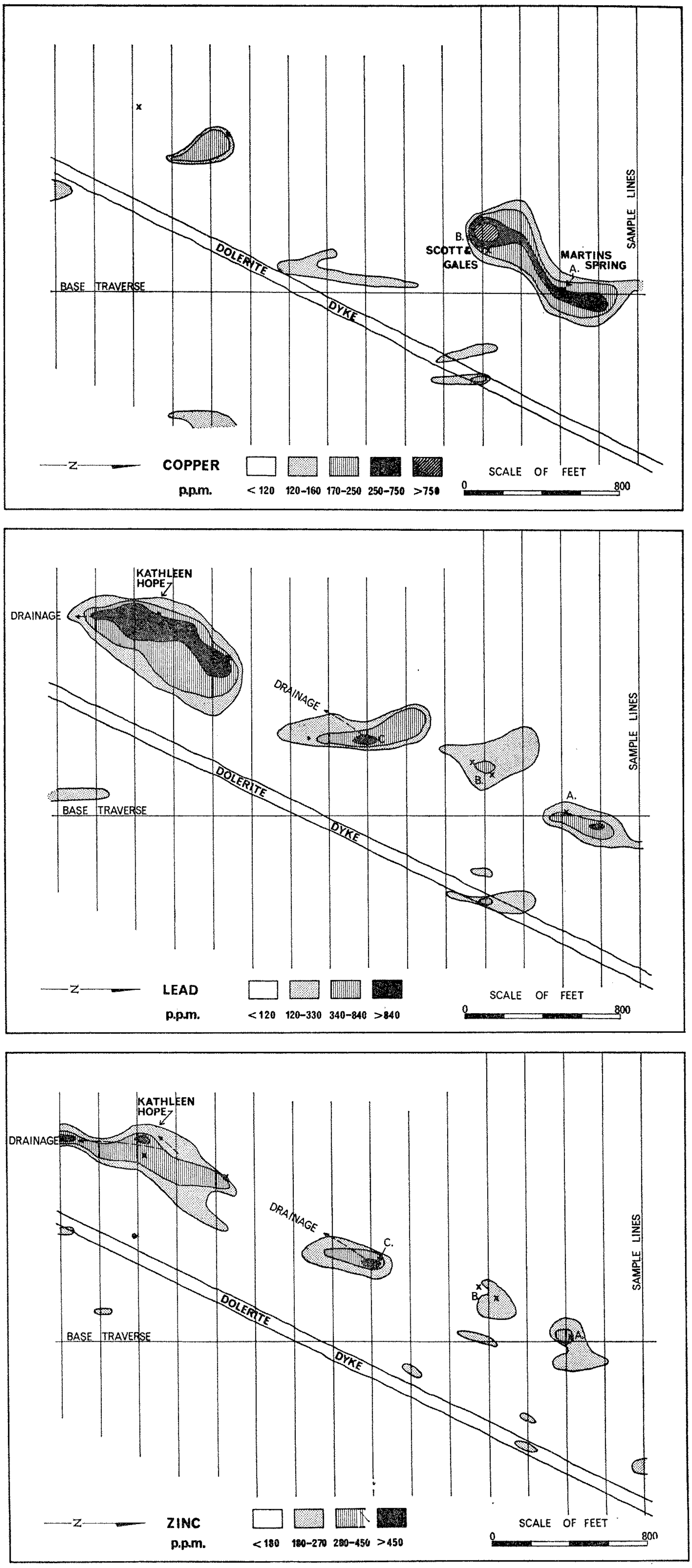

Fig. 18—Results of soil analyses for copper, lead and zinc from Martins Spring-Kathleen Ho area, Northampton Mineral Field.

Discussion

A dolerite dyke crosses the grid (Figure 18) and one sample near the northern end was slightly anomalous in copper and lead. Threshold values were recorded for all three elements around that point. However mineralization of the dyke is less evident than in the dykes at Nooka—Chiverton.

The main mineralization of the area is along a north-northeasterly line, nearly parallel to the dyke, and approximately 600 feet to the west of it. The Kathleen Hope mine is at the southern end. The mine and the resulting hydromorphic contamination pattern have given rise to the main lead-zinc anomaly. There is very little copper associated with the ore and therefore only a minor copper anomaly in the soil, over the northern shoot. The intense copper anomaly at the northern end of this line (between A and B, Figure 18) surrounds the shafts from which copper has been taken, and there is a lead-zinc anomaly near the centre of the grid between these two areas. There is no sign of any previous activity at the lead anomaly, or possible source of contemination, so the presence of another pod of ore, or of continuous mineralization between the two areas is indicated.

ROAD TRAVERSES

METHOD

Soil samples were collected from five regional traverses. Roads were selected that ran approximately from west to east, crossed the Northampton Mineral Field, and extended beyond it to the east. The soil varied from residual, usually podzolic over granite, to laterite and sandplain to the east and west of the Field. Samples were collected at intervals of 2/5ths of a mile (approximately 2,000 feet).

Two samples were collected at each locality, one from the road verge, the other about 20 feet from the road, which at most localities coincided with the firebreak around a cultivated field. In this way it was hoped to avoid erroneous results due to possible contamination (a) of the roadside sample by road traffic, or (b) of the paddock sample by fertilizers. With respect to (b) it was estimated that the prevailing wind at the time of top dressing would have been from the south so all samples were collected from the north side of the roads. Samples were taken from immediately above bedrock, or a depth of 18 inches, whichever was least. They were sieved to minus 200-microns and the fine fraction analysed for copper, lead, and zinc.

RESULTS

The results were treated statistically as previously discussed and threshold concentrations of 75 ppm copper, 130 ppm lead, and 110 ppm zinc were established.

For every locality the roadside and paddock samples gave results that were essentially the same ; the paddock results are shown graphically in Figure 19.

Traverse 1 had higher average concentrations for all elements than the other four traverses. There were a few samples with copper and zinc concentrations above threshold, but these were only very slightly higher than the majority, and are probably not significant. There was a decrease in the concentration of all elements from sample 87 eastward. Sample 87 was at the boundary between granite on the west, and the eastern sandplain.

Traverse 2 showed a clear contrast between the moderately high concentrations over granite, and the zero or near zero results over the sandplain. There was a low intensity copper-zinc anomaly at 219.

There was a major copper-lead-zinc anomaly at the eastern end of traverse 3. It was 4 miles long and had a 44-fold lead anomaly at its centre, at 305 (A, Figure 19). The results from the roadside samples for this area are also shown in Figure 20. Although the anomaly was less intense, the same pattern of results was shown by these samples as by the paddock samples.

Assays from traverses 4 and 5, as well as the western end of traverse 3 were low in all elements, showing clearly the pattern of low concentrations over the sandplains, and higher concentrations of all three elements over granite.

CONCLUSIONS

1. Results of soil sampling and analysis for base metals correlate well with the known base metal content of the underlying rock.

2. Dispersion of the trace elements in the soil is limited by the relatively high pH so that soil anomalies are relatively intense and close to their source rocks.

3. Some of the dolerite dykes contain more copper, lead and zinc than the country rock. The mineralized and non-mineralized dolerites can readily be distinguished by determining the base metalcontent of the overlying soil.

4. Geochemical prospecting is a suitable method for (a) determining the possible subsurface extensions of known ore bodies and (b) investigating in detail areas in which mineralization is thought to occur.

5. Because of the limited dispersion, anomalies are small in area so the sampling interval should be short on each traverse (e.g. 50 feet as in this survey). This must be considered when geochemical prospecting is used for large-scale exploration in the Northampton Mineral Field.

6. Geochemical prospecting over the granite can be used to search for anomalies within the Northampton Mineral Field, provided the traverses sre close-sampled, possibly at 1,000-foot intervals. However it is not a suitable exploration tool in areas covered by sandplain or transported soil.

7. Two areas that may be worth further investigation are indicated. One is the central anomaly in the Martins Spring—Kathleen Hope area and the other is the anomaly at the eastern end of road traverse 3.

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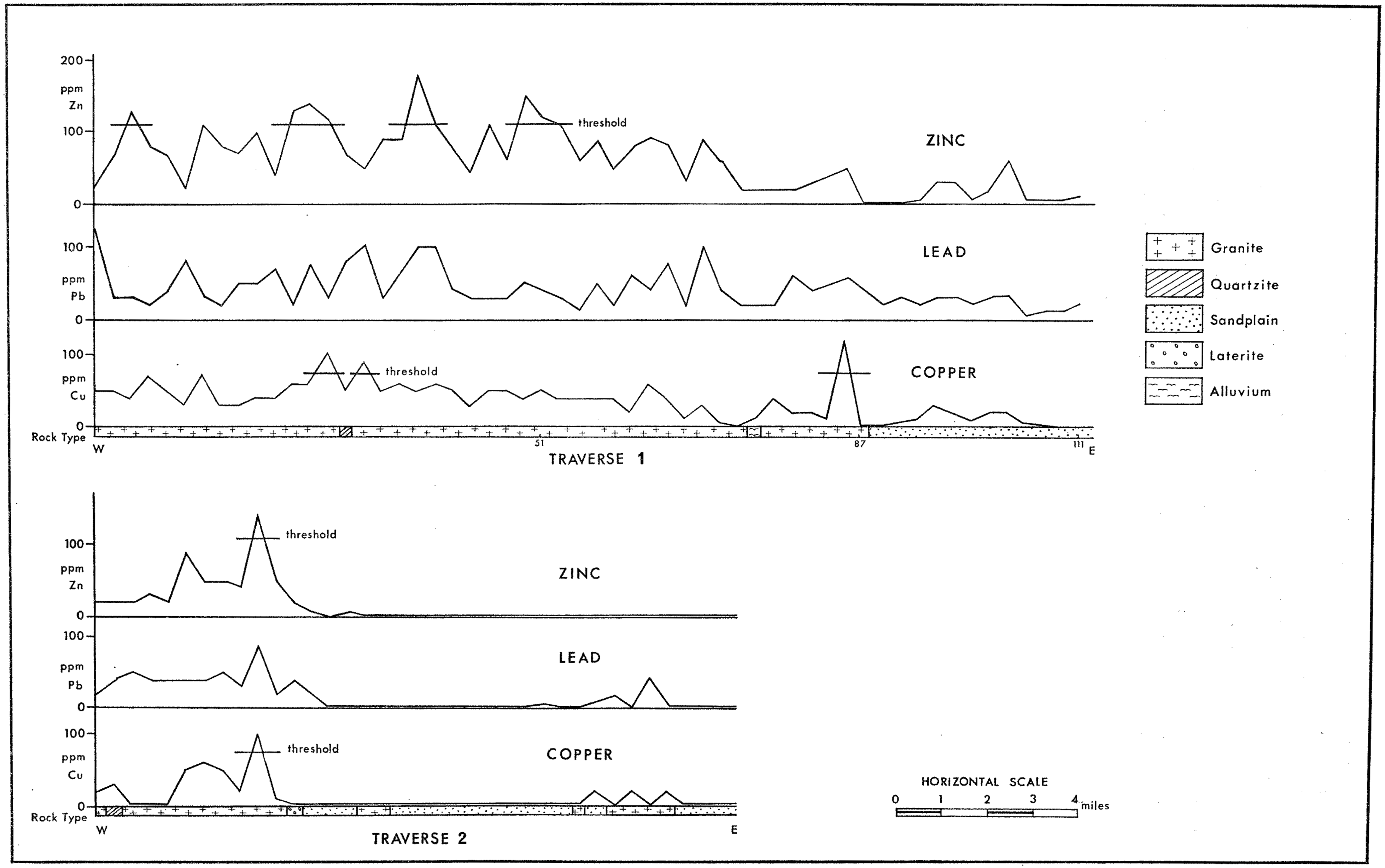

Fig. 19—Results of copper, lead and zinc analyses of paddock samples from traverses 1 and 2, Northampton Mineral Field.

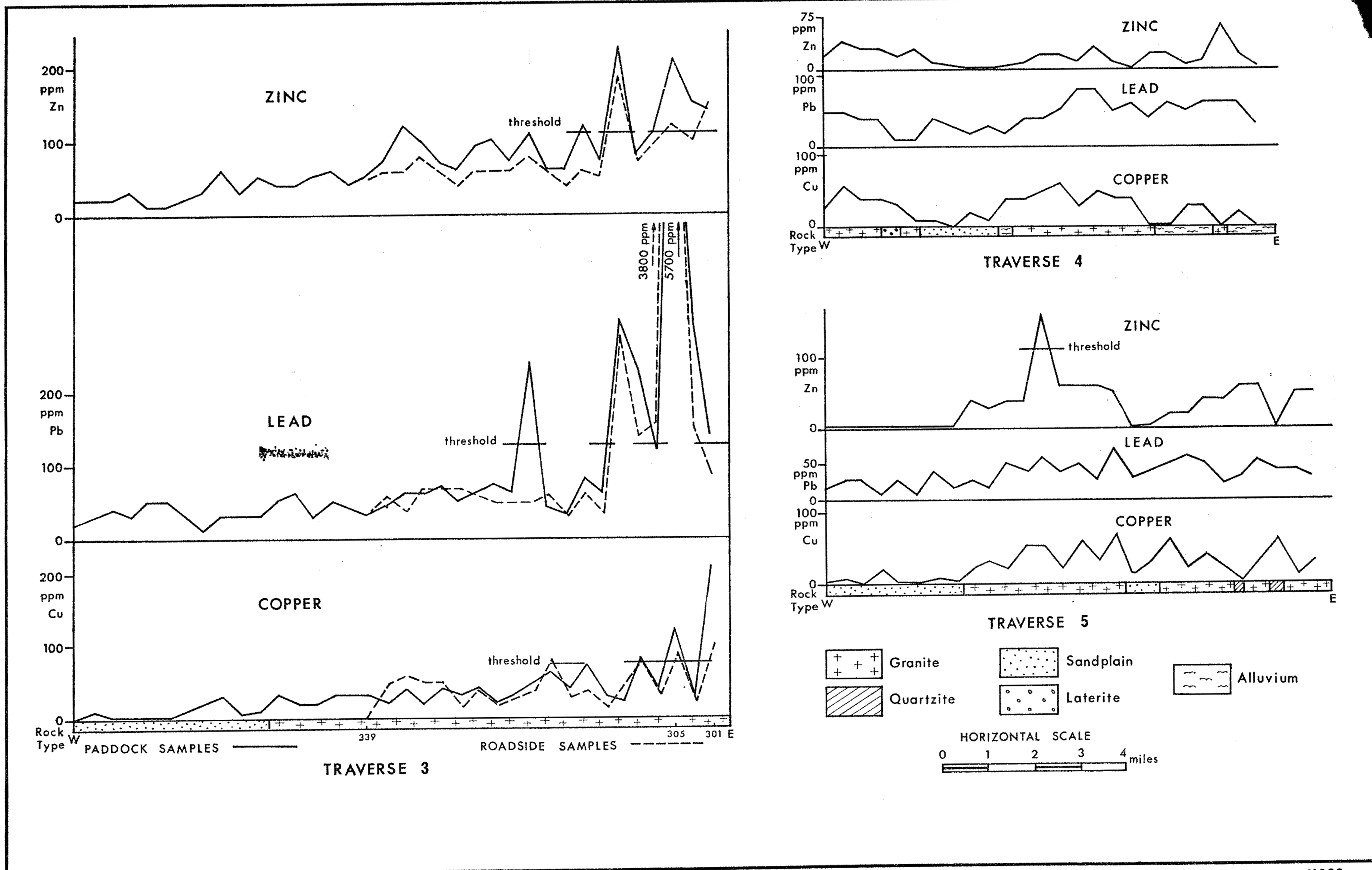

Fig. 20—Results of copper, lead and zinc analyses of samples from traverses 3, 4, and 5, Northampton Mineral Field.

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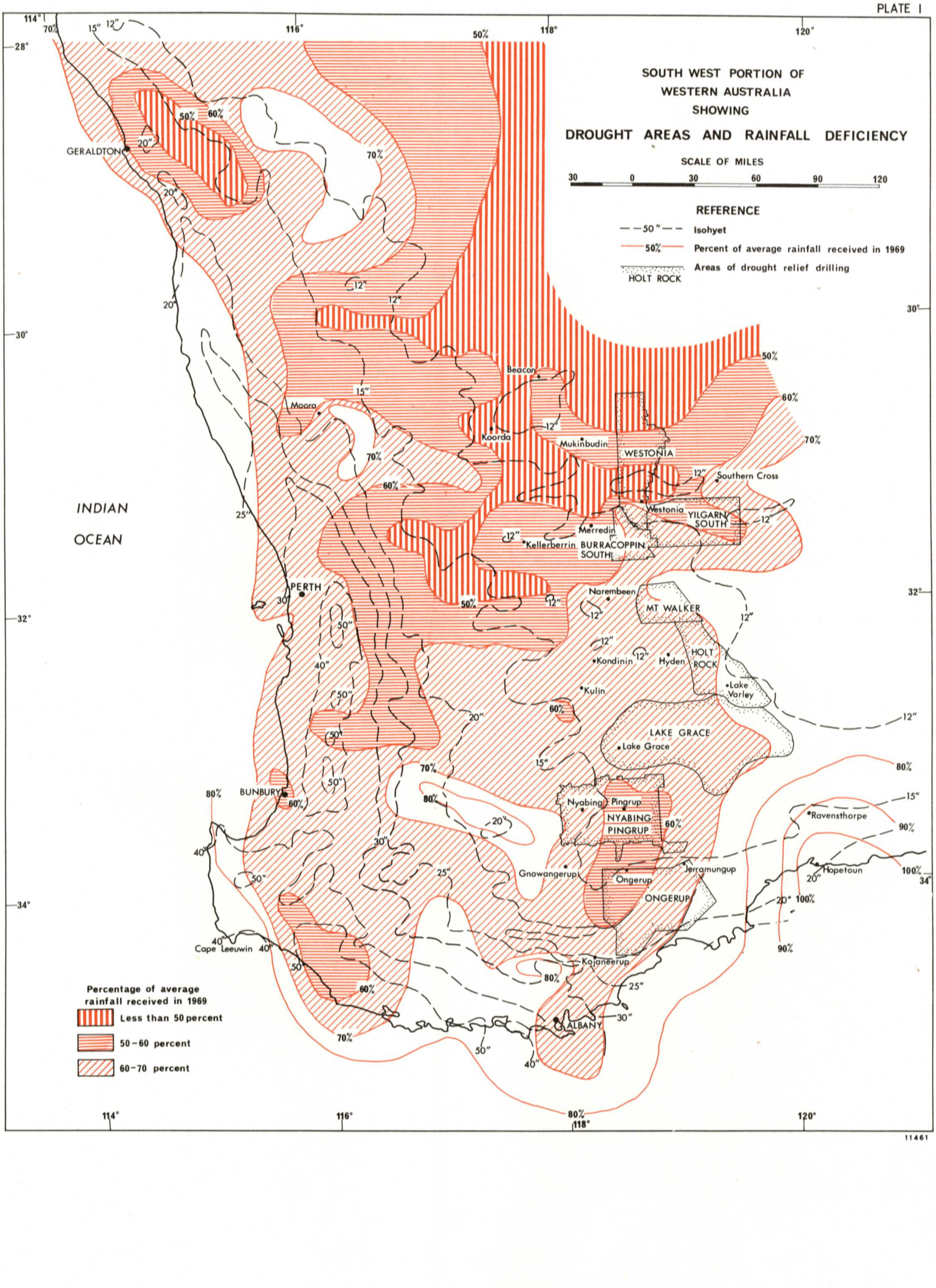
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HOLT ROCK Areas of drought relief drilling
Percentage of average rainfall received in 1969
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50 – 60 percent
60 – 70 percent
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GERALDTON
Moora
PERTH
BUNBURY
Cape Leeuwin
ALBANY
Beacon
Koorda
Mukinbudin
WESTONIA
Westonia
Southern Cross
YILGARN SOUTH
Merredin
Kellerberrin
BURRACOPPIN SOUTH
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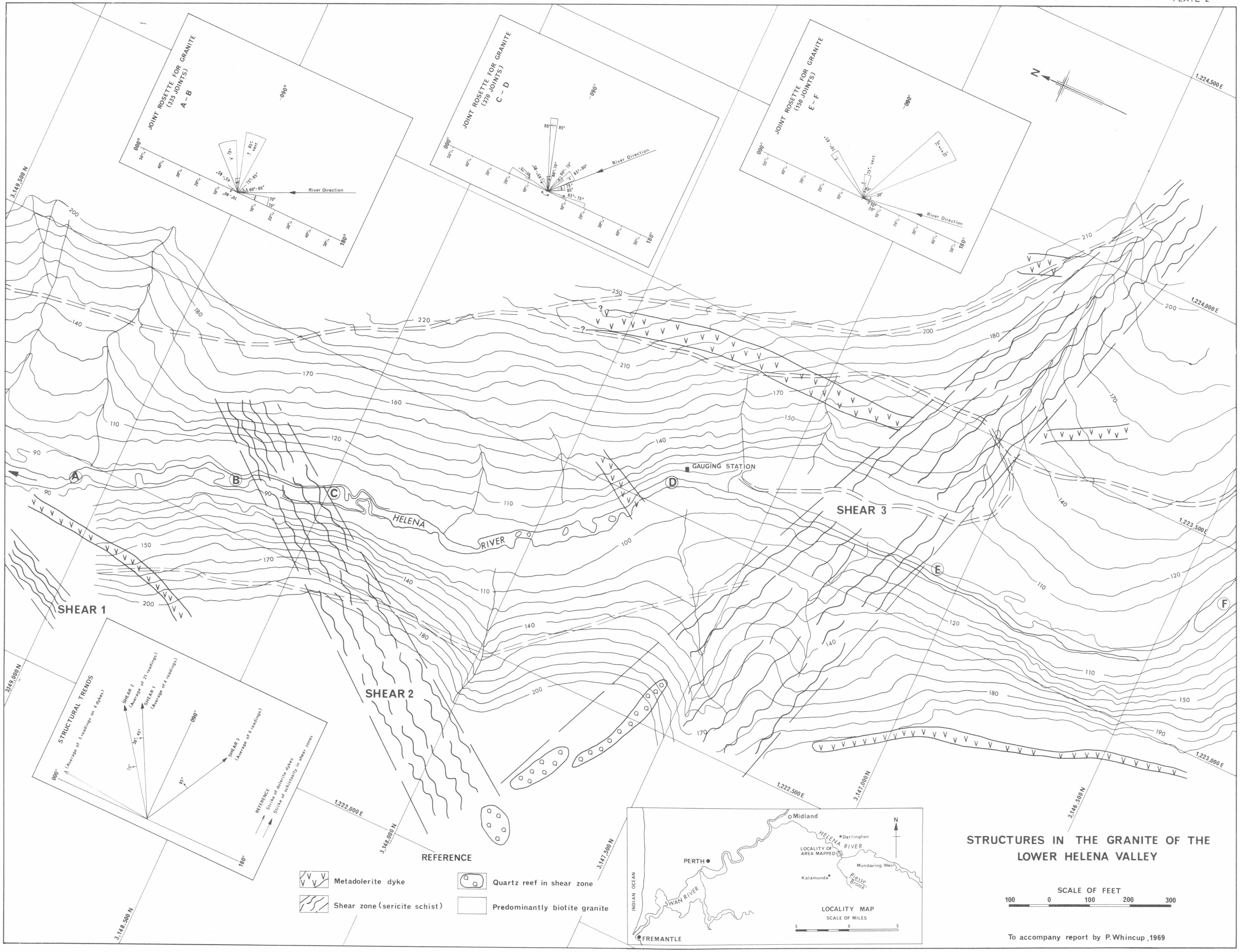
JOINT ROSETTE FOR GRANITE
(335 JOINTS)
A – B
JOINT ROSETTE FOR GRANITE
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C – D
JOINT ROSETTE FOR GRANITE
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E – F
River Direction
000°
090°
180°
N
SHEAR 1
SHEAR 2
SHEAR 3
HELENA RIVER
GAUGING STATION
A
B
C
D
E
F
3,149,500 N
3,149,000 N
3,148,500 N
3,148,000 N
3,147,500 N
3,147,000 N
3,146,500 N
1,224,500 E
1,224,000 E
1,223,500 E
1,223,000 E
1,222,500 E
1,222,000 E
STRUCTURAL TRENDS
SHEAR 2 (Average of 21 readings)
SHEAR 1 (Average of 4 readings)
SHEAR 3 (Average of 6 readings)
(Average of 5 readings on 4 dykes)
REFERENCE
Strike of dolerite dykes
Strike of schistosity in shear zones
REFERENCE
Metadolerite dyke
Shear zone (sericite schist)
Quartz reef in shear zone
Predominantly biotite granite
Midland
Darlington
HELENA RIVER
LOCALITY OF AREA MAPPED
PERTH
Mundaring Weir
Kalamunda
Piesse Brook
SWAN RIVER
INDIAN OCEAN
FREMANTLE
LOCALITY MAP
SCALE OF MILES
STRUCTURES IN THE GRANITE OF THE LOWER HELENA VALLEY
SCALE OF FEET
100 0 100 200 300
To accompany report by P. Whincup, 1969

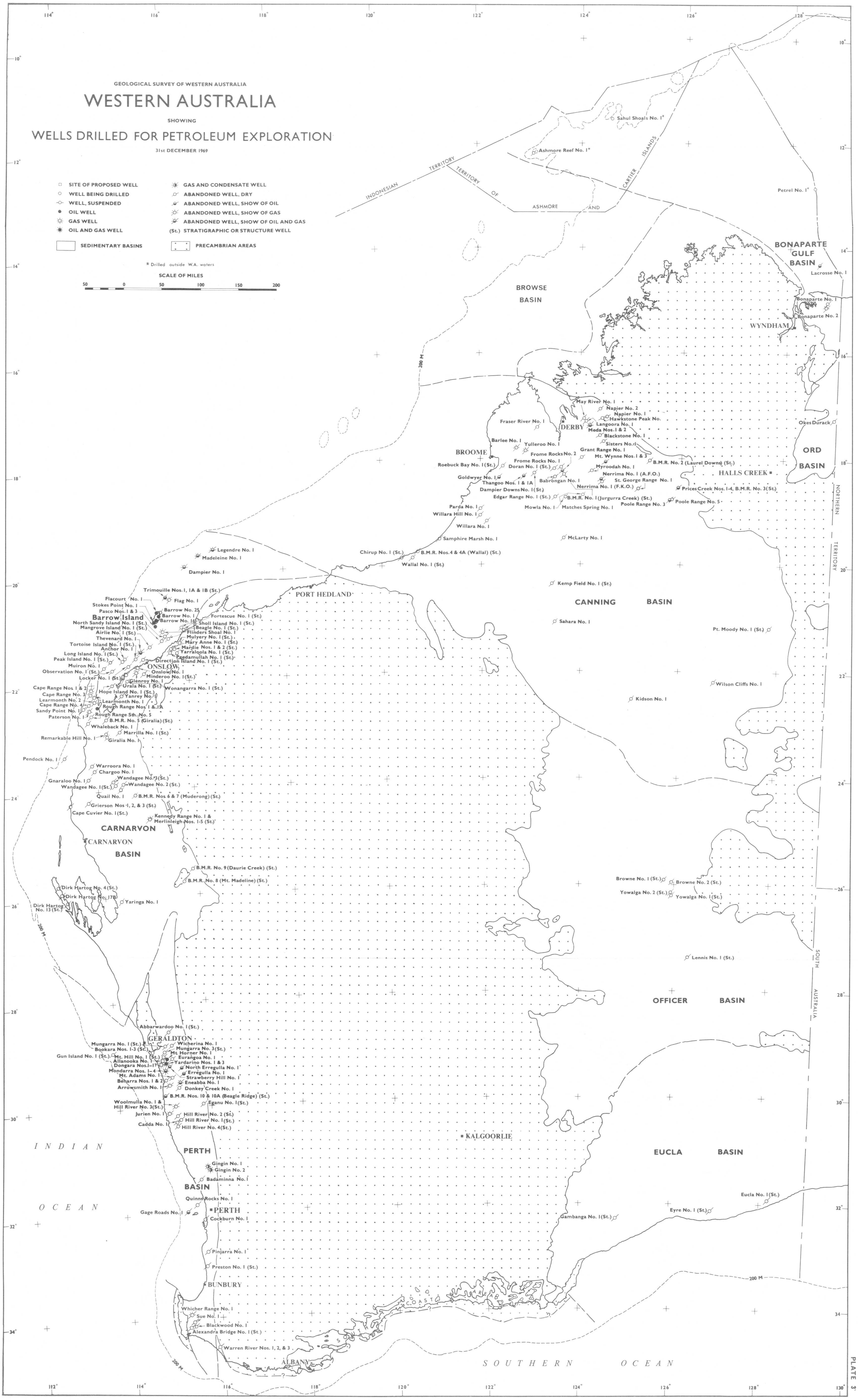
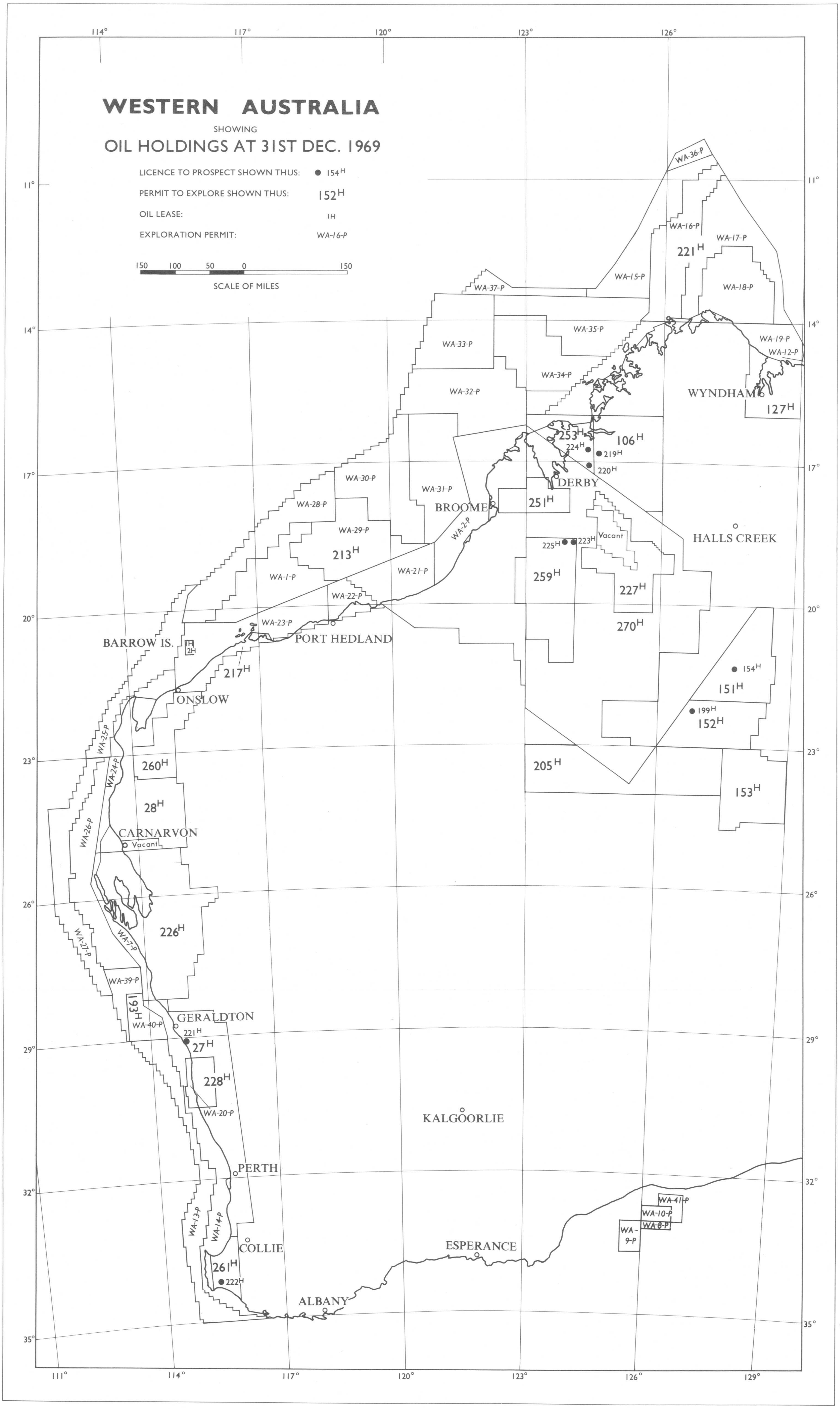
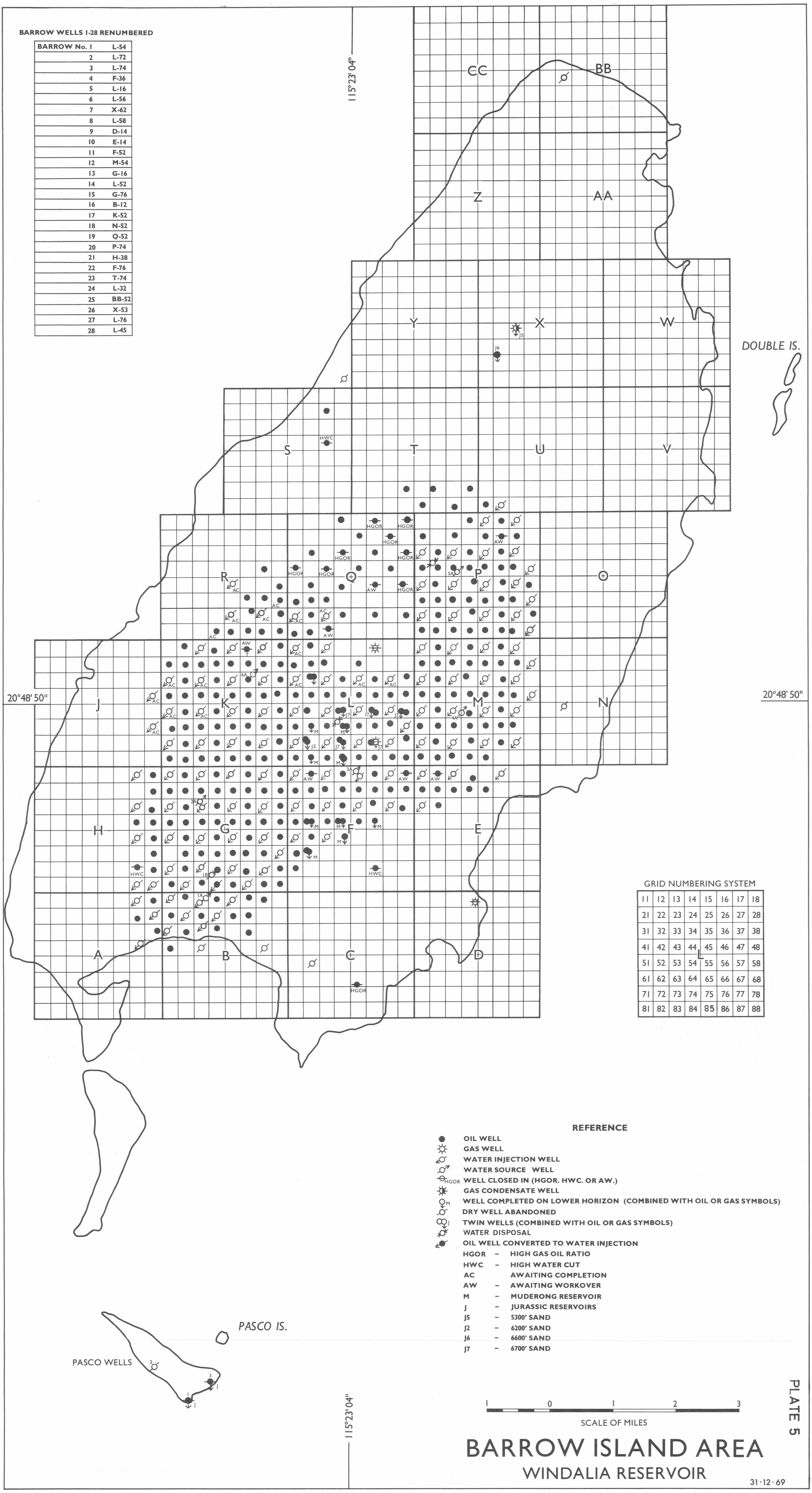

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
WESTERN AUSTRALIA
SHOWING
WELLS DRILLED FOR PETROLEUM EXPLORATION
31st DECEMBER 1969
SITE OF PROPOSED WELL
WELL BEING DRILLED
WELL, SUSPENDED
OIL WELL
GAS WELL
OIL AND GAS WELL
GAS AND CONDENSATE WELL
ABANDONED WELL, DRY
ABANDONED WELL, SHOW OF OIL
ABANDONED WELL, SHOW OF GAS
ABANDONED WELL, SHOW OF OIL AND GAS
(St.) STRATIGRAPHIC OR STRUCTURE WELL
SEDIMENTARY BASINS
PRECAMBRIAN AREAS
* Drilled outside W.A. waters
SCALE OF MILES
50 0 50 100 150 200
INDONESIAN TERRITORY
TERRITORY OF ASHMORE AND CARTIER ISLANDS
Sahul Shoals No. 1*
Ashmore Reef No. 1*
Petrel No. 1*
BONAPARTE GULF BASIN
Lacrosse No. 1
Bonaparte No. 1
Bonaparte No. 2
WYNDHAM
BROWSE BASIN
200 M
May River No. 1
Napier No. 2
Napier No. 1
Hawkstone Peak No.
Fraser River No. 1
DERBY
Langoora No. 1
Meda Nos. 1 & 2
Blackstone No. 1
Sisters No. 1
Barlee No. 1
Yulleroo No. 1
Grant Range No. 1
Mt. Wynne Nos. 1 & 3
BROOME
Frome Rocks No. 2
Frome Rocks No. 1
Roebuck Bay No. 1 (St.)
Doran No. 1 (St.)
Myroodah No. 1
B.M.R. No. 2 (Laurel Downs) (St.)
Nerrima No. 1 (A.F.O.)
St. George Range No. 1
Goldwyer No. 1
Thangoo Nos. 1 & 1A
Babrongan No. 1
Nerrima No. 1 (F.K.O.)
Dampier Downs No. 1 (St.)
Prices Creek Nos. 1-4, B.M.R. No. 3 (St.)
Edgar Range No. 1 (St.)
B.M.R. No. 1 (Jurgurra Creek) (St.)
Mowla No. 1
Matches Spring No. 1
Poole Range No. 3
Poole Range No. 5
HALLS CREEK
Okes Durack
ORD BASIN
Parda No. 1
Willara Hill No. 1
Willara No. 1
Samphire Marsh No. 1
McLarty No. 1
Legendre No. 1
Madeleine No. 1
Dampier No. 1
Chirup No. 1 (St.)
B.M.R. Nos. 4 & 4A (Wallal) (St.)
Wallal No. 1 (St.)
NORTHERN TERRITORY
PORT HEDLAND
Kemp Field No. 1 (St.)
CANNING BASIN
Sahara No. 1
Pt. Moody No. 1 (St.)
Trimouille Nos. 1, 1A & 1B (St.)
Flacourt No. 1
Flag No. 1
Stokes Point No. 1
Pasco Nos. 1 & 3
Barrow No. 25
Barrow Island
Barrow No. 1
Barrow No. 1B
Fortescue No. 1 (St.)
North Sandy Island No. 1 (St.)
Mangrove Island No. 1 (St.)
Sholl Island No. 1 (St.)
Beagle No. 1 (St.)
Airlie No. 1 (St.)
Flinders Shoal No. 1
Thevenard No. 1
Mulyery No. 1 (St.)
Tortoise Island No. 1 (St.)
Mary Anne No. 1 (St.)
Anchor No. 1
Mardie Nos. 1 & 2 (St.)
Long Island No. 1 (St.)
Yarraloola No. 1 (St.)
Peak Island No. 1 (St.)
Peedamullah No. 1 (St.)
Muiron No. 1
Direction Island No. 1 (St.)
ONSLOW
Observation No. 1 (St.)
Onslow No. 1
Locker No. 1 (St.)
Minderoo No. 1 (St.)
Glenroy No. 1
Cape Range Nos. 1 & 2
Urala No. 1 (St.)
Wonangarra No. 1 (St.)
Cape Range No. 3
Hope Island No. 1 (St.)
Learmonth No. 2
Yanrey No. 1
Cape Range No. 4
Learmonth No. 1
Sandy Point No. 1
Rough Range Nos. 1 & 1A
Paterson No. 1
Rough Range Sth. No. 5
B.M.R. No. 5 (Giralia) (St.)
Wilson Cliffs No. 1
Kidson No. 1
Whaleback No. 1
Marrilla No. 1 (St.)
Remarkable Hill No. 1
Giralia No. 1
Pendock No. 1
Warroora No. 1
Chargoo No. 1
Gnaraloo No. 1
Wandagee No. 3 (St.)
Wandagee No. 1 (St.)
Wandagee No. 2 (St.)
Quail No. 1
B.M.R. Nos 6 & 7 (Muderong) (St.)
Grierson Nos. 1, 2, & 3 (St.)
Cape Cuvier No. 1 (St.)
Kennedy Range No. 1 &
Merlinleigh Nos. 1-5 (St.)
CARNARVON
CARNARVON
BASIN
B.M.R. No. 9 (Daurie Creek) (St.)
B.M.R. No. 8 (Mt. Madeline) (St.)
Browne No. 1 (St.)
Browne No. 2 (St.)
Yowalga No. 2 (St.)
Yowalga No. 1 (St.)
Dirk Hartog No. 4 (St.)
Dirk Hartog No. 17B
Dirk Hartog No. 13 (St.)
Yaringa No. 1
200 M
Lennis No. 1 (St.)
SOUTH AUSTRALIA
OFFICER BASIN
Abbarwardoo No. 1 (St.)
GERALDTON
Mungarra No. 1 (St.)
Wicherina No. 1
Bookara Nos. 1-3 (St.)
Mungarra No. 3 (St.)
Gun Island No. 1 (St.)
Mt. Hill No. 1 (St.)
Mt Horner No. 1
Allanooka No. 1
Eurangoa No. 1
Dongara Nos. 1-17
Yardarino Nos. 1 & 3
Mondarra Nos. 1-4
North Erregulla No. 1
Mt. Adams No. 1
Erregulla No. 1
Strawberry Hill No. 1
Beharra Nos. 1 & 2
Eneabba No. 1
Arrowsmith No. 1
Donkey Creek No. 1
B.M.R. No. 10 & 10A (Beagle Ridge) (St.)
Woolmulla No. 1 &
Hill River No. 3 (St.)
Eganu No. 1 (St.)
Jurien No. 1
Hill River No. 2 (St.)
Hill River No. 1 (St.)
Cadda No. 1
Hill River No. 4 (St.)
KALGOORLIE
INDIAN
OCEAN
PERTH
BASIN
Gingin No. 1
Gingin No. 2
Badaminna No. 1
EUCLA BASIN
Quinns Rocks No. 1
Gage Roads No. 1
PERTH
Cockburn No. 1
Gambanga No. 1 (St.)
Eyre No. 1 (St.)
Eucla No. 1 (St.)
Pinjarra No. 1
Preston No. 1 (St.)
200 M
BUNBURY
Whicher Range No. 1
Sue No. 1
Blackwood No. 1
Alexandra Bridge No. 1 (St.)
Warren River Nos. 1, 2, & 3
ALBANY
SOUTHERN OCEAN
PLATE 3

PLATE 4


WESTERN AUSTRALIA
SHOWING
OIL HOLDINGS AT 31ST DEC. 1969
LICENCE TO PROSPECT SHOWN THUS: ● 154H
PERMIT TO EXPLORE SHOWN THUS: 152H
OIL LEASE: 1H
EXPLORATION PERMIT: WA-16-P
150 100 50 0 150
SCALE OF MILES
114° 117° 120° 123° 126°
111° 114° 117° 120° 123° 126° 129°
11° 14° 17° 20° 23° 26° 29° 32° 35°
WYNDHAM
DERBY
BROOME
HALLS CREEK
PORT HEDLAND
BARROW IS.
ONSLOW
CARNARVON
GERALDTON
KALGOORLIE
PERTH
COLLIE
ESPERANCE
ALBANY
Vacant
WA-36-P
WA-16-P
WA-17-P
WA-18-P
WA-15-P
WA-37-P
WA-35-P
WA-19-P
WA-12-P
WA-33-P
WA-34-P
WA-32-P
WA-30-P
WA-31-P
WA-28-P
WA-29-P
WA-2-P
WA-1-P
WA-21-P
WA-22-P
WA-23-P
WA-25-P
WA-24-P
WA-26-P
WA-7-P
WA-27-P
WA-39-P
WA-40-P
WA-20-P
WA-13-P
WA-14-P
WA-41-P
WA-10-P
WA-8-P
WA-9-P
221H
127H
253H
106H
224H
219H
220H
251H
213H
225H
223H
259H
227H
270H
217H
1H
2H
154H
151H
199H
152H
260H
205H
153H
28H
226H
193H
221H
27H
228H
261H
222H



BARROW WELLS 1-28 RENUMBERED

BARROW No. 1	L-54
2	L-72
3	L-74
4	F-36
5	L-16
6	L-56
7	X-62
8	L-58
9	D-14
10	E-14
11	F-52
12	M-54
13	G-16
14	L-52
15	G-76
16	B-12
17	K-52
18	N-52
19	Q-52
20	P-74
21	H-38
22	F-76
23	T-74
24	L-32
25	BB-52
26	X-53
27	L-76
28	L-45

GRID NUMBERING SYSTEM

11	12	13	14	15	16	17	18
21	22	23	24	25	26	27	28
31	32	33	34	35	36	37	38
41	42	43	44	45	46	47	48
51	52	53	54	55	56	57	58
61	62	63	64	65	66	67	68
71	72	73	74	75	76	77	78
81	82	83	84	85	86	87	88

BARROW ISLAND AREA
WINDALIA RESERVOIR

PLATE 6

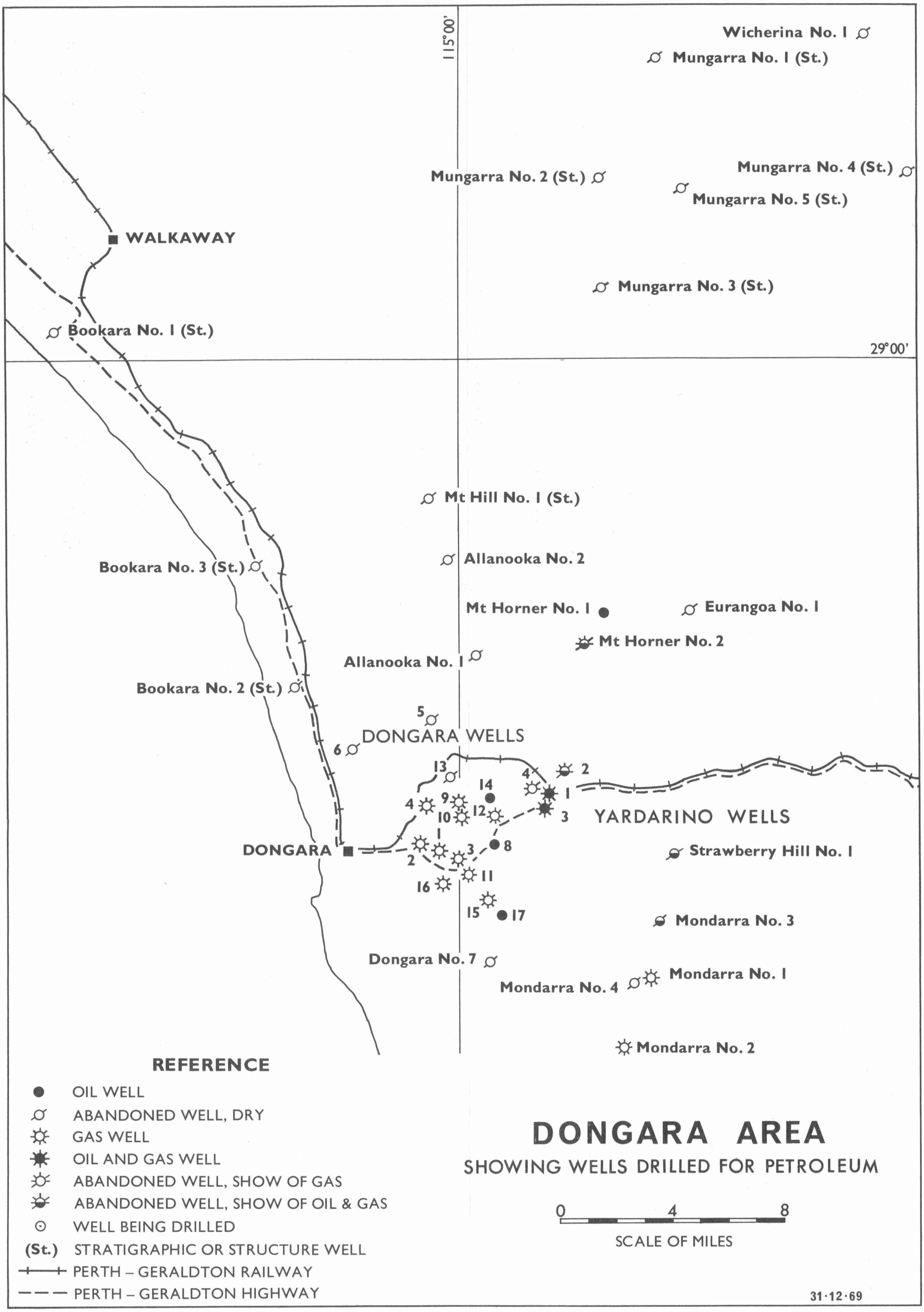
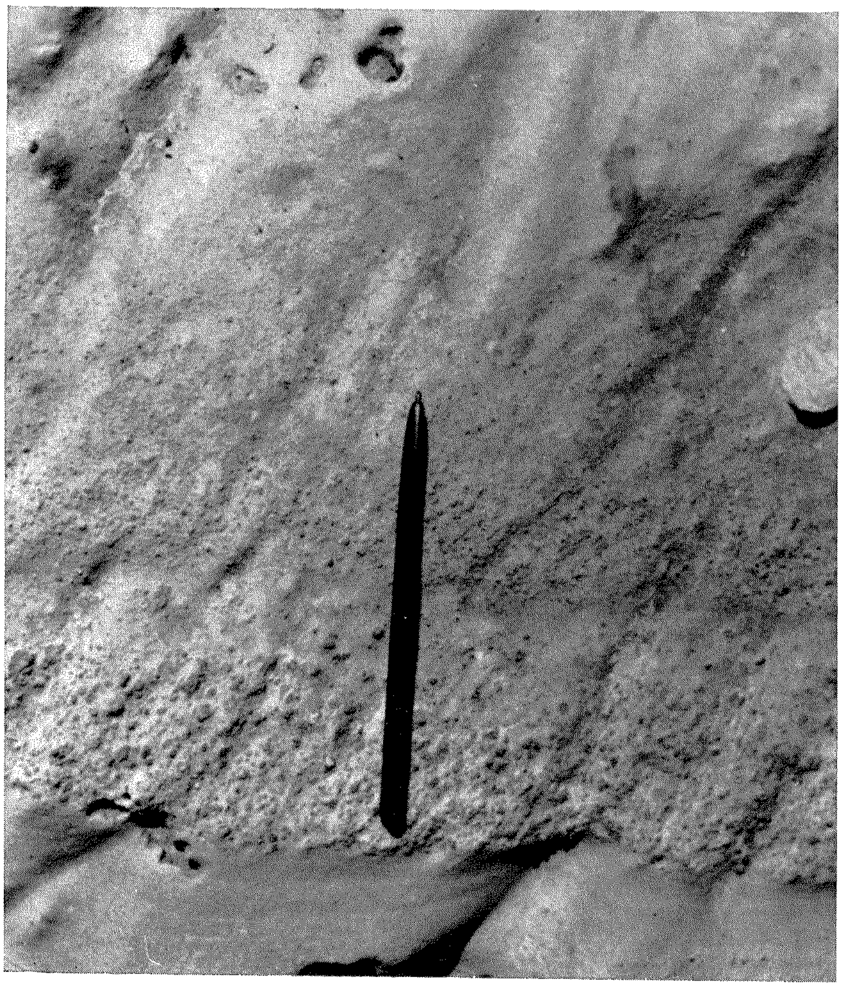

115°00'
29°00'
Wicherina No. 1
Mungarra No. 1 (St.)
Mungarra No. 2 (St.)
Mungarra No. 4 (St.)
Mungarra No. 5 (St.)
WALKAWAY
Mungarra No. 3 (St.)
Bookara No. 1 (St.)
Mt Hill No. 1 (St.)
Bookara No. 3 (St.)
Allanooka No. 2
Mt Horner No. 1
Eurangoa No. 1
Mt Horner No. 2
Allanooka No. 1
Bookara No. 2 (St.)
5
DONGARA WELLS
6
13
14
4
2
9
10
12
4
1
3
YARDARINO WELLS
DONGARA
2
3
8
Strawberry Hill No. 1
16
11
15
17
Mondarra No. 3
Dongara No. 7
Mondarra No. 1
Mondarra No. 4
Mondarra No. 2
REFERENCE
OIL WELL
ABANDONED WELL, DRY
GAS WELL
OIL AND GAS WELL
ABANDONED WELL, SHOW OF GAS
ABANDONED WELL, SHOW OF OIL & GAS
WELL BEING DRILLED
(St.) STRATIGRAPHIC OR STRUCTURE WELL
PERTH – GERALDTON RAILWAY
PERTH – GERALDTON HIGHWAY
DONGARA AREA
SHOWING WELLS DRILLED FOR PETROLEUM
0
4
8
SCALE OF MILES
31·12·69

PLATE 7

A. Well bedded siltstone and shale showing graded bedded unit. Scale: length of pick 13 inches (33 cms). (FN 1387.)



B. Close-up of graded bedded unit in A above showing variations within the graded bedded unit. Scale: length of pen 5·3 inches (13·4 cms). (FN 1388.)

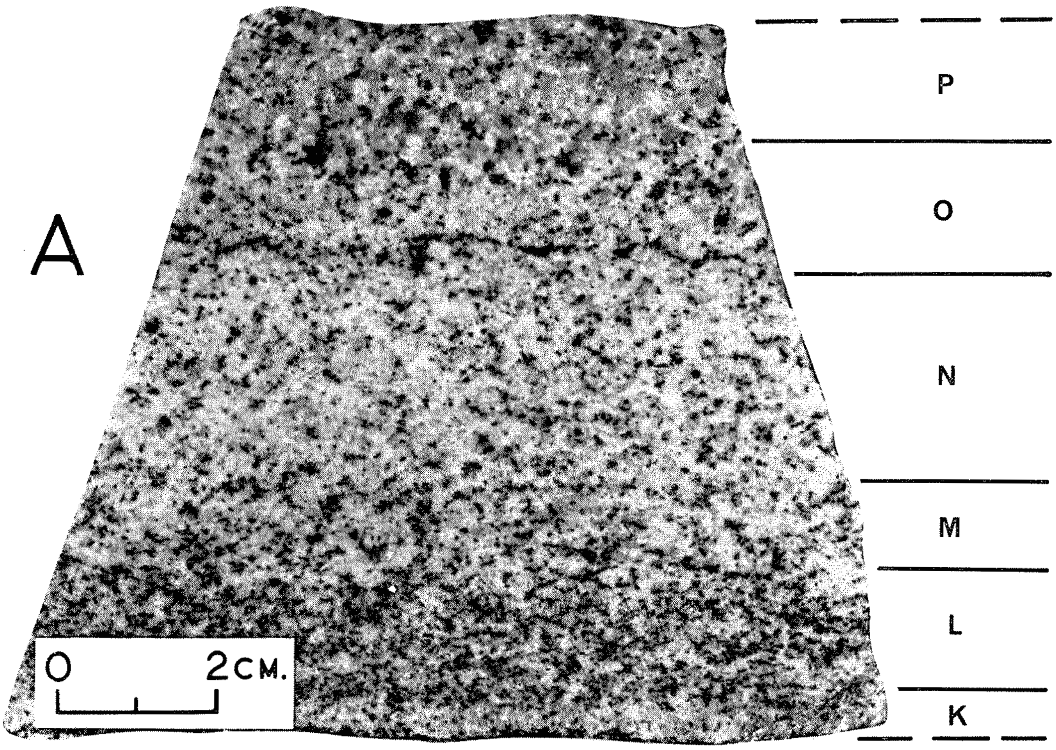
A. Poorly sorted conglomerate bed showing orientation of porphyry clasts in the direction of the cleavage. Top of bed, as viewed. Scale : length of pen 5·3 inches (13·4 cms). (FN 1389.)

B. Scour channel, contemporaneous erosion of regularly bedded sandy and silty unit ; crude graded bedding can be seen in the scour pile. Length of pick 13 inches (33 cms). (FN 1390.)

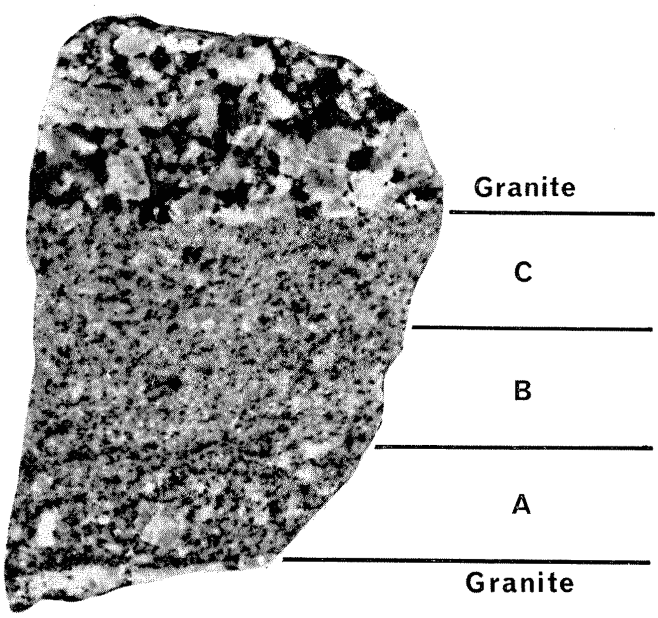
A. Slump structure involving a number of lithologic units ; directions of slumping away from viewer. Note truncation in top left hand corner of photo. Scale : length of pick 13 inches (33 cms). (FN 1391.)

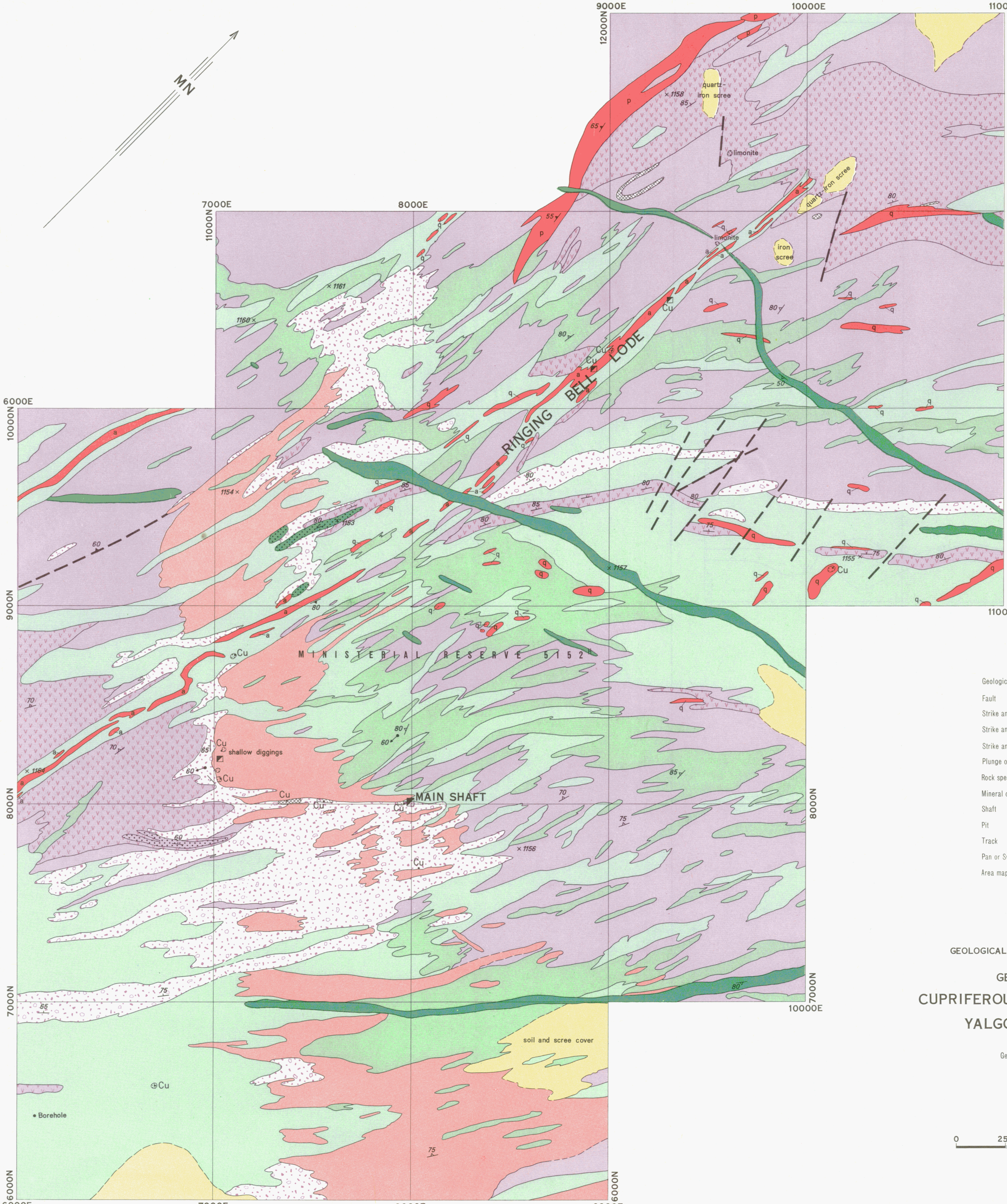
B. Dropped cobble in colour banded shaly and silty bands, thin bands 0·04 inch (1 to 2 mm). Cobble is quartz feldspar porphyry. Note small fault beneath cobble. Scale : length of pen 5·3 inches (13·4 cms). (FN 1392.)

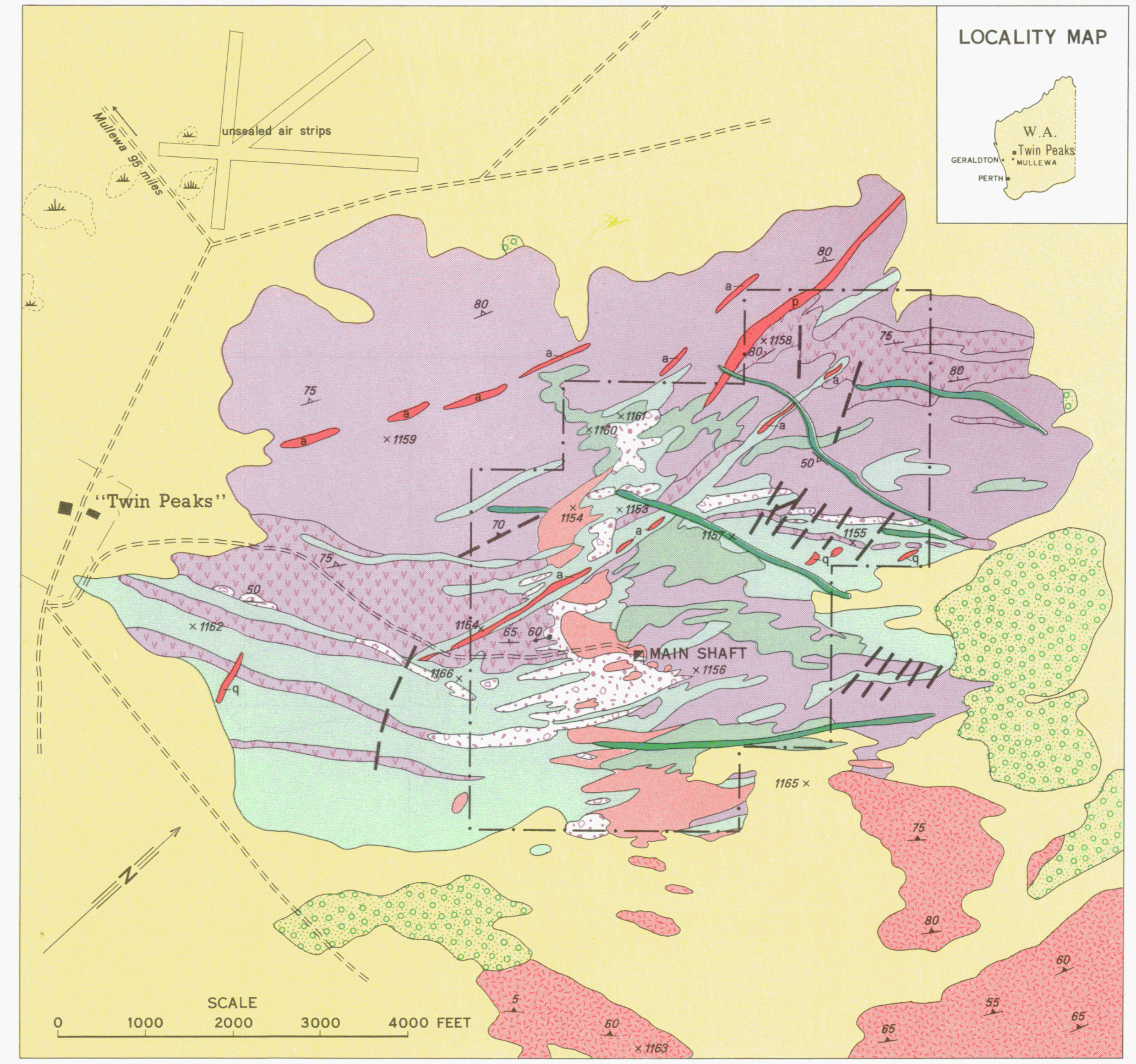
A



B







SYMBOLS

Geological boundary

Fault

Strike and dip of bedding 70

Strike and dip of foliation 75

Strike and dip of schistosity 85

Plunge of lineation 60

Rock specimen × 1156

Mineral occurrence · Cu

Shaft

Pit

Track

Pan or Swamp

Area mapped in detail

GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

GEOLOGICAL MAP OF

CUPRIFEROUS AREA AT TWIN PEAKS YALGOO GOLDFIELD, W.A.

Geology by John Sofoulis, May-July 1969

SCALE

0 250 500 750 1000 FEET

REFERENCE

CAINOZOIC

Superficial soil, stony pebbly veneers, scree

Laterite

Gossan, iron capping

PROTEROZOIC

Quartz dolerite dyke

ARCHAEAN

Intrusives

q Quartz

a Aplite

p Quartz porphyry

Granite, granodiorite, porphyritic and even-grained quartz feldspar chlorite rocks, locally with xenoliths

Granite, granodiorite, gneiss, migmatite. Fine-grained, banded and foliated, with remnant bands of country rock

Dolerite, metadolerite, fine to medium-grained; some porphyritic varieties

Altered ultramafic rocks, mainly tremolite-chlorite schist

Chlorite-talc-carbonate rocks

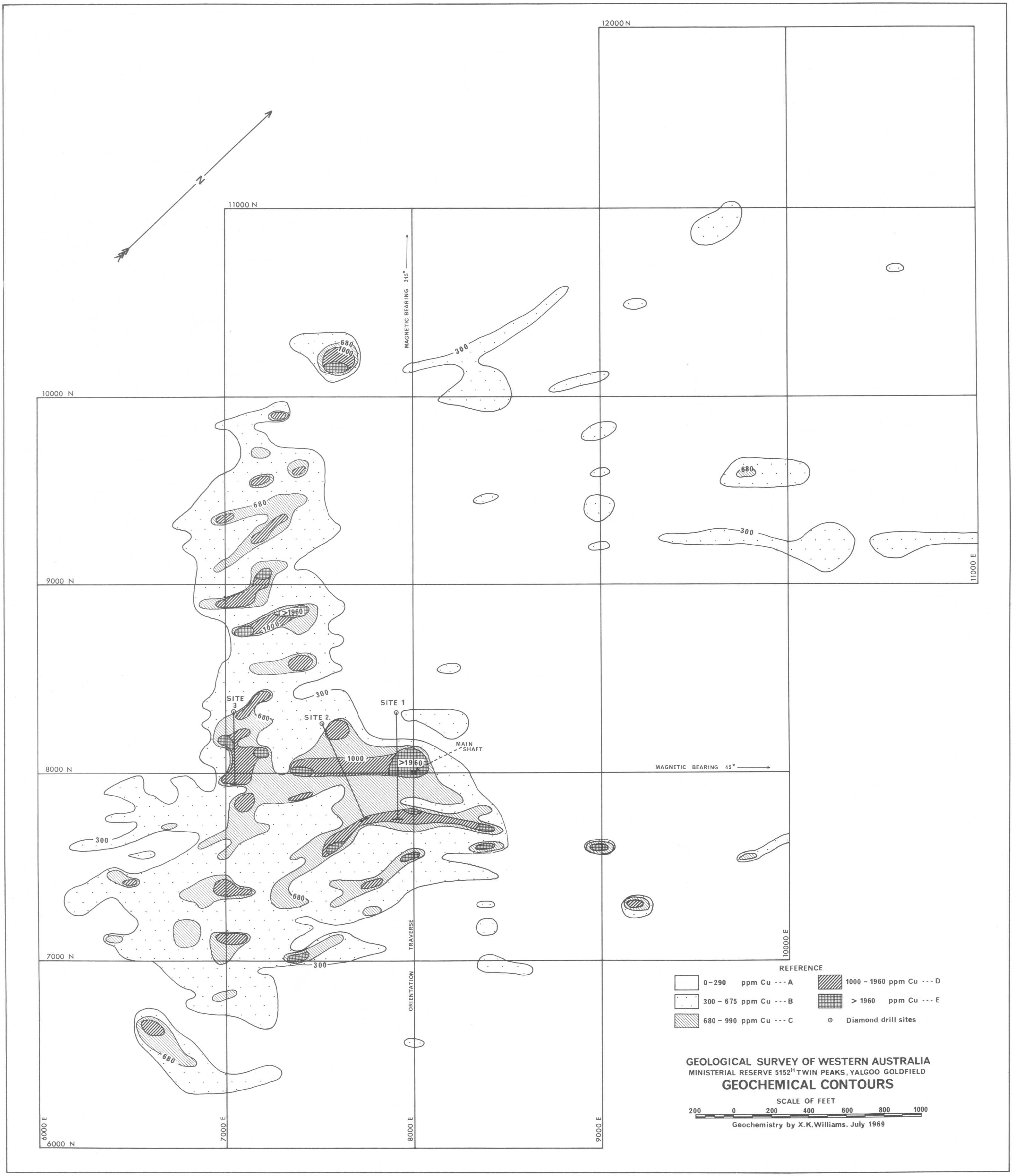
Volcanics

Altered basic to intermediate lavas, mainly amygdaloidal, with intercalated altered tuffs and metasediments.

Acid lavas, with intercalated chlorite schist and phyllite (probably altered tuff) and minor metasediments

Pyroclastics; coarse fragmental rocks with lava and tuff pyroclasts

Quartz sandstone



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

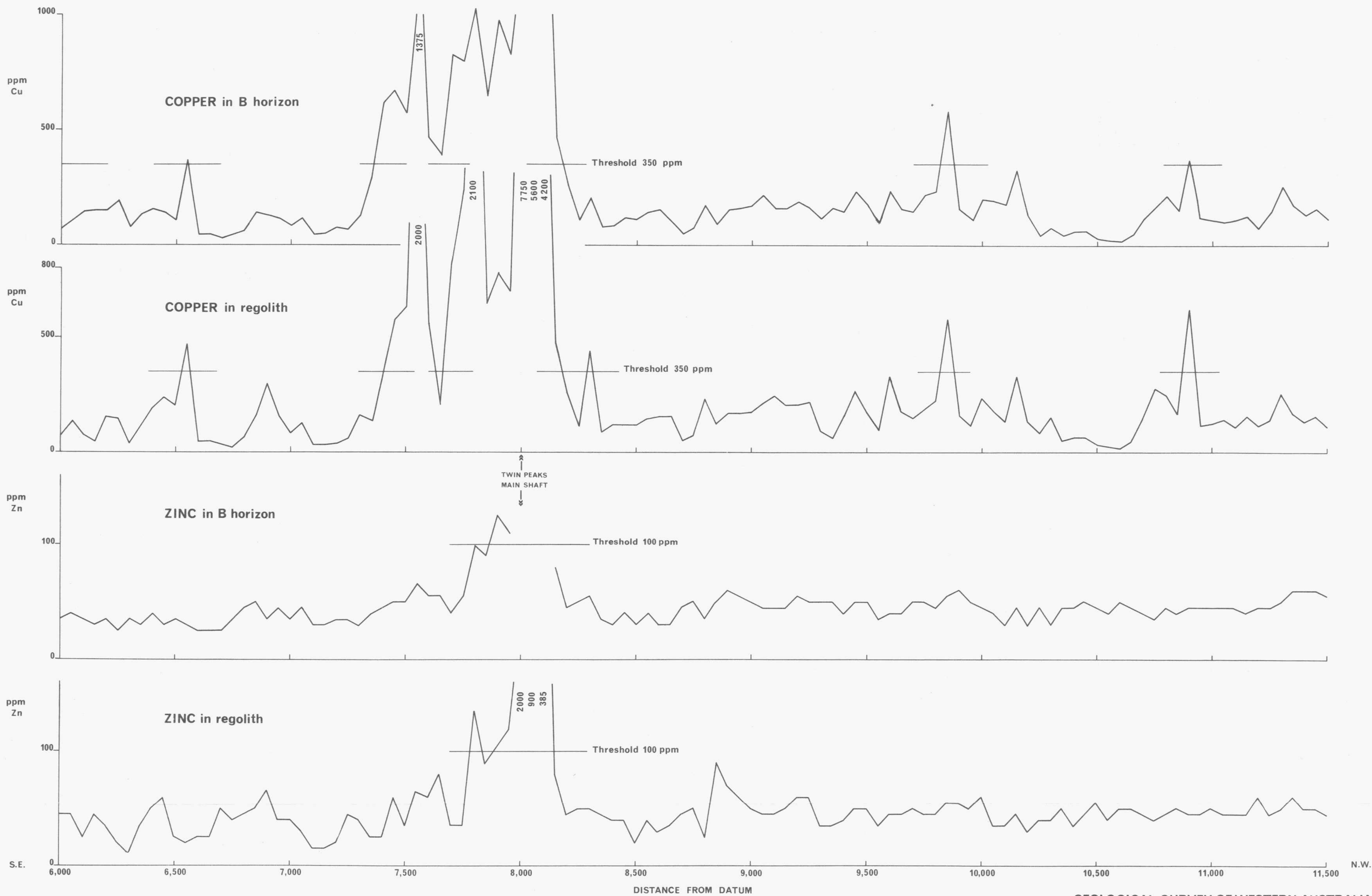
MINISTERIAL RESERVE 5152H TWIN PEAKS, YALGOO GOLDFIELD

GEOCHEMICAL CONTOURS

SCALE OF FEET

200 0 200 400 600 800 1000

Geochemistry by X. K. Williams. July 1969



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINISTERIAL RESERVE 5152H TWIN PEAKS, YALGOO GOLDFIELD

RESULTS OF ORIENTATION TRAVERSE COPPER AND ZINC

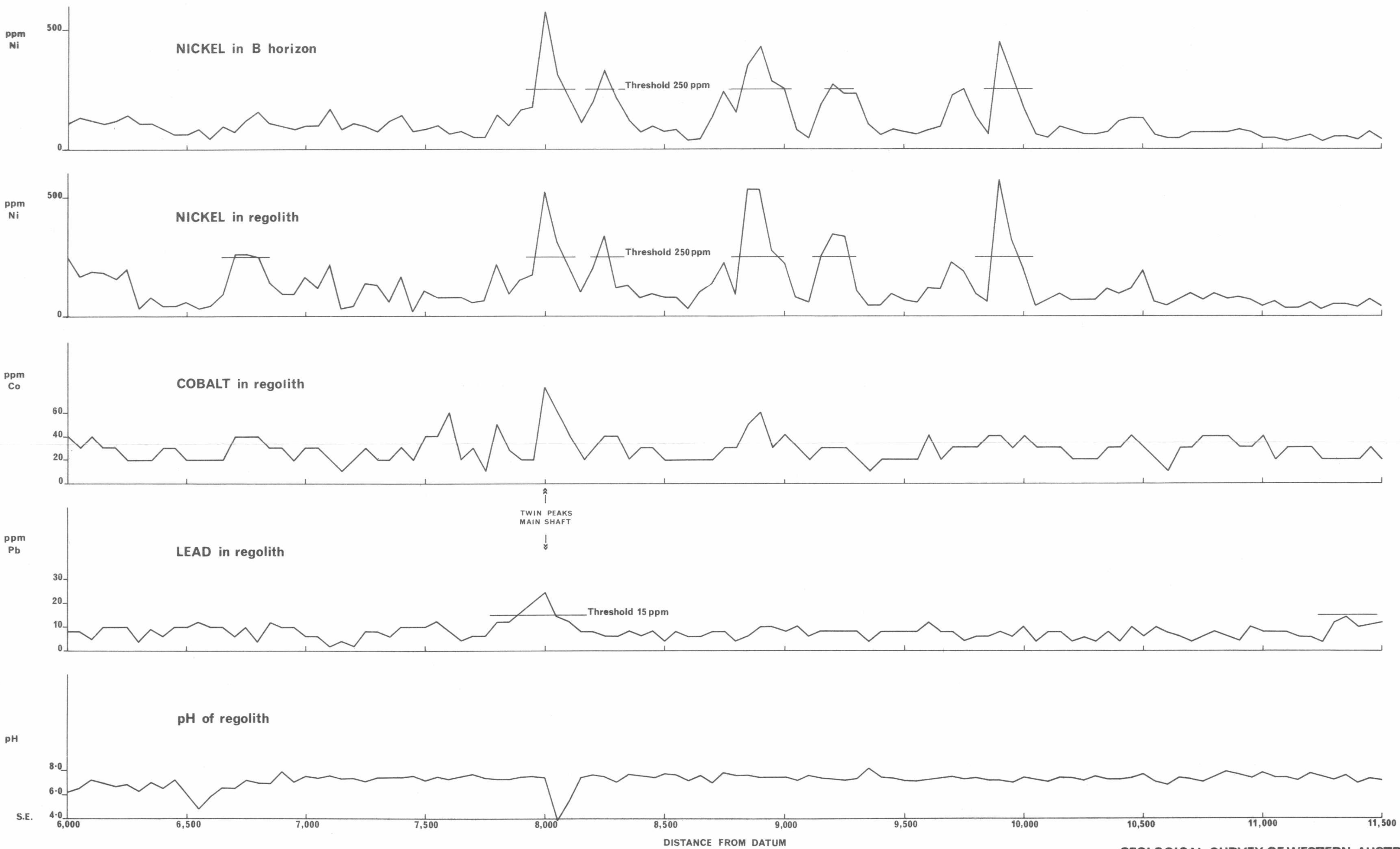
SCALE OF FEET

100 0 100 200 300 400 500

Geochemistry by X.K.Williams. June 1969

PLATE 13

11174



GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

MINISTERIAL RESERVE 5152H TWIN PEAKS, YALGOO GOLDFIELD

RESULTS OF ORIENTATION TRAVERSE
NICKEL, COBALT, LEAD AND pH

SCALE OF FEET

100 0 100 200 300 400 500

Geochemistry by X.K.Williams. June 1969

11175

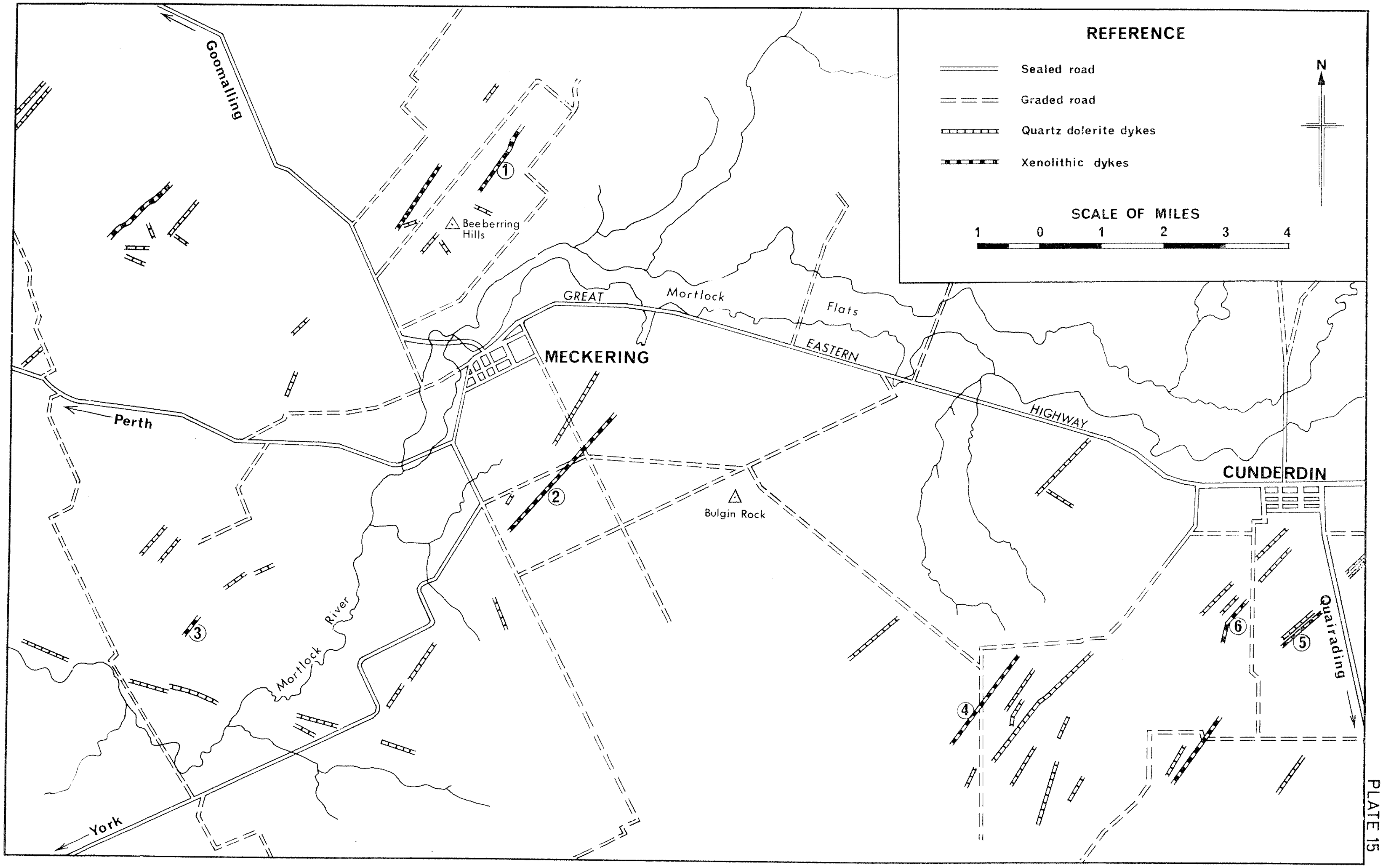
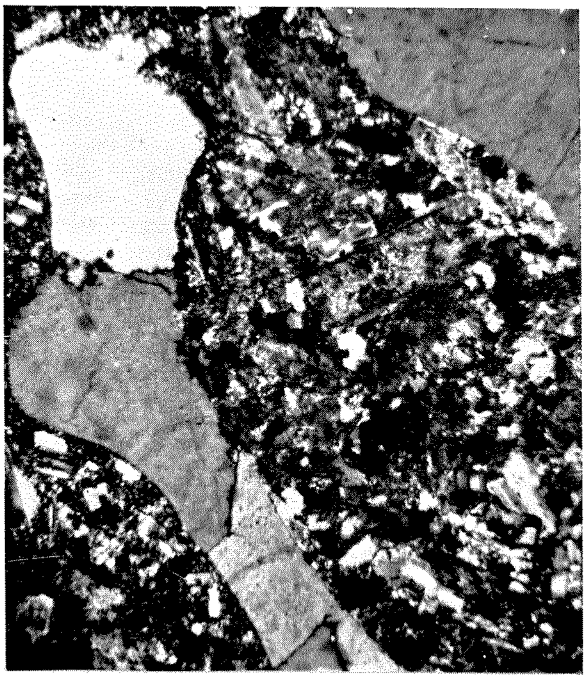
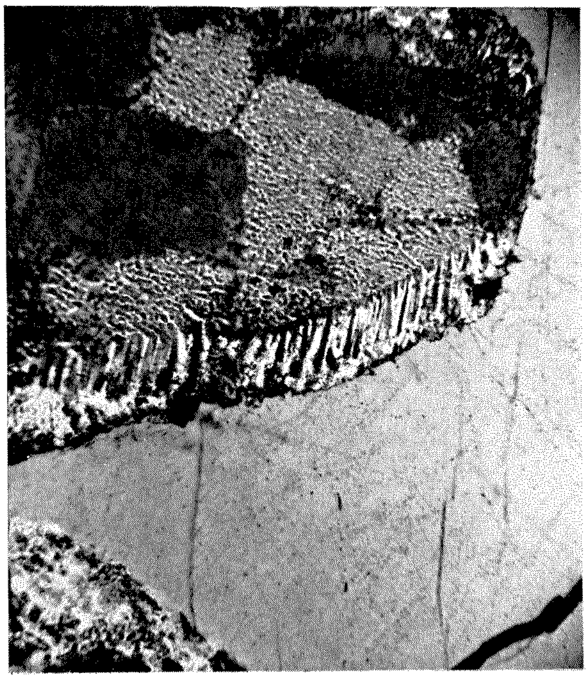

REFERENCE
Sealed road
Graded road
Quartz dolerite dykes
Xenolithic dykes
N
SCALE OF MILES
1 0 1 2 3 4
Goomalling
Beeberring Hills
GREAT
Mortlock
Flats
EASTERN
HIGHWAY
MECKERING
CUNDERDIN
Perth
Bulgin Rock
Mortlock River
York
Quairading
1
2
3
4
5
6

PLATE 15

PLATE 16


A


B


C


D


E


F

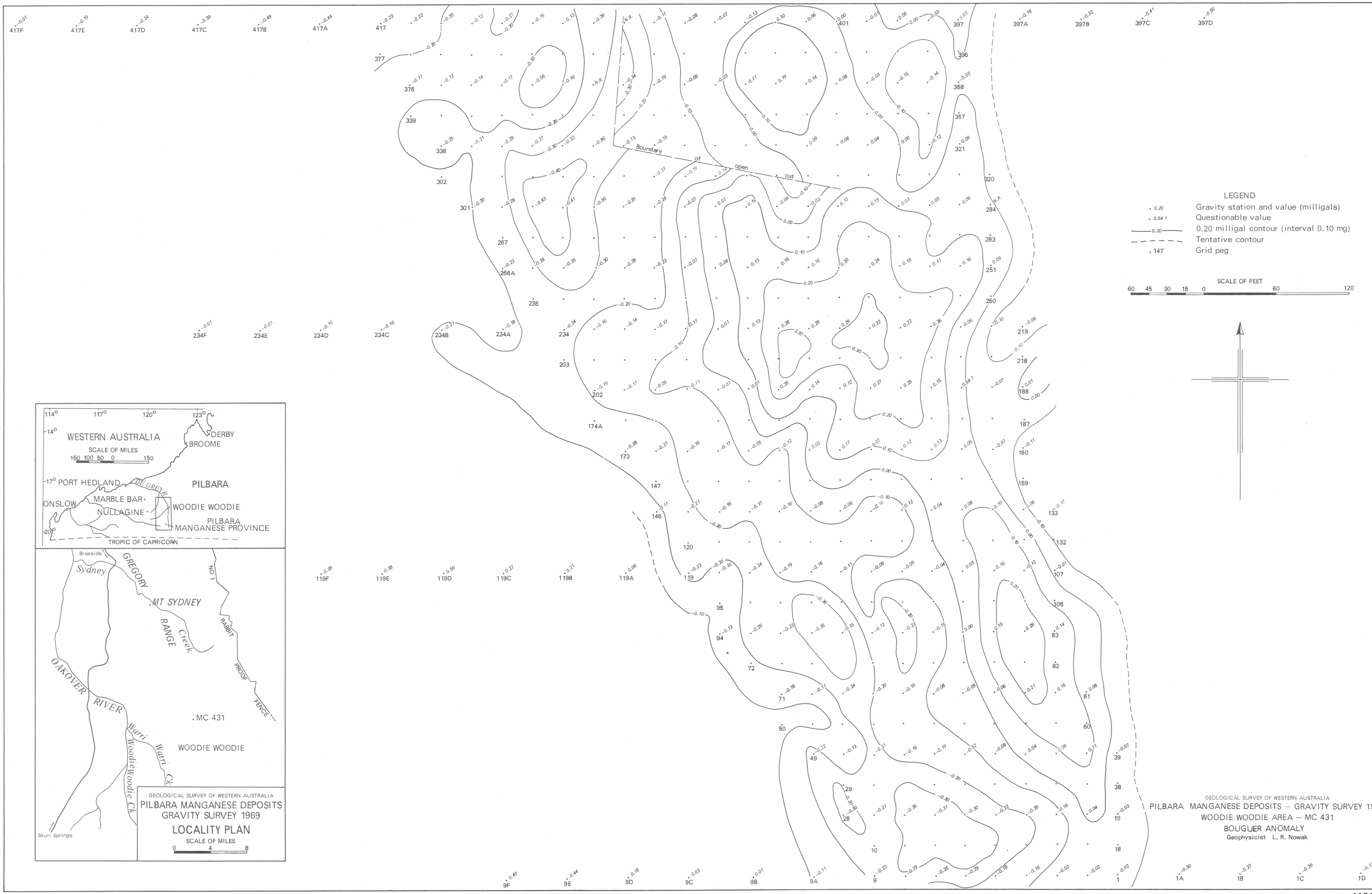
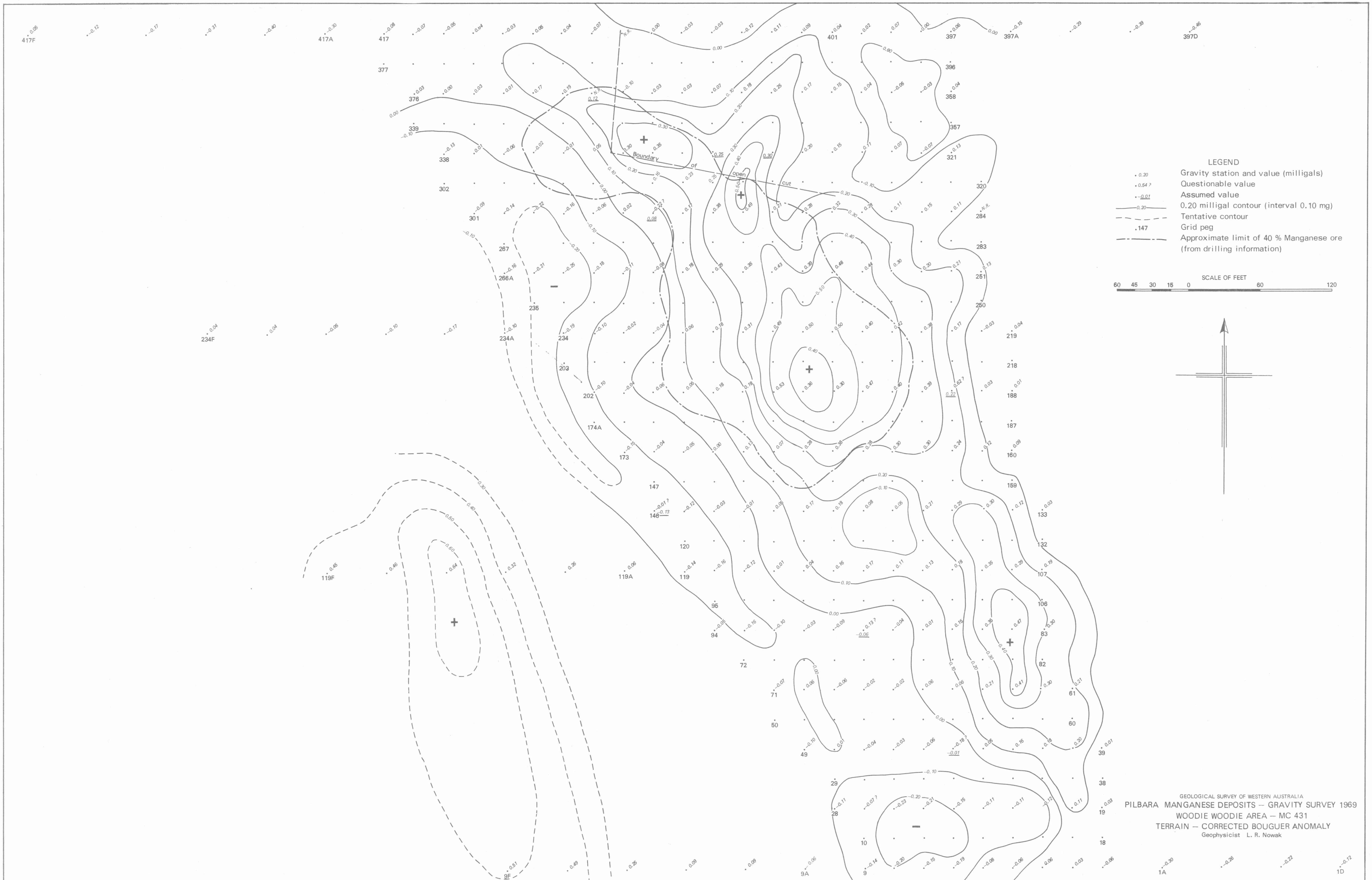

LEGEND
Gravity station and value (milligals)
Questionable value
0.20 milligal contour (interval 0.10 mg)
Tentative contour
Grid peg
SCALE OF FEET
60 45 30 15 0 60 120
Boundary of open cut
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
PILBARA MANGANESE DEPOSITS – GRAVITY SURVEY 1969
WOODIE WOODIE AREA – MC 431
BOUGUER ANOMALY
Geophysicist L. R. Nowak
WESTERN AUSTRALIA
SCALE OF MILES
150 100 50 0 150
DERBY
BROOME
PORT HEDLAND
DE GREY R.
PILBARA
ONSLOW
MARBLE BAR
NULLAGINE
WOODIE WOODIE
PILBARA MANGANESE PROVINCE
TROPIC OF CAPRICORN
Braeside
Sydney
GREGORY
MT SYDNEY
RANGE
Creek
NO 1
RABBIT
PROOF
FENCE
OAKOVER RIVER
MC 431
WOODIE WOODIE
Warri
Woodie Woodie Ck
Warri Ck
Skull Springs
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
PILBARA MANGANESE DEPOSITS
GRAVITY SURVEY 1969
LOCALITY PLAN
SCALE OF MILES
0 4 8

PLATE 18



11285