WESTERN AUSTRALIA

REPORT

OF THE

GEOLOGICAL SURVEY BRANCH

FOR THE

YEAR 1962

EXTRACT FROM THE REPORT OF THE DEPARTMENT OF MINES

70401/5/63—780

By Authority: ALEX. B. DAVIES, Government Printer

1963

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the Year 1962

CONTENTS

REPORTS

LIST OF PLATES

LIST OF FIGURES

DIVISION IV

Annual Report of the Geological Survey Branch of the Mines Department for the year 1962

The Under Secretary for Mines

I submit herewith for the information of the Honourable Minister for Mines my report on the activities of the Geological Survey for the year 1962, together with some reports on investigations made for departmental purposes.

REORGANISATION.

Recruitment for the enlargement of the Geological Survey, explained in the 1961 Annual Report, continued and by the end of 1962 all positions had been filled, but five appointees had not arrived.

Delays in filling the new positions have been due to shipping, appointees accepting a position and later reversing their decisions, and the desire to obtain the best available staff.

Due to the great demand for hydrological services a new position of Chief Hydrogeologist was created. Mr. E. P. O'Driscoll has been appointed to this position and is expected to take up his duties early in 1963.

The reorganisation has created a heavy load on the administrative side of the Survey but this is expected to ease when all staff become familiar with their new positions and with the geology and geography of the State.

The demand for geological services has grown even more rapidly than the staff. This applies in particular to the Hydrology and Engineering Division.

STAFF.

Appointments.

Professional:

Name	Position	Effective Date
R. C. Horwitz, D.Sc. (Switz.)	Senior Geologist	3/1/1962
N. J. Mackay, B.Sc. (Hons.)	Deputy Govt. Geologist	9/1/1962
P. E. Playford, Ph.D., B.Sc. (Hons.)	Senior Geologist	11/1/1962
W. N. MacLeod, Ph.D., M.Sc.	Senior Geologist	15/1/1962
F. R. Gordon, B.Sc., A.O.S.M.	Geologist	24/1/1962
I. Gemuts, B.Sc. (Hons.)	Geologist, Grade 2	26/1/1962
J. R. Passmore, B.Sc. (Hons.)	Geologist, Grade 2	30/1/1962
A. D. Allen, M.Sc.	Geologist, Grade 2	12/3/1962
D. L. Rowston, B.Sc.	Geophysicist	16/4/1962
D. C. Lowry, M.Sc.	Geologist, Grade 2	27/4/1962
G. R. Ryan, B.A. (Hons.)	Geologist, Grade 1	4/5/1962
H. S. Edgell, Ph.D., B.Sc. (Hons.)	Palaeontologist	11/5/1962
A. F. Trendall, Ph.D., B.Sc. (Hons.)	Petrologist	14/5/1962
R. Halligan, B.Sc. (Hons.)	Geologist, Grade 2	23/5/1962
C. Emmenegger, D.Sc. (Switz.)....	Geologist, Grade 2	2/8/1962

Clerical and General:

N. Stoyanoff	Typist	13/3/1962
H. F. Rettig	Core Librarian	2/7/1962
P. F. Jefferies	Laboratory Assistant	16/7/1962

Promotions:

W. R. K. Jones	Geologist Grade 2 to Geologist Grade 1	15/1/1962
J. D. Wyatt	Geologist Grade 2 to Geologist Grade 1	15/1/1962

Transfers:

R. D. Macliver	Clerk — transferred to Mines Dept.	16/4/1962
S. C. Crew	Clerk — transferred from Mines Dept.	16/4/1962

Resignations:

W. M. Bock	Geologist Grade 2	17/8/1962

ACCOMMODATION.

The accommodation provided for the Geological Survey is unsatisfactory from an administrative viewpoint. The Survey occupies three separate office buildings and a fourth is being prepared. The scattered nature of the office accommodation and the isolation from the Drafting Branch and Head Office of the Department, all create many time consuming difficulties.

The storage of rock collections, drill cores, drill samples and camping equipment is spread between Welshpool, the W.A. Museum and our store at Dianella. The latter must be enlarged as the store at Welshpool is required by the Department of Industrial Development and the Museum has moved the Survey's rock and mineral collection from display to temporary storage.

It is urged that plans should be made now for the future housing of the Survey together in suitable office accommodation and for the enlargement of the Dianella Store.

OPERATIONS.

The programme of work set down for 1962 was followed and items not completed are included in the 1963 programme set out later in this report.

The Government Geologist attended the Southern Queensland Conference of the Institute of Mining and Metallurgy and inspected the Moonie and Roma oil and gas fields as a guest of the Queensland Geological Survey. The Jubilee Conference of the Australian and New Zealand Association for the Advancement of Science was attended in Sydney.

The Deputy Government Geologist attended the Underground Water Conference in Adelaide. The next meeting will be held in Perth in 1963. As a result of the conference, the Honourable Premier arranged for a State Committee on Underground Water to be established with the Government Geologist as Convenor. The main function of this inter-departmental committee is to co-ordinate and to advise on underground water problems within the State.

HYDROLOGY AND ENGINEERING DIVISION.

K. Berliat (Senior Geologist), F. R. Gordon, J. D. Wyatt, K. H. Morgan, C. Emmenegger, J. R. Passmore and A. D. Allen.

Hydrology.

The investigation of the underground water resources of the Perth Basin was continued during the year.

In the Byford-Kwinana area four exploratory bores were completed and the drilling programme is continuing. The object of the drilling programme is to correlate Jurassic and Cretaceous aquifers across the Basin, and to assess their lateral continuity, salinity and capacity.

Drilling was commenced in the Lake Allanooka area, centred 20 miles southeast of Geraldton, to ascertain the potential of Mesozoic aquifers in the area as an additional source for the Geraldton town water supply. Three exploratory bores were completed and the drilling programme is continuing.

Exploratory drilling for domestic water supplies was carried out at Jurien Bay, Mandurah, Busselton, Billeranga Hills and Whitby Falls.

Three bores were drilled at Australind to successfully complete the programme which obtained a large supply of good quality water for industrial use by Laporte Titanium Ltd.

Hydrological advisory work and an assessment of ground water resources in the Halls Creek district was carried out in conjunction with regional mapping in the East Kimberley area.

An extensive bore siting programme was undertaken for orchardists in the Karagullen—Pickering Brook—Kalamunda area.

Miscellaneous investigations as required were carried out on a State-wide basis.

Engineering Geology.

A detailed examination was made of the Avon Valley Deviation of the Standard Gauge Railway between Midland Junction and Northam. These geological observations formed the basis of the site investigation reports issued by the consulting engineers (Maunsell and Partners) to all prospective tenderers. Several relocations were suggested or approved, the stability of deep cuts was assessed, and drilling results for bridge and route investigations were rationalized. Ballast and borrow sources were delineated and evaluated. Geological reconnaissance was carried out on the proposed route between Northam and Kellerberrin, and ballast and borrow sources were also investigated.

Examination of borehole samples and geological reconnaissance enabled preliminary recommendations as to damsite locations, investigations and further drilling at South Canning, Gooralong Brook and Upper and Lower Wongong damsites for the Metropolitan Water Supply Department.

Detailed work on the Ord River Damsite was designed to give an assessment of the problems of stability and water leakage and the feasibility of underground construction. Seismic refraction work with a portable seismic timer was used to evaluate spillway conditions.

Preliminary geological and geophysical work was commenced at the Dimond Gorge Damsite on the Fitzroy River and at the site of the proposed barrage of the Fitzroy River near Gogo Station.

SEDIMENTARY (OIL) DIVISION.

P. E. Playford (Senior Geologist), G. H. Low, and D. C. Lowry.

Field work was conducted during the year in the Canning and Perth Basins. In the Canning Basin a detailed study of the Devonian reef complexes exposed on the Lennard Shelf was initiated, and this will continue during 1963. In the Perth Basin regional geological mapping was undertaken in the Augusta-Nannup area at the southern end of the Basin. This project will also be continued in 1963, extending the mapping to as far north as Perth.

The progress of oil exploration in Western Australia was followed closely during the year.

The Senior Geologist accompanied the Government Geologist on a visit to the Moonie oil field and the Roma gas field in Queensland during August. They also attended the Australasian Institute of Mining and Metallurgy annual conference in Southern Queensland, the theme of which was "Oil in Australasia", and the Jubilee Congress in Sydney of the Australian and New Zealand Association for the Advancement of Science.

REGIONAL GEOLOGY DIVISION.

R. C. Horwitz (Senior Geologist), J. Sofoulis, G. R. Ryan, M. J. B. Kriewaldt and I. Gemuts.

Three geologists were engaged in mapping on the Dampier and Roebourne 1:250,000 Sheets. Dampier Sheet was completed.

One geologist was engaged in mapping on the Widgiemooltha 1:250,000 Sheet, and, accompanied by the Senior Geologist, a reconnaissance of the Warburton Range area was made.

One geologist was engaged in mapping on the Gordon Downs and Dixon Range 1:250,000 Sheets in conjunction with the Bureau of Mineral Resources. Gordon Downs Sheet was completed.

The Senior Geologist worked with the Dampier-Roebourne and Widgiemooltha parties for various periods during the field season.

Short reports were written on hydrological and mineral resources problems in areas covered by the geological sheets being mapped and in other areas of the State.

MINERAL RESOURCES DIVISION.

W. N. MacLeod (Senior Geologist), L. E. de la Hunty, W. R. K. Jones and R. Halligan.

The major task of this Division was a regional investigation of the iron ore deposits of the Hamersley and Ophthalmia Ranges in the North-West Division. This involved mapping of the Mt. Bruce 1:250,000 Sheet and portions of the Yarraloola, Wyloo, Roy Hill and Mt. Newman Sheets, together with sampling and examination of the numerous and varied iron ore deposits. Close liaison was maintained with the mining companies engaged in exploratory and assessment programmes in the region. The extent of the Hamersley Iron Province was determined and relationships between the ore deposits and the stratigraphy were established. An overall estimate of the iron resources of the Province was made.

Weld Range, near Cue, was mapped and an additional seven iron ore lenses were discovered. Drilling to test the previously known iron ore lenses was completed.

The low-grade manganese deposits near Ravensthorpe were re-examined for the purpose of planning a drilling programme to test the persistence and grade of the material in depth.

Portion of the Greenbushes Tinfield was examined and drilled following a request from the Shire Council for release of ground for orcharding purposes. Cassiterite was found in part of the area tested.

The Senior Geologist also examined the iron ore deposits at Mt. Goldsworthy, Yampi Sound, Koolyanobbing, Mt. Jackson, Bungalbin, Windarling, Tallering Peak and Koolanooka during the year.

COMMON SERVICES DIVISION.

Petrology (A. F. Trendall).

During the year the more important collections of rocks described came from the Weld Range, the Dampier-Roebourne area, the Hamersley Iron Province, and the Widgiemooltha area. Specimens were also examined from the Warburton Range and the Ord River area, and rocks received both from the public and from other Divisions of the Geological Survey were identified. Two hundred and two rocks were added to the registered collection, 460 thin sections were prepared in the laboratory, and 22 file reports were written. Most of the work was carried out for the Regional Geology and Mineral Resources Divisions but some work was done for the Hydrology and Engineering Division.

Although brief examination and description of almost all rocks collected is an important part of survey petrological work, detailed studies of particular aspects of the rocks of an area contribute more, in the long run, to the general understanding of Western Australian geology. Such special studies included the porphyries of the Widgiemooltha area, dolerite of Weld Range, a particular horizon of banded ironstones of the Hamersley succession, basalt drill core from Boyanup, and acid volcanic rocks from the Hamersley and Dampier areas. The last named topic is reported on elsewhere in this Annual Report.

Palaeontology (H. S. Edgell).

Previous palaeontological activity by the Geological Survey was prior to 1926 (by Etheridge, Chapman, Glauert, etc.) and consisted of description of new and known species which have provided the basic stratigraphy of the State. Much more taxonomic work of this kind is required in advancing our knowledge of the geology of the State.

The emphasis of palaeontological investigations has been on palynology and studies of microplankton. These methods are particularly applicable to the largely non-marine or paralic sediments in the marginal basins of Western Australia. Palynology, or spore and pollen analysis, has now been established in the Geological Survey as a means of age determination and correlation of samples from bores for oil and water as well as suitable surface samples. During the year macerations have been examined palynologically from some 300 samples representing 20 bores, mostly in the Perth Basin.

Palynological age determination of cores from Hawkstone Peak No. 1 Well were carried out at the request of West Australian Petroleum Pty Ltd. Determinations of the age of 90 thin sections of Tertiary limestone samples from Barrow Island were also made for West Australian Petroleum Ltd.

Megafossil determinations included interesting discoveries from the Precambrian of the Pilbara area, surface Triassic ammonites from the Perth Basin, and stromatolites from the East Kimberley area. In connection with reef-studies by the Sedimentary (Oil) Division, palaeontological study of Devonian algae and stromatoporoids from the Lennard Shelf (West Kimberley area) was initiated.

Geophysics (D. L. Rowston).

Field activities were restricted by the initial shortage of geophysical instruments to several brief experimental and practical surveys mainly concerned with hydrological and engineering problems. An increased demand for practical assistance in 1963 is anticipated as geophysical equipment on order is received.

Several experimental resistivity surveys were carried out at orchard properties in the Carilla-Karragullen area to evaluate the use of the method in groundwater search. A resistivity survey was also made in the Belka Valley for the Soils Division of C.S.I.R.O. to delineate saline aquifers and to determine the depth to granitic bedrock.

A residual gravity interpretation of available gravity data of the Mt. Hill-Geraldton area defined a shallow sedimentary basin with an area of about 25 square miles. Exploratory drilling carried out during the groundwater search of the area confirmed the thickness of sediments.

Refraction seismic surveys were carried out in several places using "Dynametric" seismic timer equipment. At the South Canning damsite additional information augmenting borehole data was obtained. At the request of the Main Roads Department, a refraction seismic survey obtained bedrock information to aid foundation design and specifications of a proposed bridge over the Helena River near Mundaring Weir.

Technical Information Office (R. R. Connolly).

This section, embracing library, laboratory, clerical and general staff, was hard pressed during the year to keep pace with necessary administrative reorganisation and the increased work output of the enlarged professional staff.

A new unpublished series of Records was commenced and 24 Records had been issued by the end of the year. Editing and preparation for the Government Printer of publications was continued. Two information pamphlets were prepared and two mineral exhibits were arranged.

General library services were maintained by the Library Assistant, and recataloguing of library books and serial publications were completed.

The core library at Dianella Store was organised by the Core Librarian, and laboratory facilities for the Petrologist and Palaeontologist were maintained.

ACTIVITIES OF THE COMMONWEALTH BUREAU OF MINERAL RESOURCES.

Both geological and geophysical work was carried out by the Bureau of Mineral Resources within the State. The following projects were undertaken:—

(1) Regional mapping of the Gordon Downs and Dixon Range 1: 250,000 Sheets in the East Kimberley area, jointly with the Geological Survey of Western Australia.

(2) Continuation of the reconnaissance seismic survey between Giles and Carnegie homestead in the southeastern part of the Canning Basin, together with gravity readings at 78 stations.

(3) Seismic surveys of the Poole Range structure in the Canning Basin.

(4) Regional gravity survey of 55,000 square miles in the southeastern part of the Canning Basin using helicopters.

(5) Magnetic survey of the Scott River iron ore deposits.

PROGRAMME FOR 1963.

HYDROLOGY AND ENGINEERING DIVISION.

Hydrology:

(i) Continuation of the hydrological survey of the Perth Basin.

(ii) Hydrological investigations and exploratory drilling for underground water supplies in the following areas:—

- Allanooka and Wicherina for Geraldton town supply.
- Lake Gnangara for Perth town supply.
- Mandurah for town supply.
- Eaton for town supply.
- Capel for town supply.
- Arrowsmith River for Morawa town supply.
- Byford-Kwinana.
- Hyden-Forrestonia.

(iii) Hydrogeological investigation of the "Hills," Chittering and Bridgetown fruit growing areas.

(iv) East Kimberley area—hydrological assistance to pastoralists:—

(a) Regional geological mapping in conjunction with the Commonwealth Bureau of Mineral Resources.

(b) Bore site selection as required by pastoralists.

(v) Miscellaneous investigations as requested from other Departments and the public.

Engineering Geology:

(i) Ord River Damsite—rock testing for underground power house when required.

(ii) Fitzroy River Barrage—supervision of drilling.

(iii) Standard Gauge Railway — Merredin-Southern Cross and Koolyannobbing Sections, and reassessment of Northam-Merredin Section.

(iv) Investigation of damsites for Metropolitan Water Supply Department:—

- Wungong Brook (2 sites).
- South Canning.
- Gooralong Brook.
- Dandalup Brook (2 sites).

SEDIMENTARY (OIL) DIVISION.

(i) Active interest in the exploratory programmes of companies engaged in oil prospecting in this State.

(ii) Investigations pertinent to oil prospecting in the Perth Basin.

(iii) Continuation of the geological survey of the Lennard Shelf area, Canning Basin.

(iv) Miscellaneous investigations as required.

REGIONAL GEOLOGY DIVISION.

(i) Completion of regional mapping on the Widgiemooltha 1 : 250,000 Sheet in the Kalgoorlie-Norseman Area.

(ii) Continuation of regional mapping on the Roebourne and Pyramid 1 : 250,000 Sheets in the Pilbara Area.

(iii) Continuation and completion of regional mapping, in conjunction with the Bureau of Mineral Resources, of the Dixon Range and Lissadell 1 : 250,000 Sheets in the East Kimberley area.

MINERAL RESOURCES DIVISION.

(i) Continuation and completion of the regional investigation of the Hamersley Iron Province. This involves mapping on the following 1 : 250,000 Sheets:—

Yarraloola, Wyloo, Turee Creek, Newman, Robertson and Roy Hill.

(ii) Investigation of low-grade manganese deposits near Ravensthorpe in conjunction with a drilling programme by the Bureau of Mineral Resources.

(iii) Investigation of the clay deposits of the Metropolitan Area (if required).

(iv) Investigation of the pegmatites of the Yalgoo and Murchison Goldfields.

(v) Miscellaneous investigations as required.

PUBLICATIONS AND RECORDS.

At the end of 1962 there were three Bulletins and one Annual Report with the Government Printer awaiting publication. Due to the long delay in printing and in order to release technical information, an innovation in the form of Records series was introduced. This met the need for quick dissemination of reports to interested parties and presented technical reports in a more enduring form. Records, which are duplicated, are not true publications in that they cannot be obtained freely by the public. They are issued under three classifications: *Confidential,* for departmental use only, *Restricted,* for departmental use and for interested persons entitled to the information, and *Unrestricted,* which can be perused at the Survey library or be made available to interested parties.

Records of enduring scientific or of other value will be selected for publication in the Annual Report together with a list of the Records produced each year.

In addition, it is proposed to issue a new Information Pamphlet series. These will be small duplicated pamphlets on items of general geological interest intended to assist prospectors or persons interested in the search or development of the mineral resources of this State. The first two titles "How and Where to Look for Copper in W.A." and "Opening an Aggregate Quarry," should be available early in 1963.

Issued During 1962:

Annual Progress Report for 1960.

In the Press:

Annual Progress Report for 1961.

Mineral Resources of Western Australia, Bulletin No. 8, Copper.

Bulletin No. 115, The Geology of Portion of the Pilbara Goldfield covered by the Marble Bar and Nullagine 4-mile Sheets.

Bulletin No. 116, The Geology of the Manganese Deposits of Western Australia.

In Preparation:

Geological Map of the Boorabbin 1 : 250,000 Sheet (SH51-13 International Grid) with Explanatory Notes.

Geological Map of the Balfour Downs 1 : 250,000 Sheet (SF51-9 International Grid) with Explanatory Notes.

Geological Map of the Dampier 1 : 250,000 Sheet (SF50-2 International Grid) with Explanatory Notes.

Geological Map of the Mt. Bruce 1 : 250,000 Sheet (SF50-11 International Grid) with Explanatory Notes.

Bulletin, Palaeontological Contributions to the Geology of Western Australia Series VIII.

Records Produced:

No.	Author(s)	Title
1962/1	Berliat, K. .... Morgan, K. H.	Report on Exploratory Drilling for Water at Jurien Bay, W.A.
1962/2	MacLeod, W. N.	Report on Drilling of Portion of the Greenbushes Tinfield.
1962/3	Berliat, K.	Report on Exploratory Drilling for Water at the Mental Hospital, Whitby Falls.
1962/4	Sofoulis, J.	Report on Gold Prospect PA7077, Lake Cronin Area, Yilgarn Goldfield, W.A. (*Restricted.*)
1962/5	Kriewaldt, M.	Report on Underground Water at Point Sampson, West Pilbara G.F., North West Division.
1962/6	Sofoulis, J.	Report on Water Supply, Cundeelee Mission, N.E. Coolgardie Goldfield, W.A.
1962/7	Gordon, F. R.	Report on Rock Stability, Mundaring Weir pumphouse.
1962/8	MacLeod, W. N.	Interim Report on the Pilbara Iron Ore Deposits. (*Confidential.*)
1962/9	Sofoulis, J.	Report on Groundwater Potentialities, Central Aborigines Reserve, Eastern Division, W.A.
1962/10	Playford, P. E.....	Notes on the Devonian—Lower Carboniferous Rocks of the Lennard Shelf, Western Australia.
1962/11	Gordon, F. R.	South Canning Damsite—A Preliminary Appraisal.
1962/12	Passmore, J. R.	Report on Laporte Nos. 1, 2, 3 and 4 Water Bores, Australind W.A. (*Restricted.*)
1962/13	Playford, P. E..... Lowry, D.	Wells Drilled for Petroleum Exploration in Western Australia to the end of 1962.
1962/14	Sofoulis, J.	Report on a Copper Prospect, Higginsille area, Coolgardie Goldfield, W.A. (*Restricted.*)
1962/15	MacLeod, W. N.	An Outline of the Results of Recent Iron Ore Exploration in Western Australia, 1961–62. (*Confidential.*)
1962/16	Sofoulis, J.	Water Supply Eyre Highway, Eucla Division.
1962/17	MacLeod, W. N.	Report on the Exploration for Iron Ore in the North Pilbara by Mt. Goldsworthy Mining Associates. (*Confidential.*)
1962/18	Passmore, J. R.	Report on G.S.W.A. Mandurah No. 1 Water Bore, Mandurah, W.A.
1962/19	Passmore, J. R.	Report on Busselton Shire Council Water Bore, Milne St., Busselton, W.A.
1962/20	Rowston, D. R. Gordon, F. R.	Geophysical Investigation of the Helena River Bridgesite, Kalamunda-Mundaring Road.
1962/21	Trendall, A. F.	Plagioclase Phenocrysts in a Basalt from Boyanup, Western Australia.
1962/22	Sofoulis, J.	The Occurrence and Hydrological Significance of Calcrete Deposits in Western Australia.
1962/23	Edgell, H. S.	The Correlative Value of Microplankton in the Cretaceous of the Perth Basin, W.A.
1962/24	Edgell, H. S.	Precambrian Fossils from the Hamersley Range, Western Australia and their bearing on Diagenesis in Jaspilite Formation.

15th March, 1963.

J. H. LORD,
Government Geologist.

AN ASSESSMENT OF THE UNDERGROUND WATER RESOURCES OF WESTERN AUSTRALIA.

by

N. J. Mackay.

INTRODUCTION.

In September, 1962, the Underground Water Committee of Western Australia was requested by Public Works Department to prepare an assessment of the underground water resources of the State. The assessment was required for inclusion in a report giving an assessment of the surface and underground water resources of Australia for the Standing Committee of the newly formed Water Resources Council.

Information supplied by Public Works Department, Metropolitan Water Supply Department, Department of Agriculture, and the Geological Survey was used in the compilation.

The State was divided into eight sedimentary basins and seven hard-rock provinces, and some of these basins and provinces were subdivided into areas for the purpose of the assessment. A map (Plate I) of the State showing the underground water basins and provinces accompanies this assessment. Areas where underground water is developed are also shown on this map.

The Standing Committee requested that the assessment be made under two main headings, Pressure Water and Non-Pressure Water, and that details for each basin or province be given under six standard sub-headings.

METHOD OF ASSESSMENT.

The assessment is presented under the following main headings and units of area:—

Pressure Water:

Perth Basin.
Carnarvon Basin.
Canning Basin.
Bonaparte Gulf Basin.
Ord Basin.
Officer Basin.
Eucla Basin.
Collie Basin.

Non-pressure Water:

Perth Basin.
Carnarvon Basin.
Canning Basin.
Bonaparte Gulf Basin.
Ord Basin.
Officer Basin.
Eucla Basin.
Collie Basin.
South-West Shield Province.
North-West Province.
Pilbara Province.
Kimberley Province.
Halls Creek Province.
Musgrave Province.
Blackstone Province.

Details under each Main Heading for each Unit of Area. (Where water yields are given or reserves are estimated, they are classified in terms of quality under the general "type of use" headings of domestic; irrigation; stock; other):

(a) Area of each unit. Area within each unit—
prospected; or
developed for underground water.

(b) The number of bores from which water is obtained and an indication of location or intensity of bores in more important areas.

(c) An estimate of the amount of water withdrawn during 1961-62.

(d) Area within each unit not prospected but regarded as having high potential; estimate of possible yield.

(e) Recharge characteristics, if known.

(f) An estimate of the total reserves of underground water.

PRESSURE WATER.

Perth Basin.

(a) Approximately 23,000 square miles.

(i) *Northern Area:*

Approximately 12,000 square miles from Perth north to Geraldton and the Greenough River. Main aquifers are Mesozoic sandstones.

Inadequately prospected by about 15 bores; slight development by about 6 bores.

Artesian and sub-artesian water.

(ii) *Southern Area:*

Approximately 3,000 square miles from Perth south to Busselton. Main aquifers are Mesozoic sandstones.

Inadequately prospected by about 70 bores; developed mainly as town and private supplies at Bunbury and Busselton, and as industrial supplies in the Bunbury-Busselton area.

Artesian and sub-artesian water.

(iii) *Perth Area:*

Approximately 140 square miles of the Perth Metropolitan Area. Main aquifers are Mesozoic sandstones, with some production from Tertiary sandstones.

Well prospected by at least 50 bores; developed as town and private supplies.

Mainly artesian water.

(b) At least 130 bores.—Greatest intensity is at Bunbury (at least 50 bores in an area of 5 square miles) and in the Perth Area (at least 50 bores in an area of 140 square miles).

(c) Only very approximate information available, except for town supplies at Perth, Bunbury and Busselton.—Estimated total withdrawn during 1961-62—approximately 3,000 million gallons. Quality of water is mainly domestic.

(d) Mesozoic aquifers: (i) In the large area between Perth and the Arrowsmith River, and (ii) south of Busselton to the southern coast, have potential yields of 500,000 gallons per day per bore, quality ranging from domestic to stock.

(e) Recharge is from local rainfall and from run off from the Darling Range in the southern half of the Basin. Dams in the Darling Range may have an effect on recharge in the future. No information on rates of depletion and recharge.

(f) Total reserves unknown, but must be very large for the Mesozoic aquifers.

Carnarvon Basin.

(a) Approximately 50,000 square miles.

(i) *Western Area:*

Approximately 30,000 square miles from Exmouth Gulf south to the Murchison River. Main aquifers are the Birdrong Formation (Lower Cretaceous) and Tumblagooda Sandstone (Lower Silurian). Less important aquifers are the Windalia Radiolarite (Lower Cretaceous) and the Lyons Group (Lower Permian).

Adequately prospected by at least 200 bores; development restricted to pastoral requirements (approximately 14,000 square miles). No development in the Exmouth Gulf area where the aquifers are over 2,500 feet deep, or in the south-eastern section of the area.

Artesian water restricted to the coastal area 30 to 60 miles wide, sub-artesian elsewhere inland.

(ii) *Eastern Area:*

Approximately 10,000 square miles from Lyndon River south to Murchison River. Main aquifers are Permian sandstones (Byro Group, Wooramel Group, Lyons Group).

Inadequately prospected by about 40 bores; development restricted to pastoral requirements.

Sub-artesian water only.

(b) At least 250 bores.—Greatest intensity of bores is in the Western Area between the Gascoyne River and the Murchison River (at least 150 bores in an area of 10,000 square miles). The other bores are scattered through the Eastern Area and north of the Gascoyne River.

(c) Only very approximate information available. Estimated total withdrawn during 1961-62 —approximately 22,000 million gallons. Quality of water is stock.

(d) In the section of the Eastern Area between Lyndon River and Minilya River, the Wooramel Group (Permian) has a good potential for sub-artesian water, quality ranging from domestic to stock.

(e) The main intake area of the most important aquifer (Birdrong Formation) is the Kennedy Range, 80 miles east of Carnarvon. Another important intake area for this aquifer is in the north-eastern side of the Basin between the Ashburton River and the Lyndon River.—Recharge appears adequate at present as there is no known appreciable reduction in flow of artesian bores. The artesian flows are unrestricted and if production is increased substantially, recharge of the main aquifers in the Western Area may become inadequate. No information on rates of depletion and recharge.

(f) Total reserves unknown, but must be very large for the two main aquifers (Birdrong Formation and Tumblagooda Sandstone).

Canning Basin.

(a) Approximately 175,000 square miles.

(i) *Fitzroy Drainage Area:*

Approximately 17,000 square miles from King Sound southeast to Luck Range. Main aquifers are Permian sandstones (Liveringa Formation, Poole Sandstone, Grant Formation), with some production from Mesozoic sandstones and Devonian limestones and conglomerates.

Adequately prospected by at least 550 bores; development restricted to pastoral requirements.

Mainly sub-artesian water, few artesian bores.

(ii) *Coastal Area:*

Approximately 5,000 square miles, from Breaker Inlet north-east to Cape Leveque. Main aquifers are Mesozoic sandstones (Alexander Formation, Wallal Sandstone, Erskine Sandstone).

Inadequately prospected by about 50 bores; development restricted to pastoral requirements.

Mainly sub-artesian water, artesian only along a narrow coastal strip.

(b) At least 600 bores.—At least 550 bores are scattered through the Fitzroy Drainage Area (approx. 17,000 sq. miles). Other bores are restricted to the Coastal Area.

(c) Only very approximate information available. —Estimated total withdrawn during 1961/62 —approx. 3,000 million gallons. Quality of water ranges from mainly domestic in the Fitzroy Drainage Area to mainly stock in the Coastal Area.

(d) (1) Mesozoic and Permian aquifers in the large inland area of the Canning Basin have potential yields of 500,000 gallons per day per bore, quality ranging from domestic to stock.

(ii) Mesozoic aquifers in the Dampier Peninsula (between King Sound and Broome) have a high potential for sub-artesian water, quality ranging from domestic to stock.

(e) Recharge is from local rainfall with additional recharge in the Fitzroy Drainage Area by the Fitzroy River, Lennard River and smaller streams when they flow in the "wet" season. Recharge appears adequate at present, but a prolonged drought could have a marked effect on recharge in the Fitzroy Drainage Area. No information on rates of depletion and recharge.

(f) Total reserves unknown, must be very large.

Bonaparte Gulf Basin.

(a) Approx. 2,000 sq. miles.

Palaeozoic aquifers inadequately prospected by about five scattered bores which are developed for pastoral requirements.

Sub-artesian water, some of which may be non-pressure water.

(b) About five bores.

(c) Estimated total withdrawn during 1961/62—approx. 10 million gallons. Quality of water is unknown, presumably stock or better.

(d) The Palaeozoic aquifers have potential yields of about 20,000 gallons per day per bore, quality ranging from domestic to stock.

(e) Recharge is from local rainfall and from stream flow in the "wet" season.

(f) Total reserves unknown.

Ord Basin.

(a) Approx. 6,000 sq. miles.

Aquifers are Cambrian sediments and volcanics. Approx. 1,000 sq. miles inadequately prospected by about 30 bores; development restricted to pastoral requirements.

Sub-artesian water, some of which may be non-pressure water.

(b) About 30 bores.—The bores are mainly scattered over 4 small areas totalling approx. 1,000 sq. miles.

(c) Estimated total withdrawn during 1961/62—approx. 50 million gallons. Quality of water is mainly domestic, occasionally stock.

(d) The unprospected 5,000 sq. miles of the Basin have potential yields of about 20,000 gallons per day per bore, quality ranging from domestic to stock.

(e) Recharge is from local rainfall and by the Ord River and smaller streams in the "wet" season.

(f) Total reserves unknown.

Officer Basin

(a) Approx. 75,000 sq. miles.—No prospecting or development known.

(b) None known.

(c) None known.

(d) None known.

(e) Recharge is from local rainfall.

(f) Total reserves unknown.

Eucla Basin.

(a) Approx. 50,000 sq. miles.

Tertiary and Mesozoic aquifers inadequately prospected by about 40 bores; development restricted to several areas totalling about 1,000 sq. miles and to along the Transcontinental Railway Line.

Sub-artesian water except at Madura where the water is artesian. Some of the water may be non-pressure water.

(b) About 40 bores.—About 17 bores are scattered along 250 miles of the Transcontinental Railway Line and about 14 bores are in an area of 800 sq. miles in the central-western part of the basin.

(c) Estimated total withdrawn during 1961/62—Approx. 30 million gallons. Quality of water ranges from stock to saline.

(d) None known; parts of the Basin have potential yields of about 10,000 gallons per day per bore, but the quality ranges from stock to saline.

(e) Recharge is from local rainfall.

(f) Total reserves unknown.

Collie Basin.

(a) Approx. 90 sq. miles.—Permian sandstones prospected by more than 60 coal-exploration and other bores; no development known. Mainly artesian water.

(b) None known.

(c) None known: Quality of water is mainly domestic.

(d) None known.

(e) Recharge is from local rainfall and from flow of the Collie River.

(f) Total reserves unknown.

NON-PRESSURE WATER.

Perth Basin.

(a) Approx. 23,000 sq. miles.—Approx. 18,000 sq. miles between the Greenough River and south of Busselton. Main aquifers are river sands and gravels, coastal limestones, Tertiary and Mesozoic sandstones, and older sediments. Adequately prospected over most of the area; development restricted to approx. 11,000 sq. miles.

(b) At least 12,000 bores and wells, probably many more.—Greatest intensity is in the Perth Metropolitan Area (at least 9,100 bores and wells in an area of 200 sq. miles). At Wicherina there are 13 producing bores in 6 sq. miles.

(c) Only very approximate information available, except for five town supplies.—Estimated total withdrawn during 1961/62—approx. 4,500 million gallons. Quality of water is mainly domestic, occasionally stock.

(d) Mesozic aquifers in the area between the Moore River and the Greenough River have potential yields of 20,000 gallons per day per bore, quality ranging from domestic to stock.

(e) Recharge is from local rainfall with additional recharge by the major rivers of the Basin. Recharge appears adequate.

(f) Total reserves unknown.

Carnarvon Basin.

(a) Approx. 50,000 sq. miles.

(i) Scattered prospecting and development of sands and gravels along the main rivers (Gascoyne, Minilya, Lyndon, Wooramel, etc.). Full development of river sands and gravels for six miles upstream along the Gascoyne River from Carnarvon.

(ii) Scattered prospecting and development of Quaternary, Tertiary, and Cretaceous aquifers in the northern part of the Basin between Cape Range and Cape Preston (6,000 square miles).

(iii) Slight prospecting and development of Quaternary sand dunes along the central part of the western coast from Maud Landing to Shark Bay (2,000 square miles).

(iv) Slight prospecting and development of coastal limestones along the northern and southern parts of the western coast (3,000 square miles).

(v) Springs along the Kennedy Range in the central part of the Basin have been developed for pastoral requirements.

(b) At least 1,000 bores and wells, probably many more.—The bores and wells are scattered mainly along the streams and the coastal part of the Basin. Greatest intensity is near Carnarvon where about 350 bores and wells along six miles of the Gascoyne River are used for irrigation and town supplies.

(c) Only very approximate information available, except for irrigation and town supplies at Carnarvon and town supply at Onslow.—Estimated total withdrawn during 1961-62—approximately 2,200 million gallons. Quality of water is mainly domestic, occasionally stock.

(d) None known.

(e) Recharge is from local rainfall with additional recharge of river sands and gravels by the main rivers. Recharge appears adequate at present but lack of river flow in droughts has a marked effect on recharge, especially in developed areas such as Carnarvon.

(f) Total reserves unknown.

Canning Basin.

(a) Approximately 175,000 square miles.

(i) *Fitzroy Drainage Area.*—Approximately 17,000 square miles from King Sound southeast to Luck Range. Scattered prospecting of river sands and gravels and Mesozoic aquifers; development restricted to pastoral requirements and Derby town supply.

(ii) *Coastal Area.*—Approximately 5,000 square miles from Breaker Inlet northeast to Cape Leveque. Scattered prospecting of Mesozoic aquifers; development restricted to pastoral requirements, settlement supplies and Broome town supply.

(iii) About 26 shallow wells developed along about 300 miles of the Canning Stock Route across the inland part of the Basin.

(iv) Springs in Devonian limestones and along the south-western margin of the Fitzroy Drainage Area have been developed for pastoral requirements.

(b) At least 400 bores and wells.—The bores and wells are scattered mainly through the Fitzroy Drainage Area and along the Coastal Area.

(c) Only very approximate information available, except for town supplies at Derby and Broome.—Estimated total withdrawn during 1961-62—approximately 800 million gallons. Quality of water is mainly domestic, occasionally stock.

(d) Mesozoic and Permian aquifers in the large inland area of the Canning Basin have potential yields of 10,000 to 20,000 gallons per day per bore, quality ranging from domestic to stock.

(e) Recharge is from local rainfall with additional recharge of river sands and gravels in the Fitzroy Drainage Area by the Fitzroy River, Lennard River and smaller streams. Recharge appears adequate at present.

(f) Total reserves unknown.

Bonaparte Gulf Basin.

(a) Approximately 2,000 square miles.—Virtually unprospected.

(b) None known; some of the five bores in the Basin may be drawing from non-pressure water.

(c) None known; all water withdrawn is included in the pressure water figure for the Basin.

(d) Sands and gravels along the main streams have potential yields of 20,000 gallons per day per bore, quality mainly domestic.

(e) Recharge is from local rainfall and from flow of the main streams.

(f) Total reserves unknown.

Ord Basin.

(a) Approximately 6,000 square miles.—Approximately 1,000 square miles inadequately prospected.

(b) None known; some of the 30 bores in the Basin may be drawing from non-pressure water.

(c) None known; all water withdrawn is included in the pressure water figure for the Basin.

(d) Sands and gravels along the Ord River and smaller streams have potential yields of 20,000 gallons per day per bore, quality mainly domestic.

(e) Recharge is from local rainfall, and from flow of the Ord River and smaller streams.

(f) Total reserves unknown.

Officer Basin.

(a) Approximately 75,000 square miles.—No prospecting or development known.

(b) None known.

(c) None known.

(d) None known.

(e) Recharge is from local rainfall.

(f) Total reserves unknown.

Eucla Basin.

(a) Approximately 50,000 square miles.—Inadequately prospected over about 1,000 square miles and along the Transcontinental Railway Line.

(b) None known; some of the 40 bores in the Basin may be drawing from non-pressure water.

(c) None known; all water withdrawn is included in the pressure water figure for the Basin.

(d) None known; parts of the Basin have potential yields of about 10,000 gallons per day per bore, but the quality ranges from stock to saline.

(e) Recharge is from local rainfall.

(f) Total reserves unknown.

Collie Basin.

(a) Approximately 90 square miles.—Adequately prospected and developed by at least 20 bores.

(b) At least 20 bores and wells scattered through the Basin.

(c) Estimated total withdrawn during 1961-62—approximately 15 million gallons. This figure does not include approximately 500 million gallons withdrawn during dewatering of coal mines in the Basin. Quality of water is mainly domestic.

(d) None known.

(e) Recharge is from local rainfall and from flow of the Collie River. Recharge appears adequate.

(f) Total reserves unknown.

South-West Shield Province.

(a) Approximately 350,000 square miles.

Non-pressure water occurs in superficial zones of weathering and sediments overlying igneous rocks (mainly granite), and in alluvial deposits associated with rivers and internal drainage areas.

Widespread prospecting and development of Area "A" (approximately 80,000 square miles) for farming and pastoral requirements and six town supplies. Scattered prospecting and development of Area "B" (approximately 160,000 square miles) for pastoral requirements and five town supplies. Area "C" (approximately 110,000 square miles) is virtually unprospected or undeveloped.

(b) At least 37,000 bores and wells.—Greatest intensity is in Area "A" (at least 30,000 bores and wells in an area of approximately 80,000 square miles). About 7,000 bores and wells are scattered through approximately 150,000 square miles of Area "B." At Wiluna in the northern part of the Province there are about 60 bores in an area of 10 square miles.

(c) Only very approximate information available, except for 11 town supplies.—Estimated total withdrawn during 1961-62—approximately 16,000 million gallons. Quality of the water ranges from domestic to stock.

(d) Some internal drainage areas in Area "B" and Area "C" north of Latitude 29 degrees have a high potential for domestic and irrigation supplies. Potential yields could be as high as 200,000 gallons per day per bore.

(e) Recharge is from local rainfall with additional recharge by the main rivers and by percolation along internal drainage areas.

(f) Total reserves unknown.

North-West Province.

(a) Approximately 95,000 square miles.—Non-pressure water occurs in bedding planes and zones of weathering and fracturing in Proterozoic sediments and volcanics, and in sands and gravels along the main rivers (Fortescue River, upper part of the Ashburton River, etc.) and smaller streams.

(i) Scattered prospecting and development of approximately 30,000 square miles of the Western Area (approximately 60,000 square miles) for pastoral requirements and one town supply. The Eastern Area (approximately 35,000 square miles) is not prospected or developed except for the Canning Stock Route.

(ii) Numerous springs and spring-fed pools, particularly along the Fortescue River, are used for pastoral requirements.

(b) At least 1,000 bores and wells, scattered through approximately 30,000 square miles of the Western Area.

(c) Only very approximate information available, except for Wittenoom town supply—Estimated total withdrawn during 1961-62—approximately 700 million gallons. Quality of water ranges from domestic to stock.

(d) The Eastern Area is considered to have potential yields similar to the Western Area. Some internal drainage areas may have a high potential for domestic and stock water.

(e) Recharge is from local rainfall with additional recharge of river sands and gravels by the main rivers. Recharge appears adequate except during periods of extended drought conditions.

(f) Total reserves unknown.

Pilbara Province.

(a) Approx. 33,000 sq. miles.

Non-pressure water occurs in superficial zones of weathering and sediments overlying igneous and and metamorphic rocks, and in sands and gravels along the main rivers (De Grey, Oakover, Coongan, Shaw, Turner, Yule, etc.,) and smaller streams.

Widespread prospecting and development of the *Western Area* (approx. 22,000 sq. miles) for pastoral requirements and for three town supplies. The *Eastern Area* (approx. 11,000 sq. miles) is not prospected or developed.

(b) At least 1,500 bores and wells.—Greatest intensity is the Roebourne—Marble Bar—Port Hedland area and along the De Grey—Oakover river system.

(c) Only very approximate information available, except for three town supplies. Estimated total withdrawn during 1961/62—approx. 1,100 million gallons. Quality of water ranges from domestic to stock.

(d) In the Eastern Area internal drainage areas (Rudall River, Cotton Creek, etc.) draining into the Lake Dora—Lake Blanche system have a high potential for domestic and stock supplies.

(e) Recharge is from local rainfall with additional recharge of river sands and gravels by the De Grey, Oakover, Coongan, Shaw, Turner, Yule and smaller streams. Extended drought conditions and lack of river flow have a serious effect on recharge.

(f) Total reserves unknown.

Kimberley Province.

(a) Approx. 53,000 sq. miles.

Non-pressure water occurs in bedding planes and zones of weathering and fracturing in Proterozoic sediments and volcanics, and in sands and gravels along the main streams.

Slight prospecting and development of approx. 1,000 sq. miles in two small areas in the southern part of the Province.

(b) About 25 bores and wells, scattered over two areas totalling approx. 1,000 sq. miles.

(c) Only very approximate information available.—Estimated total withdrawn during 1961/62—50 million gallons. Quality of water ranges from domestic to stock.

(d) Proterozoic sediments over most of the Province have a good potential for pressure and non-pressure water, quality ranging from domestic to stock. Potential yields are 20,000 gallons per bore, per day.

(e) Recharge is from local rainfall with additional recharge by the main rivers. Recharge appears adequate.

(f) Total reserves unknown.

Halls Creek Province.

(a) Approx. 15,000 sq. miles.

Non-pressure water occurs in superficial zones of weathering overlying igneous (mainly granite) and metamorphic rocks, and in sands and gravels along the main streams.

Scattered prospecting and development of approx. 3,000 sq. miles in the eastern part of the Province for pastoral requirements and one town supply.

(b) At least 70 bores and wells, scattered through approx. 3,000 sq. miles in the eastern part of the Province.

(c) Only very approximate information available, except for Halls Creek town supply.—Estimated total withdrawn during 1961/1962—130 million gallons. Quality of water is mainly stock, occasionally domestic.

(d) The area north of Turkey Creek has a good potential for stock supplies, potential yields being 10,000 gallons per day per bore.

(e) Recharge is from local rainfall with additional recharge by the main streams. Recharge of the Halls Creek town supply is not affected by seasonal conditions, but bores drawing from superficial zones of weathering are affected by extended drought conditions.

(f) Total reserves unknown.

Musgrave Range Province.

(a) Approx. 20,000 sq. miles.

Non-pressure water occurs in bedding planes and zones of weathering and fracturing in Proterozoic sediments, and in sands and gravels along Sturt Creek.

Slight prospecting and development of approx. 350 sq. miles in two small areas in the northern part of the Province.

(b) About 15 bore sand wells, scattered over two small areas totalling approx. 350 sq. miles.

(c) Only very approximate information available.—Estimated total withdrawn during 1961/62—30 million gallons. Quality of water is mainly stock.

(d) Internal drainage areas scattered through the Province may have a potential for domestic and stock water.

(e) Recharge is from local rainfall with additional recharge by percolation along internal drainage areas. Recharge could be seriously affected by extended drought conditions.

(f) Total reserves unknown.

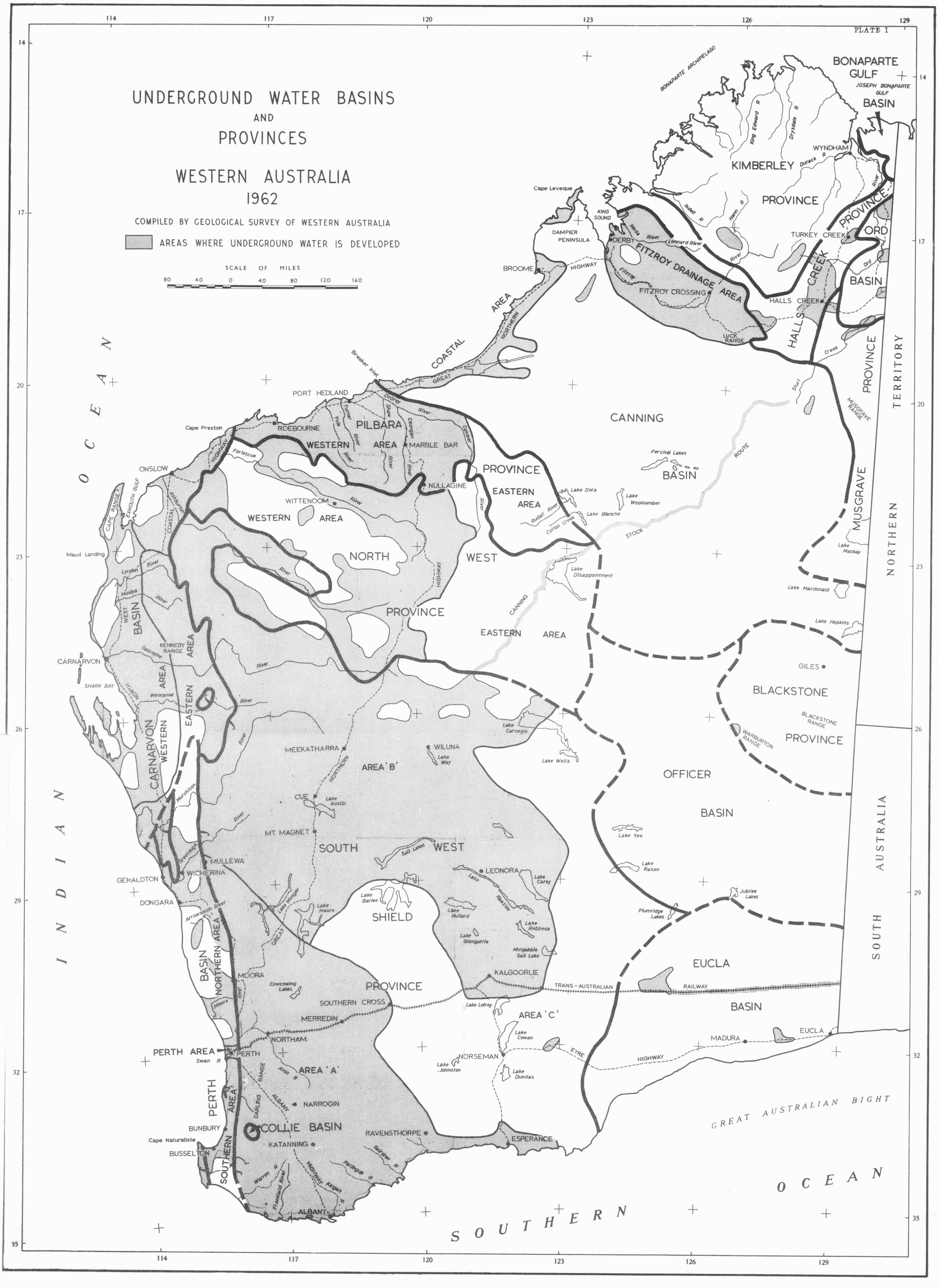

PLATE I
UNDERGROUND WATER BASINS
AND
PROVINCES
WESTERN AUSTRALIA
1962
COMPILED BY GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
AREAS WHERE UNDERGROUND WATER IS DEVELOPED
SCALE OF MILES
80 40 0 40 80 120 160
114
117
120
123
126
129
14
17
20
23
26
29
32
35
BONAPARTE GULF
JOSEPH BONAPARTE GULF
BASIN
BONAPARTE ARCHIPELAGO
KIMBERLEY
PROVINCE
WYNDHAM
ORD
BASIN
PROVINCE
TURKEY CREEK
HALLS CREEK
HALLS CREEK PROVINCE
Cape Leveque
KING SOUND
DAMPIER PENINSULA
DERBY
FITZROY DRAINAGE AREA
Lennard River
FITZROY CROSSING
LUCK RANGE
BROOME
HIGHWAY
NORTHERN
COASTAL AREA
GREAT
Breaker Inlet
PORT HEDLAND
ROEBOURNE
Cape Preston
PILBARA
WESTERN AREA
MARBLE BAR
NULLAGINE
PROVINCE
EASTERN AREA
ONSLOW
EXMOUTH GULF
CAPE RANGE
WITTENOOM
WESTERN AREA
NORTH WEST
PROVINCE
Maud Landing
CANNING
Percival Lakes
BASIN
Lake Dora
Lake Wooloomber
Lake Blanche
Lake Disappointment
CANNING STOCK ROUTE
EASTERN AREA
MUSGRAVE
PROVINCE
MUSGRAVE RANGE
Lake Mackay
Lake Macdonald
Lake Hopkins
NORTHERN TERRITORY
GILES
BLACKSTONE
BLACKSTONE RANGE
PROVINCE
WARBURTON RANGE
CARNARVON
SHARK BAY
KENNEDY RANGE
CARNARVON BASIN
WESTERN
EASTERN AREA
MEEKATHARRA
WILUNA
Lake Way
Lake Carnegie
Lake Wells
AREA 'B'
CUE
Lake Austin
MT. MAGNET
OFFICER
BASIN
Lake Yeo
Lake Rason
SOUTH WEST
SHIELD
PROVINCE
MULLEWA
GERALDTON
WICHERINA
DONGARA
LEONORA
Lake Carey
Lake Barlee
Lake Moore
Lake Ballard
Lake Rebecca
Mulgabbie Salt Lake
KALGOORLIE
Jubilee Lakes
Plumridge Lakes
EUCLA
BASIN
TRANS-AUSTRALIAN RAILWAY
SOUTH AUSTRALIA
BASIN
NORTHERN AREA
MOORA
Cowcowing Lakes
SOUTHERN CROSS
MERREDIN
Lake Lefroy
AREA 'C'
Lake Cowan
NORSEMAN
Lake Johnston
Lake Dundas
EYRE HIGHWAY
MADURA
EUCLA
NORTHAM
PERTH AREA
Swan R
PERTH
AREA 'A'
DARLING RANGE
NARROGIN
PERTH AREA
BUNBURY
Cape Naturaliste
BUSSELTON
COLLIE BASIN
KATANNING
RAVENSTHORPE
ESPERANCE
SOUTHERN AREA
ALBANY
GREAT AUSTRALIAN BIGHT
INDIAN OCEAN
SOUTHERN OCEAN

Blackstone Province.

(a) Approx. 30,000 sq. miles.

Non-pressure water occurs in superficial zones of weathering overlying igneous and metamorphic rocks, and in alluvial deposits associated with internal drainage areas.

Slight prospecting and development of approx. 25 sq. miles at Warburton Mission and several bores at Gile Meteorological Station in the northern part of the Province.

(b) About 10 bores and wells, mostly in 25 sq. miles at Warburton Mission.

(c) Only very approximate information available.—Estimated total withdrawn during 1961/62—5 million gallons. Quality of water is mainly domestic.

(d) Internal drainage areas in the Warburton Range area and in the northern part of the Province have a good potential for domestic and stock water.

(e) Recharge is from local rainfall with additional recharge by percolation along internal drainage areas. Recharge could be seriously affected by extended drought conditions.

(f) Total reserves unknown.

Table 1.

SUMMARISED ESTIMATE OF UNDERGROUND WATER DEVELOPED IN WESTERN AUSTRALIA.

Unit of Area	Pressure Water		Non-Pressure Water		Total	
	No. of Bores	Annual Yield (million gals.)	No. of Bores	Annual Yield (million gals.)	No. of Bores	Annual Yield (million gals.)
Perth Basin	130+	3,000	12,000+	4,500	12,130+	7,500
Carnarvon Basin	250+	22,000	1,000+	2,200	1,250+	24,200
Canning Basin	600+	3,000	400+	800	1,000+	3,800
Bonaparte Gulf Basin	5	10	....	....	5	10
Ord Basin	30	50	....	....	30	50
Officer Basin	....	....	....	....	....	....
Eucla Basin	40	30	....	....	40	30
Collie Basin	....	....	20+	15	20+	15
South-West Shield Province	....	....	37,000+	16,000	37,000+	16,000
North-West Province	....	....	1,000+	700	1,000+	700
Pilbara Province	....	....	1,500+	1,100	1,500+	1,100
Kimberley Province	....	....	25	50	25	50
Halls Creek Province	....	....	70+	130	70+	130
Musgrave Range Province	....	....	15	30	15	30
Blackstone Province	....	....	10	5	10	5
Totals	1,055+	28,090	53,040+	25,530	54,095+	53,620

Total No. of Bores :—At least 54,000.

Annual Yield :—At least 53,000 million gallons.

NEW GEOLOGICAL INFORMATION OBTAINED FROM AN EXPLORATORY BORE FOR UNDERGROUND WATER AT JURIEN BAY, PERTH BASIN.

by K. Berliat.

Location of the Drill Site.

New geological information was obtained from a departmental exploratory bore for domestic water at Jurien Bay, 194 miles by road north of Perth via Moora and Badgingarra. The drill site, close to the Indian Ocean, is at latitude 30°18′15″S and longitude 115°2′20″E.

General Geology.

Jurien Bay is in the central part of the Perth Basin, lying over the Beagle Ridge, a shallow sub-surface basement high, bounded to the east by the Beagle Fault. The fault runs south from latitude 29°30′S to latitude 30°18′S, and at Jurien Bay is approximately 4 miles east of the coast.

The nearest Mesozoic outcrops of Lower Jurassic Cockleshell Gully Sandstone occur approximately 9 miles east of the drill site. In the coastal area the Mesozoic sediments are obscured by Pleistocene Coastal Limestone and by beach sand dunes, in which the drill site is located.

Stratigraphy.

The bore, completed at a total depth of 628 feet, penetrated a sequence of grey, argillaceous, micaceous, partly calcareous siltstones and sandstones, and grey, micaceous, silty mudstones. Palynological examinations of sludge samples from 500 feet and 620 feet, carried out by B. E. Balme, indicated a Middle to Upper Triassic age for the 500 feet sample, whilst the 620 feet sample is correlated with the Upper (non-marine?) section of the Lower Triassic Kockatea Shale. It is considered, on lithological grounds, that the sequence from 87 feet (base of the Coastal Limestone) to 595 feet, is of Middle to Upper Triassic age, and that from 595 feet to 628 feet is of Lower Triassic age (Kockatea Shale).

Hydrology.

Two aquifers were encountered in the bore hole, viz. the 10 feet to 87 feet interval, and the 505 feet to 595 feet interval.

The top aquifer derives its supply from superficial sand dunes and from the underlying Coastal Limestone. The salinity of the water within this zone increases rapidly with depth, i.e. from 4,710 p.p.m. at 20 feet to 27,600 p.p.m. at 87 feet (total dissolved solids).

The second aquifer produced from 90 feet of Middle to Upper Triassic sandstones directly overlying the Kockatea Shale. The salinity of this aquifer is very high, total dissolved solids amounting to 49,300 p.p.m.

Contribution to Geological and Hydrological Knowledge.

Stratigraphically the bore has shown that in the Jurien Bay area the Jurassic is not represented to the west of the Beagle Fault, and that the youngest sediments underlying the Pleistocene Coastal Limestone are of Upper to Middle Triassic age.

Hydrologically it has indicated that underground water, suitable for domestic purposes, does not occur in the Triassic sediments to the west of the Beagle Fault. The Kockatea Shale, in which the bore bottomed, is known from previous experience (Geraldton bores, B.M.R. Beagle Ridge No. 10 and No. 10A stratigraphic holes) to contain only highly saline water. In these bores the Kockatea Shale has a thickness in excess of 1,000 feet. In the Beagle Ridge bores the formation is underlain by Permian sediments, which are equally unsuitable as a source for domestic water.

The favourable area to carry out further deep drilling is to the east of the Beagle Fault, where Jurassic sediments, known to contain suitable aquifers, can be expected.

Subsequent shallow drilling has shown that, locally, fresher ground water overlies the main body of saline water. Supplies of up to 2,000 gallons per hour have been located in poorly consolidated aeolianites and beach deposits at depths of less than 30 feet. The salinity of this water, however, is near the maximum permissible for domestic use.

ENGINEERING GEOLOGY OF THE ORD RIVER MAIN DAMSITE NO. 2, KIMBERLEY DIVISION.

by F. R. Gordon.

METHODS AND SCOPE.

Two drilling and investigational programmes have been completed at the Ord River Main Damsite No. 2, with 27 drill holes and two adits supplying material for a preliminary picture of foundation conditions. Geological mapping and supervision of the diamond drilling were carried out by Geologist J. D. Wyatt, and the results obtained have been embodied in two comprehensive reports, published in the Annual Reports of the Geological Survey for 1960 and 1961. The main conclusions arrived at were that the site was quite suitable for the construction of a 180 foot high concrete gravity-section dam, but that the western abutment contained clay-filled shears, possibly liable to movement if saturated and under pressure from a filled reservoir.

The writer with the guidance of Geologist Wyatt made a brief examination of the damsite in order to appraise its suitability for the building of an earth and rockfill dam. In addition, detailed work on joints and faults was initiated so that rock mechanics methods could be applied to the question of underground construction and also to assess the problem of water leakage under the dam, and the possibility of structural failure.

With the aid of the Public Works Department's new R117 Seismic Timer, several sections were explored in the spillway area, and by using the existing boreholes for correlation purposes, an assessment was made of the type and nature of the rock materials. Seismic section lines were also run across the sandy flats of the river channel in order to determine the depth to bedrock and the nature of the rock surface.

SITE GEOLOGY.

Stratigraphy.

The stratigraphy and structure of the Main Damsite have already been dealt with in some detail by Geologist Wyatt. A geological plan incorporating additional field work done during the 1962 season is appended (Plate II), together with an engineering plan showing the proposed concrete dam and ancillary works (Plate III).

In the general area of the damsite, there occurs a succession of Precambrian rocks, consisting of phyllites, quartzites, phyllitic quartzites, sandstones, shales and siltstones. These rocks have been severely faulted and folded and later eroded by the cutting of river gorges and the infilling of depressions.

At the site itself, thin bedded phyllitic quartzites overlie a massive white quartzite, 30 to 250 feet thick, which is found above a grey-green phyllite or slaty shale.

Topography.

The Ord River Damsite is located on the south-eastern edge of the Halls Creek Ridges physiographic unit, which constitutes the roughest country in the area and contains numerous strike ridges and controlled streams. Bandicoot Bar is situated on the northern edge of the same rugged area which is about 40 miles wide, with the Ord River largely contained in gorges between the two sites. South of the Main Damsite No. 2 is the Ord River Basin, largely consisting of undulating plain, while to the South of Bandicoot Bar, the Cambridge Gulf Lowlands consist of large areas of sandy lowlands.

The proposed No. 2 site is situated at the second constriction of the Ord valley downstream from Argyle Downs, and immediately upstream there is an area of flat plain about a mile square before the first constriction or old No. 1 site is encountered. North of Argyle Downs Station, extensive black soil plains occur, and extend north and east for many miles. Through these extensive alluvial plains the lower Ord and its tributaries meander as old rivers. In the gorge area the river may be classed as mature, with the main work, the shifting of vast quantities of alluvial materials in flood time.

The Ord is reduced to a mere trickle in the winter months, but it rises rapidly and irregularly in the monsoonal "wet" or summer season, and the peak flow at Coolibah Pocket has exceeded 1 million cusecs average over 24 hours on two occasions since records have been taken. Due to overgrazing, especially round the water holes and courses, active erosion has commenced in the upper water shed with gullying, causing canyons in silt as much as 60 feet deep. This has resulted in a large suspended sediment load that at flood time has been recorded as high as 250 tons of mud per second.

Rock Types and Properties.

Massive quartzite caps the western abutment and forms the major part of the eastern foundation. It is white when free of staining. Surfaces covered sporadically by the river show a golden brown or even an iridescent bluish-black surface colouring. The rock itself is iron-stained pinkish-red to a depth of about 40 feet below the ground surface, this being due to the inworking of ferruginous material from largely open joints.

Although physical tests have yet to be carried out on the rock, in general it has excellent engineering properties, being dense, largely homogeneous, and physically strong against compressive and shear forces. The rock is highly jointed (Fig. 1) tending to the belief that it is brittle, but this is not strictly correct as the greatest difficulty is experienced in breaking the joint blocks to a smaller dimension. The joint pattern varies markedly from place to place, but the general tendency is the formation of large sheet joints parallel to the ground surface, then the formation of blocks 2 feet by 4 feet by 1 foot with the two major joints dipping into the hillside on the western abutment and standing vertically on the eastern abutment. The joints are usually open in the river bed to about 20 feet and are filled with ferruginous and clay materials in the abutments. Such faulting as could be examined, especially on the eastern abutment, did not produce a crush or gouge zone; minor adjacent breakage, slickensides and displacement being the usual signs. In some cases the fault zone which may have had an opening up to 1½ inches wide, is partially filled with ferruginous material or secondary silica.

In the adits driven in the western abutment (Plate VII) the quartzite is free standing, and although there are drummy sections these are mainly the result of stress relief, and blocks remain locked in the arch until actively dislodged by outside forces. About 60 per cent. of the exposed tunnel shows ferruginous staining on what must have been almost microscopic joints. In this fashion a little overbreak is to be expected in any tunnel or underground excavation, and with the likelihood that there will be less joints at depth, consequently the break to the joint planes will give an irregular profile. The quartzite, as noted, tends to break in blocks down the joint spacing, then in elongated fragments with conchoidal faces. This material is very abrasive. Due to the coherent nature of the rock some difficulty will be experienced in excavating underground or surface structures. Only short pulls from each tunnel-round will be feasible—say 7 feet from a 5 feet hole, and drilling holes will be very demanding on machines and steel.

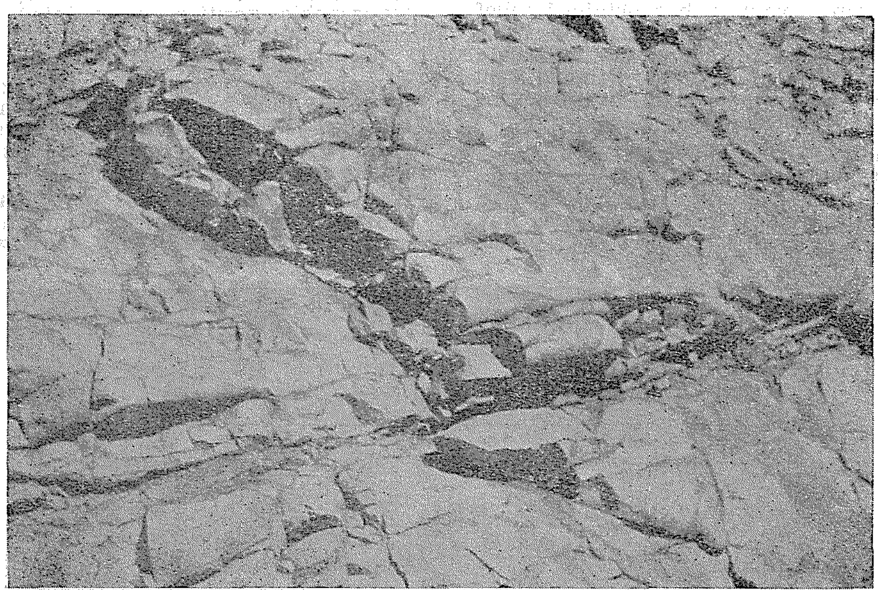

Fig. 1. Quartzite exposed on west abutment.

Phyllite is found underneath the massive quartzite, is well bedded, and strongly jointed, and is of a light greenish-grey colour in the unweathered state which is usually found about 100 feet below the ground surface. The oxidised material, as in the outcrop 150 feet downstream of the dam centreline, is a dull red, and the phyllite exposed in the adits near the quartzite contact is a light creamy-green with brown-stained joint faces. Physically, the phyllite from these three localities differs also. The deeper bore material gives good cores with the rock apparently quite firm in compression. Due to the thin bedding the shear and tensile strengths are low and, furthermore, this material like the adit phyllite, quickly gives up included water and separates readily on the bedding planes. Apart from this, the adit material is extensively crushed and broken by joints, most of which are at least partially filled with clay. The most conspicuously clay-filled joint is along the bedding plane, showing that alternate wetting and drying has already allowed a minor degree of slaking. The phyllite exposed on the surface is also strongly contorted and broken by faulting and jointing, but the material has reached some degree of induration. Due to curling and crumpling this material would consolidate under pressure to a small extent.

Examination of the core logs of holes drilled through the western abutment indicates that the phyllite is notably affected for at least 40 feet from the quartzite contact (Drillhole 4M).

Excavation of the phyllite will be characterized by reasonably easy drilling, and the production of tabular masses breaking off on the bedding planes. Overbreak will be thus governed by the local inclination of the bedding. Long pulls will be possible but this may be compromised if overbreak tends to be excessive. The most undesirable feature of "slaking" means that special measures have to be taken where it is desired to pour concrete against phyllite or where a clean face is desired. Underbreak to within 1 foot of the final line followed by excavation immediately before concreting, or spraying with bitumen or gunite on excavation are possible remedies. The tabular pieces produced by a tunnel round will be somewhat difficult to load due to the tendency of the shovel to be guided along the dominant planes of large pieces rather than into the pile.

Thin bedded or phyllitic quartzite is found on the eastern abutment above the massive quartzite. It weathers much more rapidly than the massive material and usually the outcrop is obscured under 5-10 feet of rubble, as in the spillway section. Exposed in the cliff section above the tributary creek, are bands of white massive quartzite-sandstone up to 4 feet thick, separated by 1 foot 6 inch bands of red coloured phyllite. Differential weathering of the phyllite has allowed the formation of overhangs and rock falls. Elsewhere, the material is much thinner bedded, as shown in drillhole 18M.

Physically the strength of the rock is governed by the strength of the phyllitic portions and while slaking is not a conspicuous feature in the surface rock, undoubtedly this undesirable property will be encountered in some measure in the less oxidised material at depth. Possibly, too, some form of "rebound" would occur in deep excavations in this material. Laboratory or field testing of samples, especially the determination of the modulus of elasticity, would be of value in the estimation of any tendency for elastic rebound.

Most of the joints exposed in the phyllitic quartzite are sheet joints along the bedding planes. Two other joints are usually present, but the dominantly anticlinal folding on the eastern abutment has meant separation along the weaker layers. The drillhole records from the underground powerhouse and spillway areas shows that the phyllitic quartzite is less jointed, and that adjacent faulting as well as arching has been responsible for the formation of joints.

The tendency of this material is to break in flat tabular pieces, and hence the inclination of the bedding plane to any excavation will largely govern the amount of overbreak. Drilling speeds in this rock will vary, but will in general be reasonably fast. Loading of a rock pile will be difficult due to the dominance of tabular pieces.

Jointing.

The jointing in the vicinity of the Ord River Main Damsite is both complex and abundant:—

(a) The complexity of the jointing is directly related to a series of major high-angle faults trending in a general north-northeasterly direction and to numerous additional faults, the largest of which trend either N. 45° E. or N. 20° W.

(b) The abundance of the jointing can be related to the competence of the rock type, a comparatively brittle quartzite, which has obtained relief from the various imposed stresses by complex fracturing.

The underlying, less competent phyllite, whilst showing fewer joint openings, has obtained relief by the formation of intricate fold patterns. This folding is evident on the surface in the immediate vicinity of the west abutment, but diamond drill cores, especially from drillhole 11M., on the southern spillway have revealed similar folding.

Bearing in mind the importance of rock fractures to dam design, grout hole orientation, underground rock excavation, and slope stability predictions, an analysis of the various fracture patterns was carried out, and a series of joint rosettes prepared.

These rosettes have been superimposed on the geological structural map of the two abutments of the damsite, (Plates IV and V), and show the direction and percentage of the various rock fractures and their relationship to the dam, river flow, and thus the probable water seepage directions.

For the purpose of making fracture analyses, a series of structural blocks was recognised either on the basis of their position between major joint openings, faults and flexures, or by virtue of their topographic position, as isolated river channel outcrops.

Within each structural block, two lines mutually at right angles were chosen. Along each of these measured lines every joint plane intersection was recorded as to direction, dip, tightness, and persistence. From these measured results a density per square yard could be calculated.

Eighteen different areas were analysed, in close proximity to the proposed dam wall or ancillary structures, and in all, 1,960 joints were recorded.

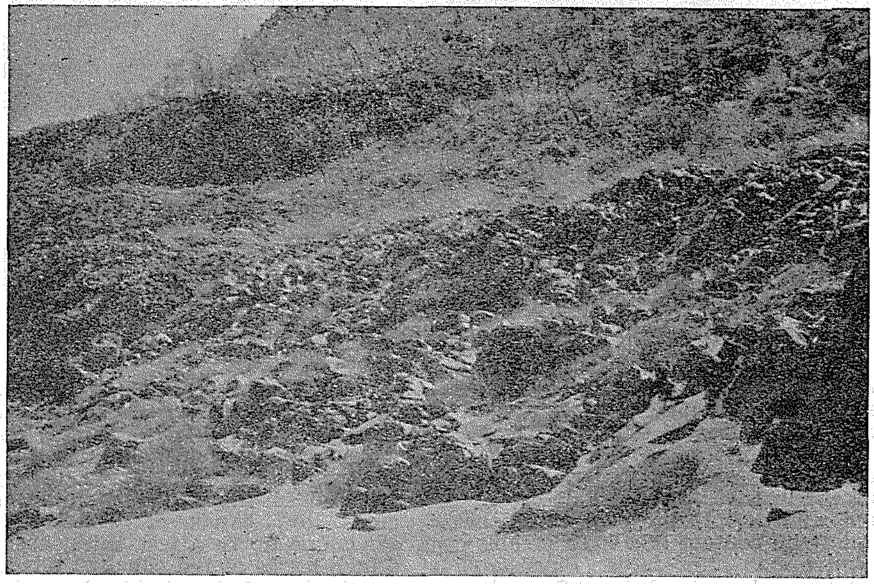

Fig. 2. Upper portion of east abutment showing block mosaic.

Overburden Conditions.

In the present river bed, unconsolidated sands, silts and small gravels lie on top of the quartzite floor to a maximum depth of 40 feet. As the quartzite crops out in the middle of the sand terraces, there are two channels, with the western one containing the 1962 winter river flow. The sands are saturated with water, ground water level being from 1 foot to 2 feet below the surface. About 100 yards above the dam site boulder beds with stones up to 1 foot 6 inches diameter, occur but except for material lying on the rock floor, only fine grained alluvials are apparent at the dam site. In view of their size, lack of consolidation and saturation, it is apparent that dewatering will have to be accomplished by the well-point method when excavation is made for the foundation of the dam. Flat angles to the batter slopes will also be essential.

On the western abutment no overburden as such is in evidence, except for the sandy terrace at the foot of the slope and a pile of rock rubble upstream of the lower adit.

The eastern abutment displays a series of nearly vertical sheet joints below rock terraces. These are formed on bedding planes and are broken by faulting. On the lower terraces especially, there are large quantities of sand. Above the highest terrace (Figure 3) thin bedded phyllitic quartzite occurs under a scree of rock rubble.

CHARACTER AND CONDITION OF FOUNDATION.

East Abutment.

The eastern abutment rises in a series of structural blocks or steps, separated by faults or big joints, with bedding joints forming the slightly inclined surfaces, and extensive near-vertical jointing breaking the whole rock mass into a mosaic of blocks with individual pieces generally about 9 inches by 9 inches. The rock exposed, as high as R.L. 240 on the centre line, is an open jointed ferruginous quartzite, and this is conformably overlain by thin bedded phyllitic quartzite to the crest at R.L. 300. Vertical displacement on faults both parallel and (mainly) at right angles to the river has affected the contact between the two rock types, and downstream of the centre line, the massive quartzite is stepped up as high as R.L. 270.

The composite joint rosette (Plate VI) shows the summation of the joint patterns for the abutment area. The structure is dominated by the bedding plane joints dipping from 14°E to 19°E away from the river and the high angle joints (dipping 45° to 80°), that dip into the river and strike between N50°W and N10°E. The other numerically prominent joint, trending N55°E, is nearly parallel to the centre line, thus at right angles to the direction of water pressure, and will be little used as a primary leakage path. The bedding-plane joint is favourably disposed as a leakage path, and the major bedding joints at 10 feet intervals will be especially prone to the entry of water under pressure. The situation of the tributary stream means increased opportunity for water entry.

One construction detail to which some consideration must be given is the production of a more or less smooth surface on which the core wall will be constructed. The accompanying photo. (Figure 2) indicates the nature of the irregular block mosaic, and with the bedding joint dipping in the wrong direction, blasting will be of limited value. A fair quantity of dental concrete would appear necessary, otherwise an irregular rock surface seems certain to be produced, and in order to obtain proper bond, wetter-than-optimum material, specially compacted with power tamping, may be necessary. All the steeper step faces will have to be cut down in order that the slopes do not exceed 1:1.

A considerable quantity of sand obscures the lower and upstream portion of the foundation rock and also fills many of the joint interstices. Much of this will be removed during the general trimming of the abutment, but the joints especially will have to be washed and/or blown clean.

As the bedrock quartzite is hard but badly broken and irregular, the making of an adequate bond will be exteremly difficult. For this reason a concrete cut-off is considered essential.

The amount of rock to be removed from this abutment will be governed by the consideration of getting an evenly graded surface on which to lay the core wall and cut-off. This may mean an average cut of about 3 feet. Removal of about 2 feet down the abutment will be sufficient to clear off the widely opened surface joints, then the cut-off will need to be embedded a further 5 feet as there is no alteration in the condition of the joints down to about 20 feet, when the openings are largely filled. The average thickness of rock that will have to be removed will thus be of the order of 5 feet overall, plus 5 feet for the core wall.

Deeper stripping will be necessary in the phyllitic quartzite above R.L. 240, and a minimum of 7 feet of cutting with the core wall embedded a further 6 feet may be found necessary.

River Bed.

Jetting has established the general shape of the rock surface in the river bed and this has been supplemented by two seismic profiles. The bedrock surface in detail will be irregular but rounded, something in the nature of a washboard profile. This will lead to difficulties in securing adequate compaction of the first layers of earthwork, as already noted for the east abutment.

Drillholes 4M and 24M show quite massive quartzite largely joint-free in the river bed, but the fact that they were drilled parallel to the strongest joint has to be considered. Lack of coverage in the deepest part of the river bed, 45 feet wide, means the foundation picture is not clear. (See later, Foundation Problems and Proposed Treatment).

There are two outcrops of quartzite within the main river channel, one midstream, in the vicinity of drillhole 24M and the other situated off the north tip of the west abutment. These were analysed for joint features but as the areal extent of each was small, they only provided a sample of the jointing in the rock at present obscured by alluvial deposits. A total of 140 joints was examined, and frequencies varied appreciably from five joints per square yard (in the river bed) to 37 joints per square yard (off the west abutment). The joint patterns obtained, however, are very similar to those showing in the west abutment, with a high proportion of sets striking north, roughly parallel to the river direction dipping about 45 degrees, with two other minor sets at N. 70° E. and N. 70° W. dipping both up and downstream at varying angles. The changes in joint significance from midstream to the east abutment is related largely to topographic situation.

From a construction point of view, the midstream outcrop which at the present site will fall beneath the main dam wall, is more important than the northern outcrop which is situated close to the downstream toe. Jointing in midstream will have a much greater significance after construction because, as with the west abutment, most of the joint sets trend in the general direction of river flow and water seepage. They dip both to the west and to the east at angles of 25°-60°.

In constructing an impervious core wall, it will be necessary to commence on a more or less level surface and this will mean that the existing outcrops will have to be removed; indeed all the numerous irregularities will need planing off.

Few joints run at right angles to the river banks and of these only a few dip upstream with the tendency to be closed by pressure from the impounded water. It is obvious from the examination of the jointing and the drillhole results that a comprehensive grouting programme will be required in the river channel section of the dam foundations.

West Abutment.

The western abutment consists of a thin slab of massive quartzite, lying on shaly phyllite dipping into the river and downstream.

A detailed examination has been made of the joints in the adits, and these results are shown on the joint rosettes (Plate IV). Furthermore, all the big joints or faults in the two openings have been recorded (Plate VII), and study of this data reveals two significant factors: (a) sheet joints, forming surfaces parallel to the ground surface, are of major importance as almost all reveal some evidence of movement (slicken), are usually partially clayfilled and appear to be continuous. Of these sheet joints, the most significant appears to be the surface at the phyllite-quartzite contact, because of the presence of clay minerals in a 10 ft broken zone and the discovery of free moisture in the lower adit. (b) The most abundant joint dips into the hillside and shows fracture zones but rarely slickensiding. This joint persists over the whole site and appears to be part of a regional pattern, parallel to major fault movement.

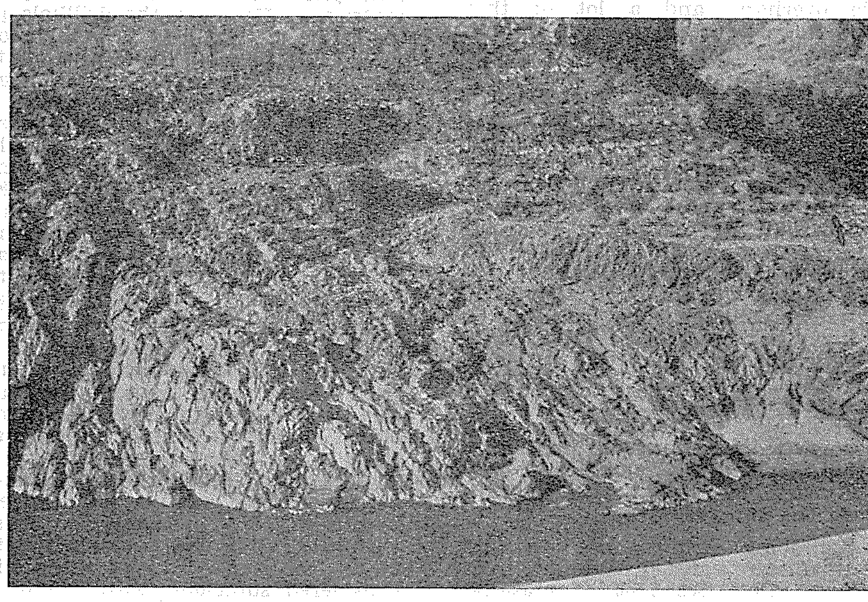

Fig. 3. East abutment showing topographic steps.

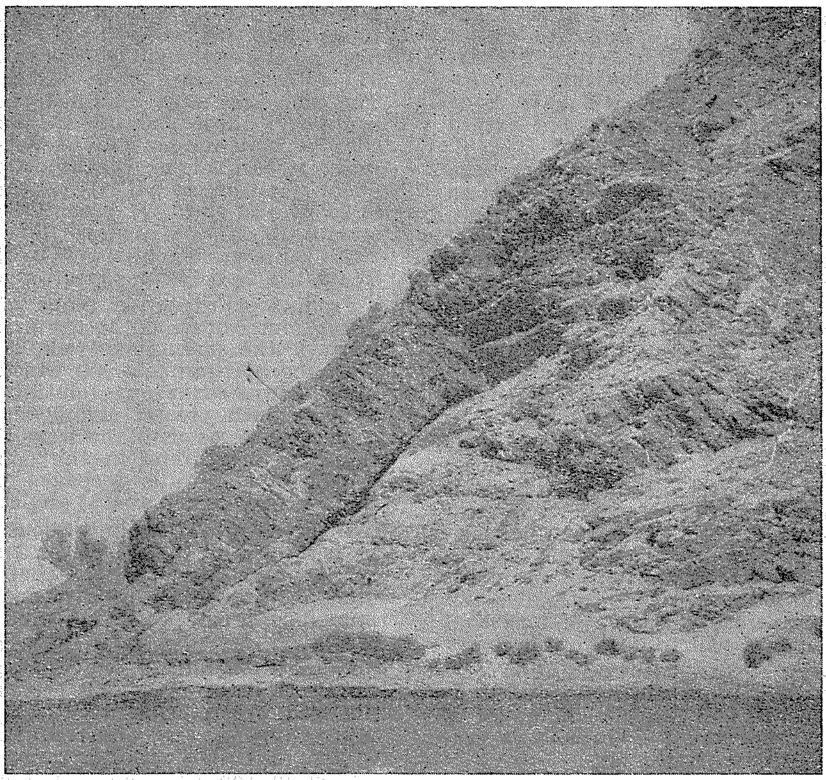

Fig. 4. West abutment showing sheet joints.

A composite joint rosette of the west abutment (Plate VIII) clearly indicates the major joint set striking N. 10° E.-N. 40° W., and dipping either into or away from the river at 30°-60°. The joint direction (when dipping into the abutment) is a shear direction which is usually brecciated and is controlled by both local and major faulting. The joint set that dips away from the abutment (sheet joints) shows slickensiding, and is probably a slip plane due to flexuring parallel to the bedding.

Both the major joint sets are weakness planes which will pose problems either along the quartzite/phyllite contact or within the phyllite, if allowed to become lubricated. Contrary to surface indications, these joints do not become completely water-tight at depths of at least 70 feet below the surface, as shown by seepages examined in the inspection adits. The topography of the abutment is largely defined by the sheet jointing, which has formed layers of rock largely parallel to the existing surface. Parts of some of these sheets have been removed largely due to the local incidence of big joints. However, this partial removal has left considerable overhang and a lot of this material will have to be removed down to a joint plane surface as the surviving sheet joints show openings as much as 2 feet wide. This will mean in effect the removal of a block of rock 10 feet thick by 100 feet high by 60 feet wide. The joint surface at 45° will be a reasonable surface on which to construct a core wall. Once this material has been removed, consideration will also have to be given as to the most effective method of pinning the relatively thin mantle of quartzite to the underlying phyllite. Most aspects of the contact between the two rock types show an apparently abrupt and plane surface. The fact that there is a gap at some contacts of as much as 12 inches, and the badly broken surface of the phyllite, suggest that overthrusting of the quartzite over the phyllite has taken place. However, a bedding thrust such as this could be equally as well explained for small movements by assuming the phyllite responded to compressive forces by folding, while the overlying rigid quartzite only arched slightly, giving separation and relative movement between the two rock types.

Apart from the joint contact, the physical condition of the phyllite revealed in the adits calls for some comment. The five feet of material exposed by the lower adit is profoundly disturbed, with clay in joints and layers of bedding planes, with the usual spacing about ¾ inch, in places as close as 1/32 inch in deeply weathered and contorted zones. Comminution of the phyllite due to movement has produced clay layers, which may be expected throughout the entire abutment close to the contact, as the clay is undoubtedly an attrition product due to local movement.

In the upper adit the phyllite is occasionally interbedded with 2-3 inch bands of quartzite, but the material as a whole is in extremely poor condition due to local breakage.

LEAKAGE AND REMEDIAL TREATMENT.

To prevent leakage under the dam, only a comparatively thin curtain (if it is a good one) will be required. It can probably be obtained by using one line of drill holes or two lines close together, located near the upstream face of the dam.

The picture derived from the cores and drilling logs is not entirely consistent with the conditions as seen in the two adits, as there are open joints revealed in the boreholes, whereas many of the adit joints are filled with clay or ferruginous materials. However, the drillhole picture pertains to the river bed, where water movement in the joints has cleared them of any filling. In the abutment area where the adits are situated there has been no water pressure clearing the joints. The filling of the dam with water and the use of the adits as inspection galleries will almost certainly allow the gradual washing out of some of the joints into the tunnels. For this reason it is considered that the joints in this abutment should be washed out before grouting, furthermore the grout curtain should be situated 20-30 feet upstream of the centre line of the tunnels.

The cross section shown on Plate IX has been prepared from the drill logs and core photos., and it shows that the foundation area may be divided vertically into three zones: (a) zone of somewhat open joints and some rock breakage due to near surface weathering; (b) zone of partially filled and closed joints; (c) zone of largely massive rock with tight joints. The top two zones are generally about 20 feet thick, whilst the third zone extends down to the phyllite contact and ranges from 30 feet to over 100 feet in thickness. This would suggest that primary or low pressure grouting to a depth of 45 feet is needed. One row of holes may be considered sufficient, with the final hole spacing about 5 feet.

Optimum conditions for the injection of grout will be present when the grout holes are at right angles to the most prominent joint opening. The dominant joint over the dam site as a whole is the set striking N. 20° W. and dipping 55° S.W., but the division of the dam into structural elements with local dominant joints requires the situation of grout holes to be a little more complex. It is perhaps unfortunate that none of the exploratory drillholes was directed to the north, as pressure testing on a drillhole in this direction would have yielded more valuable data than was obtained from the southerly directed drillholes that were tested.

Phyllite Contact Grouting.

Critical conditions with regard to leakage exist at the phyllite-quartzite contact in the western abutment. About 4½ chains upstream from the centre line an eroded triangular notch about 50 feet wide at the base (Figure 5) may allow the pounded water to obtain access to the sheet jointing parallel to the rock face.

Apart from the immediate near-surface joint, the phyllite contact has the largest opening, as the drillholes show water loss and shattered cores from the area. The phyllite is noticeably affected by the breakages, which may be linked with step faulting, and in the lower adit free moisture was detected in two places in the broken material west of the quartzite contact. Most of the joint planes are partially filled with attrition debris in the form of clay, and the grouting operations will be complicated. It is considered that compressed air, then lengthy washing at a low pressure, followed by grouting at a low pressure would represent the best approach, as the use of high pressures would displace the myriad minor fragmentary blocks and close the fissures to grout, but possibly not to water percolating along the joint from another direction.

Some crude wetting and drying tests of the abutment phyllite showed a tendency for accelerated slaking, possibly due to swelling of the clay-filled joints and bedding planes. In fact, the picture presented by the presence of such decomposed and broken phyllite is disturbing, and the utmost efforts should be made to protect it from the effects of water entry. To this end, an additional grout curtain on the western abutment to intersect the sheet jointing, particularly near the entry or 'notch', is considered essential.

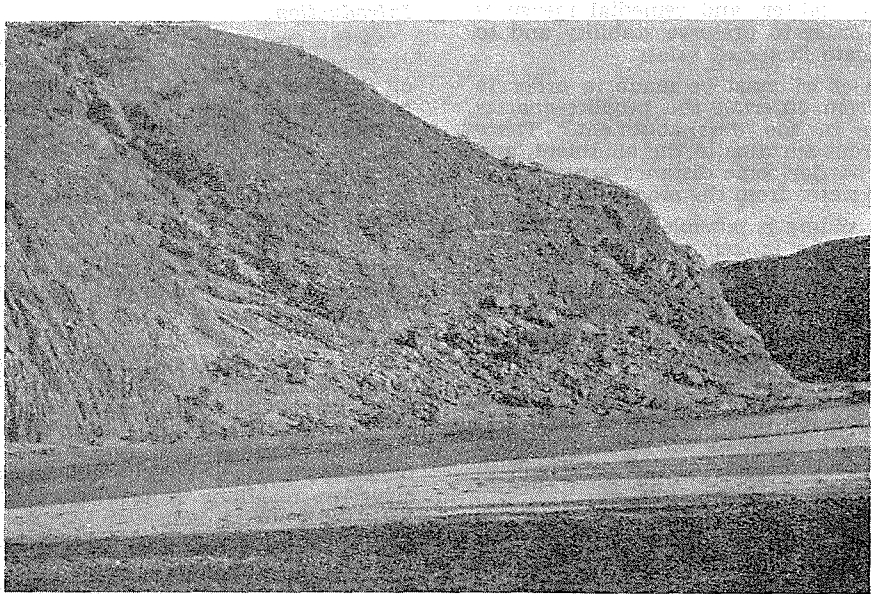

Fig. 5. West abutment showing "notch" area.

FOUNDATION PROBLEMS AND PROPOSED TREATMENT.

The diamond drilling programme has shown that most of the dam site is free of large structural defects that would require treatment. It must be pointed out, however, that a blind area, 45 feet wide, that has not been traversed by drilling, exists under the river bed. This could contain a geologic structure parallel to the major joint direction and in the deepest part of the river bed (Plate IX). In view of the probability of some structural control of the river's course to take it through the gorge areas, the existence of a fault must be considered. There is possibly displacement of the phyllite surface as picked up in the drillholes 7M and 19M and as intersected in 4M. Displacement in the opposite sense would be the case however between drillholes 20M and 24M, and these two apparent displacements may well be the result of flexure and rolling of the phyllite-quartzite contact. On the structure contour map (Plate X) this shows as a syncline, with the axis passing between drillholes 19M and 4M. Apart from this, movement on the fault could have been transcurrent, i.e. essentially horizontal shearing.

A faulted zone in this midstream position would be a probable leakage path, and a zone of weakness if loading pressures were high, as in the case of concrete gravity section. An earth dam, however, does not impose high unit loads, so except for the existence of a wide gouge or pug zone, not a great deal of remedial work would be necessary.

The entire foundation area, except for the eastern slope above drillhole 3M, will be underlain by largely similar massive quartzite, and the foundation problems will be mainly governed by local jointing in the various areas. These have been separately discussed in an earlier part of the report, but in dealing with the dam foundation as a whole, it may be recorded that the massive quartzite has excellent physical characteristics and no consolidation or remedial grouting will probably be necessary. The area where some work may be needed will be in the river bed area, and, until the rock surface has been exposed, no final decision is possible. It may be found that the joints in the river bed are open enough to warrant grouting in order to prevent minor consolidation on loading. A grout curtain to prevent leakage will of course be needed, and also a cut-off wall, but structurally there are few defects in the quartzite rock. The phyllite-quartzite contact is another matter, and merits detailed examination.

It is considered essential that the river alluvials should be removed to allow adequate emplacing of the earth dam, and a barrier upstream of the core wall will be necessary to stop water moving into the excavation. As the whole of the sand and gravel flats are saturated with water, it may be necessary to instal a well-point system to do this job.

The western abutment consists of a sheet of massive quartzite generally between 50 to 80 feet thick, with a minimum dimension of 30 feet, dipping downstream and into the river at angles ranging between 60° and 30°. The quartzite overlies strongly deformed phyllite, which appears on the surface about 150 feet downstream from the dam centre line, where the quartzite ends abruptly in a small cliff. The quartzite is strongly jointed but is remarkably coherent and stands well in the adits without any timbering. There are a few big joints and minor faults which divide the quartzite into blocks and the nature of these is shown on Figure 1. The phyllite, especially near the contact with the quartzite, is extremely broken, and the joints and even many of the bedding planes have a parting of clay minerals. With bedding parallel to the ground surface, i.e. striking parallel with the stream channel, and the entry of water assured either from ponding or from storm water, then the conditions appear optimum for the sliding of the quartzite cap under the downstream pressure exerted by a full reservoir.

The proposal to build an earth and rockfill type dam would be of decided assistance in lessening the tendency of the structure to slide, as the heavy weight of the earthfill dam provides a component efficiently opposing movement in the lower foundation areas. However, higher on the abutment this influence will be slighter, and remedial measures are essential in order to preserve stability and to provide an adequate factor of safety.

Every possible effort must be made in order to prevent water from entering the phyllite-quartzite contact zone in the west abutment. There should be two grout curtains in the abutment, and a further grout barrier some distance upstream to prevent entry of water from the eroded "notch".

The idea that sliding is possible at a point west of the contact in the broken phyllite, should be tested by shear tests in the laboratory, or preferably in the field. Samples of quartzite-phyllite, then one sample of phyllite may be pressed by a certain known load and the force required to induce sliding (with respect to the other half of the sample) can be measured, both under dry and under saturated conditions. It is possible to use a soil shear machine for this test, but a field test is preferred, using a block in which the required layers are exposed; the layers can be capped with concrete and loaded vertically, and then thrusts may be applied to the blocks with hydraulic jacks.

It would be most desirable to carry out the normal physical testing of block samples in order to get a more accurate assessment of rock strength. Special care would be necessary in securing the phyllite samples but by treating the sampling as a normal soil mechanics operation and sealing the blocks in wax after securing fresh material, reasonable specimens should be procurable.

The quartzite block liable to movement on the west abutment may have dimensions such as 60 feet thick by 150 feet wide by 200 feet long, and if the unit weight of quartzite is taken as 165 lb. per cubic foot then the block will weigh about 133,000 tons.

This block is sitting on partially-filled clay seams in the phyllite with the dip of the underlying surface at 27° in a downstream direction. As the frictional value or slip resistance for rock of this nature is between 15° and 25°, we may assume that the stability of the mass against sliding forces is low.

If the dam is 150 feet high, and assuming 1 cubic yard of quartzite gives 1.4 cubic yards of rock fill, with 0.1 cubic yards of void later filled with fines, then the pressure exerted on the foundation rock will be:—

$$150 \times 165 \times \frac{1}{1.3} = 19{,}100 \text{ pounds per square foot}$$

$$= 132 \text{ pounds per square inch}$$

If a factor of safety of 10 is used, as is usual in rock mechanics, then the quartzite is still not anywhere near its allowable compressive strength.

In addition to this, two other surfaces of breakage will be necessary in order to release the block, one parallel to the river and cutting through the quartzite, and another at right angles to the river and also reaching the phyllite or near to it. These requirements are available in the local joint sets, as detailed earlier in the report.

While grouting will be the major factor in preventing movement, a key wall may have to be constructed across the phyllite-quartzite contact, extending at least 20 feet into the phyllite and 5 feet into the quartzite, and running from near the crest to the river-bed foundation, i.e., about 250 feet long. Further adits may be necessary in order to secure access and ventilation during excavation of this slot and its filling with concrete. The undesirable property that the phyllite has of slaking and fragmenting on exposure to air means that every freshly excavated surface in the phyllite should be gunited or asphalted immediately on opening out, in order to prevent deterioration. An alternative would involve leaving the last foot of excavation until immediately before concreting.

The final decision as to whether a key wall is required may be deferred until the results of the shear and physical properties tests are known. Calculation would then enable the determination of the factor of danger—or safety.

UNDERGROUND STRUCTURES.

Introduction.

At the Ord River Main Damsite No. 2 the topographic situation has imposed severe limitations on the construction of a conventional outdoor power house. The proposal to place the facility underground involves the investigation of quite detailed properties of the rock material, as not only the load bearing potential but also the whole field of the mechanical behaviour of the rock mass has to be covered.

The important consideration in designing underground openings is the type and amount of support required during excavation; the next question is the type of permanent support that may be necessary.

The answers to these problems require a detailed study of the gross geological properties of the site as well as the microfeatures. The inherent strength of the individual rock fragments, the usable strength of the rock mass composed of interlocked blocks and the possibility of destructive or constructive reactions from residual stresses in the rock must all be considered.

The design proposal is for an intermediate type installation with the conduits both upstream and downstream of the power house of about the same length, with the whole system under pressure, without any surge tank. The layout is taken as shown on Plate III.

Intake.

The point of entry of the intake tunnel to the power house is in the tributary creek that joins the Ord on the eastern bank 200 feet upstream from the dam centre line. It is thus situated on the southern boundary of the east abutment, at the base of a steep cliff face with extensive deposits of scree material. The formation of this scree slope is the result of slip parallel to the bedding. The bedding at this point dips at various angles to the south-east as a result of strong local downwarping. There is a profound drop of the thin-bedded quartzites from where seen above the northern bank of the stream to their position under the alluviated cover below the northern bank. Seismic section line No. 8, made with the seismic timer, showed that the rock surface continued its cliff-like character downwards until a level surface was found at 60 feet below ground level.

The present proposal is that water will be admitted to the intake tower and will fall vertically before being conducted through a horizontal tunnel to the underground power house. Thus the entry channel is in effect a pressure shaft. However, the extremely poor foundations disclosed by drillhole 23M and the surface investigation make this layout rather difficult, if not impracticable.

Close to the shaft inlet, the rock type is a thin bedded phyllitic quartzite, which has formed the extensive scree slope against the southern edge of the abutment. The quartzite, which was exposed in situ in a drill platform cut into the side of the cliff, is interbedded with thin layers of phyllite, forming bands of quartzite which range in thickness from 2 inches to 14 inches.

The rock is comprehensively broken up by three main joints, and the fact that this breakage continues with depth is indicated by the nature of the core recovered from drillhole 23M, and this is shown effectively in the core photograph (Fig. 6).

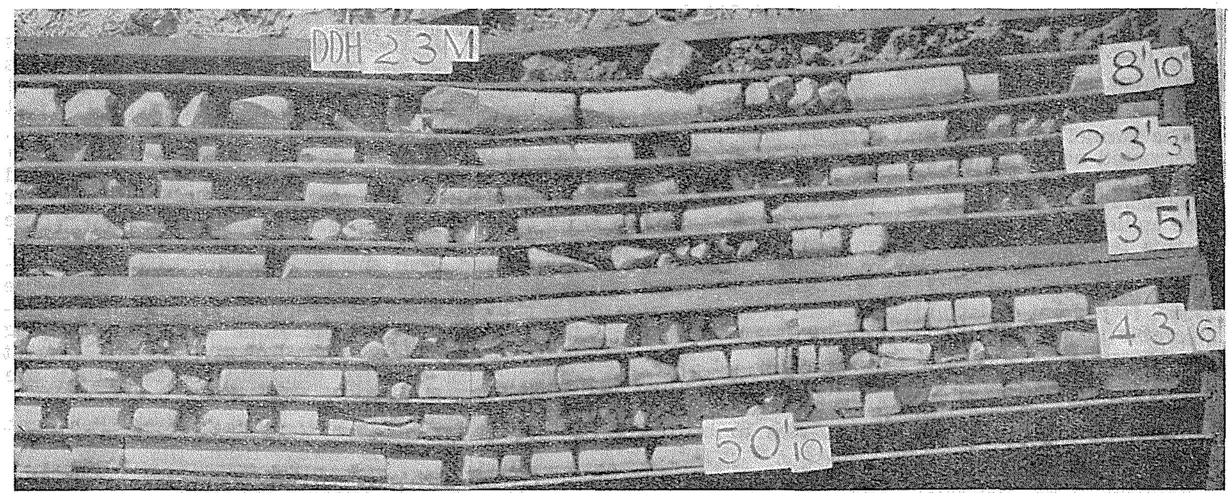

Fig. 6. Core recovery from Bore 23M.

It would appear that weathering along phyllitic seams and a minor downhill movement resulting from settlement on such eroded partings has resulted in the initial fragmentation of the local rock.

Furthermore, the intercept of the massive quartzite at 43 feet in drillhole 23M is no guarantee of good foundation, as the small length penetrated to 50 feet depth, was not adequate to allay fears that the quartzite also had been locally affected by extensive breakage.

There is no doubt that the rock could be vastly improved by an extended grouting programme involving washing and low pressure grout injection before shaft sinking commenced. Even so, the formation of a consolidated sector in an area of such extensive breakage would involve wide extension of grout treatment in an endeavour to tie the plug round the shaft to more solid material away from the cliff area. The shaft lining would have to be at a maximum.

In view of these problems it is undoubtedly preferable to move the inlet further up the tributary creek in a north-easterly direction for a distance of at least 100 feet. This would allow its emplacement in what appears to be much more quartzitic and massive material, apparently unbroken by local movement. This site would be on the western limit of anticlinal folding (Wyatt 1961, Fig. 12), and the incidence of the local fractures is shown in the joint diagram (Plate V). There will be a tendency for water to enter the shaft, and this can be better evaluated by the drilling of a diamond drill hole at the proposed location. Emphasis will of course be on core recovery, and particular attention should be focussed on the nature of the joints and their fillings, if any.

A further point must be emphasised, and that is the presence of large blocks of rock in positions of potential rock-fall near the top of the hill, immediately above the intake and its associated structures. For example, immediately above the inlet, massive quartzite layers up to 20 feet thick are interbedded with phyllitic layers. Some of the thin phyllite bands show evidence of movement with the formation of clay minerals. Furthermore, weathering and jointing has produced on the outer face of the slope, a series of quartzite blocks, some as large as 20 feet by 20 feet by 20 feet and thus weighing up to 60 tons. These blocks are lying on bedding planes dipping downhill at about 16° (Plate V), right at the critical angle for instability under saturated conditions.

Further to the northeast above the above proposed inlet, the bedding planes dip downhill at about 12°, so conditions are not so critical.

Whatever inlet position is selected, it would be necessary to remove the uphill blocks before any excavation or construction work commences.

Inlet Pressure Tunnel.

A longitudinal section drawn along the centre line of the proposed inlet tunnel (Plate XI) shows that two major problems, imposed by local geology will have to be considered.

Rock Breakage.—Firstly the large amount of broken phyllitic quartzite with highly-weathered in situ rock beneath, that will be encountered in the initial entry, will present some difficulty to tunnelling operations in that close setting and lining will be necessary. This area will have to be fully lined and reinforced for completion, and the rock will also have to be improved by grouting in order to meet the imposed stresses, as the joints are quite open and in some instances filled with soil and rock debris. Grouting will initially have to be conducted from the surface, but the steep cliff section will preclude long holes. The whole grouting operation is likely to be drawn out due to the need for careful washing-out of the joints, and the use of low pressure grout injection, necessarily done in several stages. These broken rock conditions may be expected to persist for as much as 50 feet from the portal.

As the breakage is largely in the phyllitic quartzite, conditions will improve greatly in the massive quartzite that will be encountered further into the hillside. As the bedding appears to dip quite flatly towards the portal, the tendency in the phyllitic quartzite and initially in the massive quartzite will be for long wedges of rock to fall into the tunnel. This can be countered by pattern rock bolting, preferably at right angles to the bedding. As a cover of 10 feet of massive quartzite may be considered necessary before reduction of bolting frequency, then bolts up to 12 feet long will be necessary.

Rock bolting will be a significant feature of safety measures in the massive material, as it will be used for securing blocks and broken areas.

Faulting.—The second major feature of the tunnel is that it will intersect at least five faults, almost at right angles to the tunnel direction. On the surface the faults are quite conspicuous and dip from 75 degrees to 85 degrees to the north (Plate II). They show as 6 inch zones of minor breakage and slickensiding with openings of up to 1½ inches. Vertical displacements do not appear large, the observed maximum being 4 feet, and in all cases the south side is down. As shown on the section (Plate XI) the faults cover a zone 200 feet wide, first intersecting the tunnel about 120 feet from the portal and extending to half-way across the machine hall. At depth the fault zones may be filled with quartz fragments and ferruginous material, but they constitute significant waterways that will have to be sealed off. Drillhole 5M passed through most of these faults and heavy breakages of the core at 18½-21 feet, 30½-31½ feet, 33-34½ feet and 76-77 feet, as well as water losses at 2 feet and 33 feet indicate that the zone of shattering is relatively small. However, it may be desirable to reinforce these areas.

The tunnel in its original position may also be intersected near the power house by a strong fault that shows at the eastern end of the spillway as a brecciated zone about 20 feet wide. No surface indications are available of any continuation of this feature into the hill containing the underground structures but there is ample room for it to pass between vertical drillholes 13M and 23M. If present, this fault zone will require considerable attention with reinforcement and grouting necessary.

The faults may have had a beneficial effect also, in that they represent release of stress, and it is unusual to have high residual stresses in broken or faulted areas.

Jointing and Bedding.—The bedding of the quartzite appears to steepen in dip from about 5 degrees at the portal to about 23 degrees at the power station. This is probably due to movement on the faults. This means in effect that the tunnel will be driven largely "face on" to the grain, and overbreak in the crown will tend to be moderate. The joint distribution, shown on the rosette (Plate V), is also good as only a minor joint direction is parallel to the tunnel direction. If we take into account the joint distribution and the moderate bedding dip, then pressures will tend to be fairly uniform, and a two-dimensional stress distribution may be assumed. The actual load on the crown will vary between zero and 0.25B where B is the width. Thus for a 12 foot wide tunnel the maximum rock load would be 0.25 x 12 x 165 = 495 pounds per square foot.

The unknown factor is the residual stress in the rock and its direction, and this can only be determined by in situ measurements. However, in view of the surface topography it would not be surprising if there were a high vertical compression, and two nearly-equivalent horizontal stresses, somewhat greater than the vertical stress.

As mentioned in the section on the intake structure, a reasonable alternative would involve a shift up the tributary creek of 100 feet. The tunnel would then start in solid rock, and only a little reinforcing would be required. The length of the tunnel would be greater if the power house remained in its proposed position, but as it would be beneficial to move the power house in order to place it in homogeneous rock, then the length of the tunnel would not be greatly altered.

A horizontal diamond drill hole along the tunnel line finally adopted or a pilot or exploratory tunnel to the power house, later to be enlarged to full size, would have the two-fold object of enabling the power house rock to be physically tested, and the leakage paths into the tunnel to be determined.

Power House and Transformer Halls.—Projection of the contact between quartzite and phyllitic quartzite indicates that the south-eastern top corner of the power house will be in phyllitic quartzite, with the strike almost at right angles to the length of the hall and the dip towards the intake at 23°. Within the massive quartzite itself, there is also a physical boundary between jointed, iron-stained quartzite and less jointed unstained material, and this surface is nearly parallel to the long side of the power station, and dips towards the Ord River at about 30°. However, its position with regard to the power house excavation precludes shifting the opening to a site exclusively in better material. The optimum position with regard to rock type and openings involves a northerly shift of about 70 feet. This would also clear the excavation from the influence of the phyllitic material.

The effect would be to place the power house excavation by its own width further into the hillside. This would involve alteration of the position of the inlet tunnel further up the tributary creek, a situation which is also desirable from the viewpoint of foundations of the tower and initial entry of the tunnel.

The site of the underground power house has been traversed by two inclined diamond drillholes (5M and 15M). These covered a block of rock at machine hall level measuring 65 feet by 125 feet out of design dimensions of 70 feet by 160 feet. As was found at the Snowy Mountains Tumut (T1) Power Station site, the cores from the inclined diamond drillholes are of very limited value for determining the pattern of joints and faults; these features are better determined from an exploratory tunnel and from surface exposures. The rocks exposed immediately above the proposed power house are thin bedded phyllite quartzites, and their jointing pattern is not the same as the underlying massive quartzites. Data taken from the nearest exposure of massive quartzite indicate that the dominant joints—

	Per Cent.
340° at 19°E away from the river (bedding)	19
335° at 77°W towards the river	33
190° at 80° towards the river	33

are largely at right angles to the length of the excavation, which is N. 70°E. This particular joint pattern is excellent from the viewpoint of orientation of the excavation, but some minor problem will arise with roof control because of the 19°-23° bedding joints. The solution will involve the use of roof bolts placed at right angles to the bedding planes. As the bedding frequency is 1 every 2 feet, then bolts longer than 2 feet would be necessary, and in view of the different drilling conditions, an optimum length of 10 feet is suggested. The frequency of the two sets of near vertical joints averages 3 feet. This indicates that a reasonably close spacing of the bolts will be necessary, and the ratio of length to spacing will have to be 2 or greater. Thus the bolts will have to be about 3 feet apart. For the bolts to be most effective it is desirable that they be installed as early as possible in order to control initial movements. It is also essential to commence bolting on a predetermined pattern, and to adhere to that pattern in order to avoid stress concentrations. Within the limits of the pattern it should be possible however to place each individual bolt in a position of maximum efficiency, i.e., it would be wrong to place a bolt to secure a thin sliver of rock when a 1 foot shift could secure a much thicker section.

As it is proposed that the majority of the bolts are to be at right angles to the bedding, it will be necessary to use angled washers (20°) to secure the nut to the bolt. To ensure permanency the bolts should be grouted after tensioning. Furthermore, when the roof excavation has been completed, the entire roof can be covered with wire mesh, attached to the bolts. As the stress pattern round the excavation will change markedly during excavation, it seems reasonable to defer the construction of the permanent roof support until the excavation has reached an advanced stage. This means that the permanent support will be more closely integrated with the rock than would be the case if supports were installed immediately on excavation of the roof slice. The rock walls as they are exposed may also be bolted, also in patterns, but a much wider spacing will be feasible, say 6 feet. In all cases the bolts may be stressed to a nominal load of 20,000 lb. tension, using 1 inch nominal diameter mild steel bars.

It is not possible to determine the type of permanent support for the power house and transformer hall roofs without some knowledge of the residual rock stresses. These can only be determined by in situ measurements, and consideration must be given to the driving of an exploratory tunnel to the power house area to enable the tests to be carried out. As several openings will have to be carried to the underground station—inlet and tailrace tunnels, access tunnels, cable tunnel, and lift shaft—it should be possible to utilise the exploratory opening for later use. In any case, some investigation of the proposed new position of the power house is desirable, as well as some knowledge of the transformer hall area. These objects could be achieved by means of diamond drilling from the exploratory tunnel.

Tailrace Tunnel.

The tunnel has been investigated by one inclined drillhole (12M) and the most important features revealed were the softer sandstone lenses about 1 foot thick that occurred every 10 feet or so, and the marked absence of joints, due to the fact that the drillhole was inclined nearly parallel to the most important set (335° at 77°W towards the river). Within the tunnel limits there are two sandstone lenses and a small broken area, but the quartzite on the whole appears quite massive.

The joint pattern for the area, as shown on the structure plan (Plate V), is favourably disposed to the tunnel alignment, and roof control should be easily achieved except in the area around the tunnel outlet. There is pronounced sheet jointing near the outlet, with at least one fault, striking along the tunnel length. This means that a full grouting programme will be necessary, and that some little trouble will be experienced on initial opening. Full concrete lining with reinforcing will be necessary at the outlet portal and from the draft tubes through the branch tunnels into the tailwater tunnel, elsewhere only concrete lining may be necessary.

INVESTIGATION OF NORTHERN SPILLWAY.

Seismic Timer Traverses.

An R117 seismic timer manufactured by Dynametric, Inc. was supplied by the Public Works Department for the investigation of the north-east spillway area. Four drillholes had already been completed in this area at the end of the 1961 season, and conflicting results made additional investigations desirable.

The first traverse passed along the line of drillholes 16M, 17M, and 27M. The resulting time travel graphs were all clear cut, indicating a thin cover of unconsolidated rock rubble overlying either a high velocity material which became more compact at depth (signified by the gradually increasing velocity curve), or a constant velocity material which contained high velocity layers. Either description would fit the thin bedded phyllitic quartzite as intersected in drillhole 9M.

The longest traverse ran in an east-west direction up the centre of the spillway through drillhole 9M. The velocity curves obtained were similar to those already recorded for the first traverse, that is, a low velocity cover of unconsolidated material overlying a denser, higher-velocity material.

The other two traverses were equally spaced and at right angles to the main line, and gave similar results. However, in some instances they showed very high velocities, probably due to the presence of massive quartzite, and these were recorded at the south end of each traverse. This agrees with the surface mapping which shows a massive quartzite bed underlying the thin bedded quartzite which dips flatly to the north and occupies the bulk of the spillway area.

Of the four drillholes on the intake side of the spillway, 16M, 17M and 27M indicated a sandy material commencing at various depths ranging from 2 feet to 30 feet. Seismic work in the vicinity of these holes gave no indication of sand zones, apart from the near-surface unconsolidated rubble and debris of drillhole 27M, which showed as a zone 12½ feet thick in the seismic traverse. The presence of the "sand" may be explained for the other holes in geological terms. Three possibilities may be mentioned:—

(i) The sand may exist as a bed of low velocity beneath a quartzite of higher velocity and would not be picked up by the timer.

(ii) The sand could exist as a sandy phyllite bed, interbedded with the thin layered quartzite. However, diamond drill evidence is that any phyllite lens would be of a minor nature and not as thick as the 28 feet apparently shown in drillhole 27M.

(iii) The sand could exist as an infilling in a joint or a fractured zone, intersected by the drillhole.

In view of the seismic results (coupled with surface mapping) it is most probable that drillhole 16M intersected a thin phyllite bed not more than 10 feet in thickness. Drillhole 27M most probably intersected broken phyllite in a faulted zone or sandy material filling a joint, and drillhole 17M may have done the same, although the material in this case is more likely to be drainage channel debris.

The occurrence of several phyllite outcrops amongst the quartzite scree material along the northern side of the spillway indicates that phyllite occurs beneath the quartzite rubble and boulders which litter the slope. This is most likely, as abundant phyllite also occurs on the outlet section of the spillway. In any case it is almost certain that spillway excavation will be mostly in thin bedded phyllitic quartzite containing layers of phyllite and quartzite of different thicknesses. This cut material should be rippable most of the way, especially that portion of the spillway in the vicinity of drillhole 9M.

It should be noted that the three other traverses, B-C, D-E, and E-F, all showed a few feet of rubble over phyllitic quartzite, which had a velocity range of 2,500-10,000 fps. A large percentage of the velocities do fall in the 2,000-4,000 fps range which indicates a thin bedded phyllitic quartzite, but the occasional high velocities of 8,000-10,000 fps are no doubt due to massive quartzite outcrops up to a few feet thick. These can be expected to be interbedded with the thin bedded quartzite and will no doubt require explosives for their excavation.

Therefore, from the seismic results obtained on the north-east spillway it is likely that the whole of the spillway, as investigated by the traverses, will be rippable, with explosives being necessary only where occasional thicker quartzite beds, probably on the southern side of the spillway, are encountered.

Geological Setting.

The spillway structure envisaged with a rockfill dam consists of a large open cut through a topographic saddle approximately 1,200 feet downstream from the dam on the right hand or eastern bank. In considering a spillway with a gated crest and unlined chute with no training walls, the direction of the spillway with respect to the bedding and major joint sets becomes of prime importance. The present proposal places the spillway largely along the easterly strike of thin bedded phyllitic quartzites which dip to the north between 10 degrees and 25 degrees. This means that the softer phyllitic beds will immediately erode with respect to the quartzite or harder bands, and the profound grooving thus initiated will seriously affect any hydraulic design, especially if the beds do not strike entirely along the excavation, an almost certain situation. It would thus appear essential to have a concrete chute.

The stability of the spillway walls will be determined by the positional relationship of the spillway to the joints and bedding and by the extent of weathering, past and future, in the phyllitic quartzite. The more prominent joints appear to be (1) N. 80° E. dipping 60°-80° and (2) N. 20° W. dipping 90°-80°, but these do not appear to present any great problems provided the batter slope is no steeper than 60 degrees. However, at least 30 feet of the section on top of the slope should be 1 : 1. The bedding striking along the excavation will dip into the cut at about 20 degrees on the southern slope. This is a situation which is fraught with difficulties as the interbedded massive and platy quartzite is thus in a favourable situation for sliding. This trend may be further aggravated if there is a tendency for the phyllitic material to slake on exposure, and the annual removal of surface detritus by floods would lead to wholesale deterioration. The slaking characteristic could no doubt be arrested by coating the exposed walls of the cut with gunite, immediately on opening out, but such a gunite skin would not survive the passage of flood waters. Thus to effectively deal with this problem, immediate coverage followed by the erection of a training wall will be necessary. This does not add to the overall slope stability however, and it will be necessary to provide some method of control to insure safety. The most economical solution is the use of rock bolts, set at right angles to the bedding to effectively bind the rock layers together. Hollow mild steel bars, of maximum length (say 30 feet) may be employed, to be grouted up immediately on tensioning. The recesses cut to receive the bearing plate should be brought up to the original slope surface, with concrete if below maximum flood height, in order to preserve uniform flow conditions.

The eroding potential of a flood discharge through the spillway is liable to be great in the existing channel area. The tendency will be for the eroding area to work downstream, as the beds dip in that direction. However, it is expected that the fissile phyllite beds, in particular, will erode quickly allowing the quartzite to be "plucked" or quarried. High water velocities likely to occur near the intake are also liable to cause damage due to the heterogeneous nature of the foundation rock and its differential erodibility.

As it is proposed to have a gated crest, it is essential to explore the foundation area thoroughly for the competency of the bearing materials as any differential settlement will cause the gates to jam and thus put the spillway out of service. In this connection the wide shear zone (N. 15° W., dipping at 75 degrees to the west) that shows on the southern edge of the spillway near the saddle (Plate II) is of particular interest. Drillhole 9M which was drilled largely to test the rock as a source of concrete aggregate, shows sandy ferruginous phyllite alternating with ferruginous quartzite which confirms surface indications. Two inclined holes, crossing symmetrically and drilled on the crest line, would be necessary for a full appraisal of this foundation.

It is considered that most of the material derived from the spillway excavation will be unsuitable for use as rockfill as thin slabs only are liable to be produced and these are further liable to breakdown on handling and placing. Furthermore, the suspected tendency of the phyllite to slake would render a further decrease in size suitability. Some of the massive quartzite bands encountered could be used but on the evidence available they would not account for more than 10 per cent. of the total rock section.

RESERVOIR AREA.

Examination of the reservoir area shows that the most likely path for leakage would be through the narrow phyllite ridge with occasional quartzite cappings that runs mainly parallel to the Ord, and forms the western bank, from the No. 2 damsite upstream to the No. 1 site. The most critical situation occurs about ½ mile upstream from the No. 2 site where sheet jointing resulting from folding in the quartzite has meant the presentation of continuous vertical joints to the reservoir side, and thus through the ridge to the adjacent stream valley. As shown on Fig. 7, joints spaced about 1 foot apart occur over a distance of 30 yards and some openings are as wide as 1 foot 6 inches with the average size of about 2 inches at the surface.

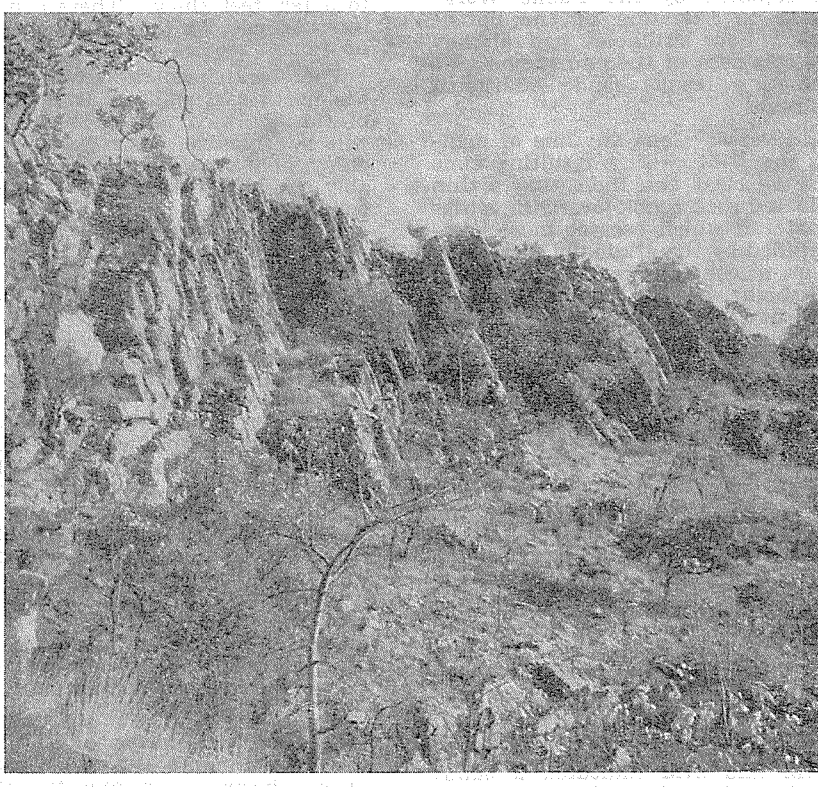

Fig. 7. Sheet jointing in quartzite, west bank.

This structure in massive quartzite is favourable to the leakage of water and is underlain by thin bedded phyllite, which offers a percolation but not a leakage path to water. Thus the height of the reservoir will determine whether leakage will take place or not, and in the absence of adjacent levels, estimation by eye suggests that the water level will not be high enough to allow entry to the structure. Reservoir level should be established in this vicinity, as the jointed sheets would readily break into good-sized blocks and prove a useful source of dimension stone if free to be used. If reservoir level does in fact reach the jointed area, then a small grout curtain will be needed with the holes angled from the ridge crest to intersect the joints at as flat an angle as possible.

Another part of this phyllite ridge which must be considered is the area of the proposed Southern Spillway, this being the thinnest part of the ridge. Most of the relevant data is shown on the cross section for drillhole 11M (Wyatt, 1960). The rock, a highly folded phyllite, is extremely broken due to surface weathering for the top 40 feet, i.e., to R.L. 336, and is oxidised for 100 feet to R.L. 270.

With the top of the dam at R.L. 300, only the bottom 50 feet of this hole need to be considered. The weight of the water will tend to close the bedding planes (dipping 85° to 45° into the Ord), while the cleavage planes (dipping 60° away from the river), although unfavourably situated, are of such sporadic appearance that they do not constitute potential leakage paths. Horizontal vuggy and broken layers occur between R.Ls. 286 and 290, and there was a 100 per cent. water loss at R.L. 297; but the phyllite generally is in good condition, and this, combined with the fact that the leakage path will be at least 500 feet long, indicates that no serious leakage will occur and that no grouting treatment will be necessary.

EARTHQUAKE RISK.

There are no instrumental recordings of major earthquakes originating in the Kimberley Division. Indeed there are very few references to tremors felt in the area, and this is not surprising when the small and scattered nature of the population is considered, allied with the lack of local recording media such as newspapers. There is no doubt that the number of tremors *felt* will increase greatly with the establishment of a permanent townsite and the installation of a seismograph at Kununurra.

As earthquakes are the result of earth movement, for shallow earthquakes usually occur on faults, the determination of recently active faults would show the presence of intermittent local earthquake activity. Careful search of the air photos covering the immediate vicinity of the Ord damsite failed to reveal any fault that could be classed as *recently* active. Three local shocks of intensity IV, recorded by Mr. J. D. Wyatt (pers. com.) in 1960, were undoubtedly situated on minor features, and the energy released was quite small.

Experience with isoseismic patterns in New Zealand and California has shown, for structures founded on the same type of material, that an earthquake of MM intensity IX at the epicentral region is still destructive (MM VIII) for a distance of about 50 miles, and semi-destructive (MM VII) to 100 miles. This means that for a structure to be endangered by an earthquake it must be within 100 miles of the epicentre of a major earthquake. This distance is modified by the fault direction and according to the type of material the structure is founded on, i.e., earthquake destruction is less effective on hard rock than on soft, and is worse on loose unconsolidated ground, especially if the loose deposits are relatively thin, say 100 feet or less.

Minor earthquakes occur almost anywhere as practically all seismological stations have recorded some earthquakes in their immediate vicinity. It is expected that minor local earthquakes will be recorded at the Kununurra station. As far as major earthquakes occurring on known faults are concerned, the Ord region must be considered aseismic. It is not thought that any special design precautions are warranted on the evidence thus far available.

SOURCES OF AGGREGATE.

Cement-Aggregate Reaction.

Deleterious cement-aggregate reaction occurs between soluble silica in aggregate and the alkali-hydroxides derived from Portland cement, and produces abnormal expansion and cracking of mortar and concrete. The definitely established reactive constituents of natural aggregates are opal, acid and intermediate volcanic glass, cristobalite, tridymite and chalcedony. All these minerals can be described as highly siliceous materials which are thermodynamically metastable at ordinary temperatures, i.e., silica not tied up in a crystalline structure that is stable under normal ambient conditions. All the known reactive aggregate constituents except cristobalite and tridymite may occur either as individual pieces in aggregates or as constituents of rocks in aggregates.

In addition to these reactive silica-minerals, certain phyllites are known to have caused deterioration of concretes through cement aggregate reaction, with hydromica as the possibly reactive component. The Tennessee Valley Authority now considers that phyllite is deleterious in aggregate for concrete (Technical Report No. 12) as does the U.S. Bureau of Reclamation (Concrete Manual, 6th Ed.). Aggregates containing more than 0.25 per cent. by weight of opal or more than 5 per cent. by weight of chalcedony are noted as causing deleterious reactions. Further, the maximum expansion tends to increase as the particle size of the reactive material decreases for sizes down to the No. 200 to No. 325 fraction.

Examination of the gravels in the Ord River immediately above the damsite has revealed the presence of pebbles of numerous varieties of chalcedonic silica. Sard, prase, agate, opal-jasper, chalcedony, chalcedonic chert and jasper are conspicuous, with the minerals varying in size from sand grains to 6 inches diameter geodes of agate. There appears to be a concentration in the smaller sizes, with the $\frac{3}{8}$-$\frac{3}{4}$ inch range heavily charged. These silica minerals were almost certainly derived from the Antrim Plateau basalts and the Tertiary limestones drained by the Ord River. A noteworthy occurrence is the large deposit of jasper resting directly on basalt a few miles below the junction of the Ord and Negri Rivers.

The intention to use aggregate from the extensive gravel deposits 4½ miles downstream from the damsite should be critically examined in view of the probable contamination by deleterious minerals, both in the form of the quartz minerals and in locally derived phyllite.

There are three methods of avoiding the dangers of deleterious cement-aggregate reaction, (1) a specification limit can be put on the alkali content of any cement used, (2) the second approach is to avoid reactive aggregate by recognizing it and using an alternative source of nonreactive aggregate economically available, (3) part of the cement may be replaced with a very finely ground reactive material—a pozzolan.

The answer to the problem will of course be based on economic considerations. However, in view of the probability of an earth and rock-fill dam type being preferred to a concrete gravity type, much less aggregate will be required, and the expense of washing and hauling aggregate-stone from the downriver deposit may not be justified. Thus the setting up of a small quarry and crusher close to the site on a massive quartzite outcrop would neatly avoid the reaction problem and probably be economically attractive. However, if the river gravels are used, detailed petrological examination and analysis (A.S.T.M. C295) on truly representative samples, along with the commencement of long term concrete tests (at least over two years) appear to be of immediate importance.

Pozzolan.

An examination of published geology of the Kimberleys revealed only one definite reference to a possible pozzolan (Traves, 1955). This concerned an altered rhyolitic tuff, found on the track from Springvale Station to Bedford Downs Station about 4½ miles from Springvale. The outcrops were examined and samples of three different varieties were submitted to the Petrologist of the Geological Survey (Dr. A. F. Trendall) for examination. His report indicated that the tuff was welded and highly deformed, and consequently the grindability would be quite high. Examination of the rock shows that the induration imposed during alteration has developed a very hard compact rock type, so that fine grinding would be a very expensive process and thus the use of this material is probably precluded.

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.

Conclusions.

An earth and rockfill type dam is preferred to a concrete gravity section due to an increased factor of safety against sliding in the western abutment. However, the fact that potential borrow material from the spillway area is largely not suitable as rockfill, and the need for lining the spillway means that there will be no great difference in the cost of the two types of structure.

Due to the presence of clay filled joints, mainly parallel to the downstream pressure of a filled reservoir, the possibility of sliding in the western abutment must be considered high, especially at the phyllite-quartzite contact. Means of reducing this propensity are—

(1) the construction of an earthfill dam;

(2) pivoting the dam axis so that an obtuse angle is made with the western abutment;

(3) the grouting of areas where water has access to sheet jointing;

(4) provision of a double grout curtain in the west abutment;

(5) the possible construction of a key wall.

Further physical tests on the rock will assist in elucidating this problem.

Slight uncertainty exists as to foundation conditions due to incomplete drilling coverage across the river bed. As the joints in this area have been washed clean, some consolidation may be achieved on loading, but this can only be assessed by exposure of bed rock in the river course. Of the three rock types constituting the foundation materials, the quartzite is extensively broken by joints, and in particular the contact with the underlying phyllite is a zone of heavy breakage. A grouting programme for the prevention of leakage should be at least 40 feet deep and should be designed to be largely directed at right angles to the dominant joint planes.

The underground installations as tentatively designed are not in harmony with the rock environment and other layouts can be considered. Further exploration and especially rock testing from a heading is considered essential.

The protection of the northern spillway against scour-grooving and slope failure will mean the provision of a concrete chute, gunited batters, the erection of a training wall on the southern side, rock bolting and suitably designed slopes. The provision of a gated crest will involve further drilling exploration.

All historical and instrumental records so far available indicate that the Ord District is practically aseismic. Installation of a seismograph at Kununurra will doubtless reveal numerous local earthquakes but large tremors are unlikely, and special design precautions are not warranted on the evidence available.

Recommendations.

The following recommendations for future work are made:—

(1) The drilling of a diamond drill hole from the lower adit entrance at a bearing of 260 degrees and angle of depression 45 degrees east, with a probable length of 190 feet. This is desirable especially if a concrete gravity dam-type is adopted.

(2) The drilling of two drill holes at the crest of the proposed spillway, with a probable length of about 200 feet each.

(3) Some test shooting in the proposed aggregate quarries.

(4) Petrological examination of a representative sample of aggregate gravel from the Ord River.

(5) An exploratory tunnel or shaft to be driven to the site of the underground power station and this to become part of the permanent installation. Measurements of modulus of elasticity, residual stress (preferably by the flat-jack method), ground-water level and physical determinations of joints and rocks should be made. Roof bolting and pulling tests would also be of value.

(6) The possibility of sliding in the western abutment should be investigated by physical tests of phyllite and quartzite in the adits, including field jacking tests to determine the forces necessary to induce sliding. Definition of properties such as specific gravity, water absorption, compressive and shear strengths, modulus of elasticity and wetting and drying properties should also be undertaken.

(7) Consideration should be given to a new layout of underground installations with regard to the new knowledge of the gross geologic features such as faulting and jointing, presented in this report.

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THE AVON VALLEY DEVIATION, W.A.G.R. STANDARD GAUGE RAILWAY, SOUTH-WEST DIVISION.

By F. R. Gordon.

INTRODUCTION.

This report concerns certain selected topics from a large compilation of data detailing the engineering geology of the route of the proposed standard gauge railway between Midland Junction and Northam, in particular in the gorges and river valleys of the Swan-Avon River system. The work was done for the purpose of assisting the detailed site drilling and investigation, and was intended to supplement, not to supersede, that examination. However, the drilling results posed nearly as many problems as they solved, and their rationalisation was largely dependent on geological advice.

The engineering works were let as a series of three contracts, in chronological order:—

Contract 1: 15m. 40c. to 29m. 00c. (north of Midland Junction to 2 miles up the Swan Gorge).

Contract 2: 52m. 20c. to 71m.00c. (West Toodyay to Northam).

Contract 3: 29m.00c. to 52m.20c. (The Swan-Avon Valley to West Toodyay).

Geological appraisals were carried out in sections largely corresponding to these contract areas, but equal standards of accuracy were not possible, as survey data was incomplete at the time of the examination. A pegged centre line was available for the 1st Contract section, a line drawn on air

G. S. W. A.

ORD RIVER MAIN DAMSITE No 2

GENERAL GEOLOGICAL PLAN

KIMBERLEY GOLDFIELD

SCALE : 200 FEET TO AN INCH

100 0 100 200 300 400 500

Base sheet from P.W.D. Contour Plan 34959
Plane Table and Telescopic Alidade Survey by J. D. Wyatt and A. J. Smith
May – June 1960, and 1961.

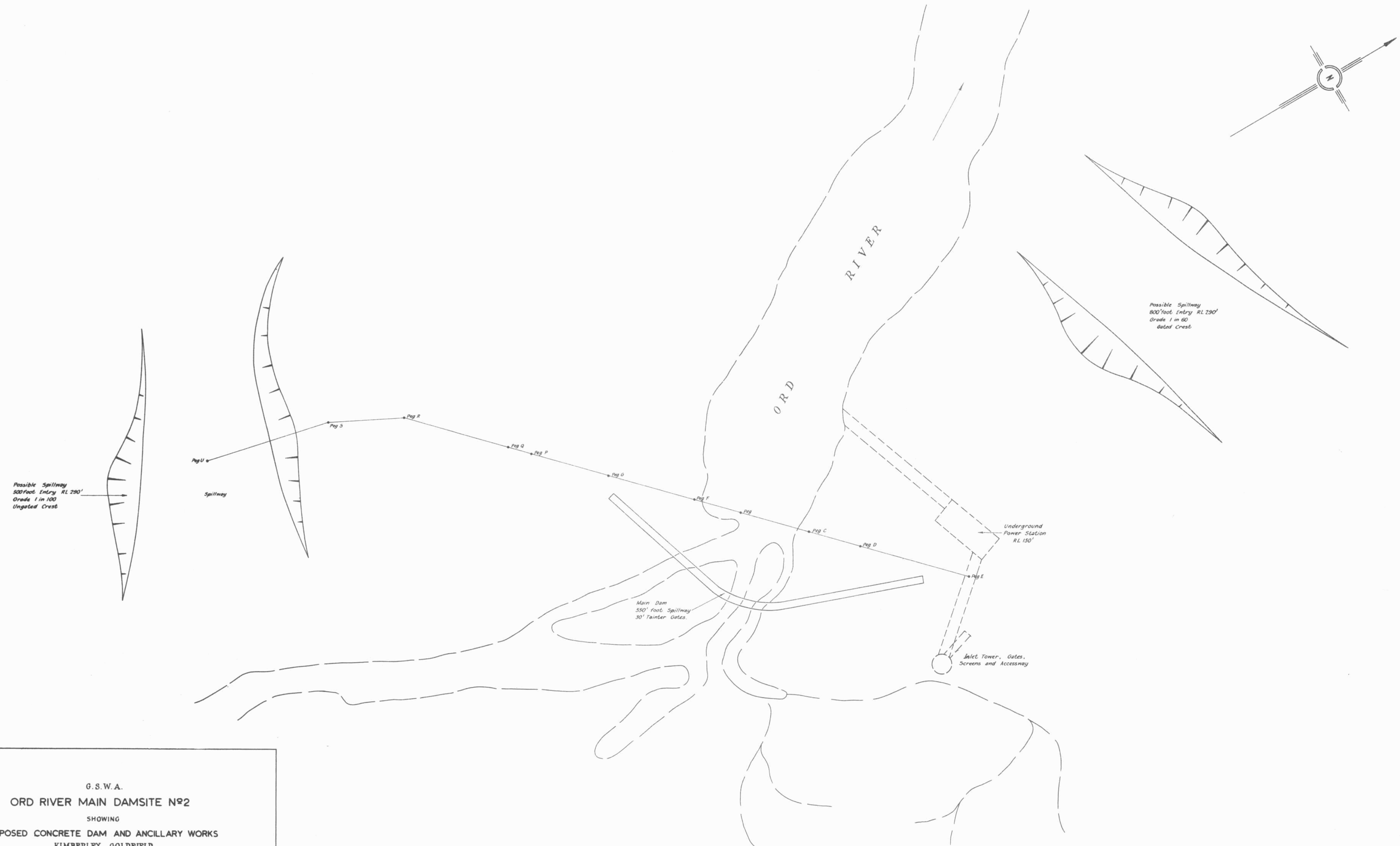
LEGEND

Recent		Alluvium
Undifferentiated Proterozoic		Quartzite
		Phyllite

- Observed or intersected geological boundary.
- Assumed geological boundary.
- Dip and strike jointing.
- Dip and strike bedding.
- Horizontal bedding.
- Dip and strike of overturned bedding.
- Shear or fault.
- Quartz veinlets.
- Direction and plunge of folds.
- Direction and dip of drillholes.
- Probable low angle fault
- Seismic section lines

7283

Revised 18.11.62



G.S.W.A.

ORD RIVER MAIN DAMSITE Nº2

SHOWING

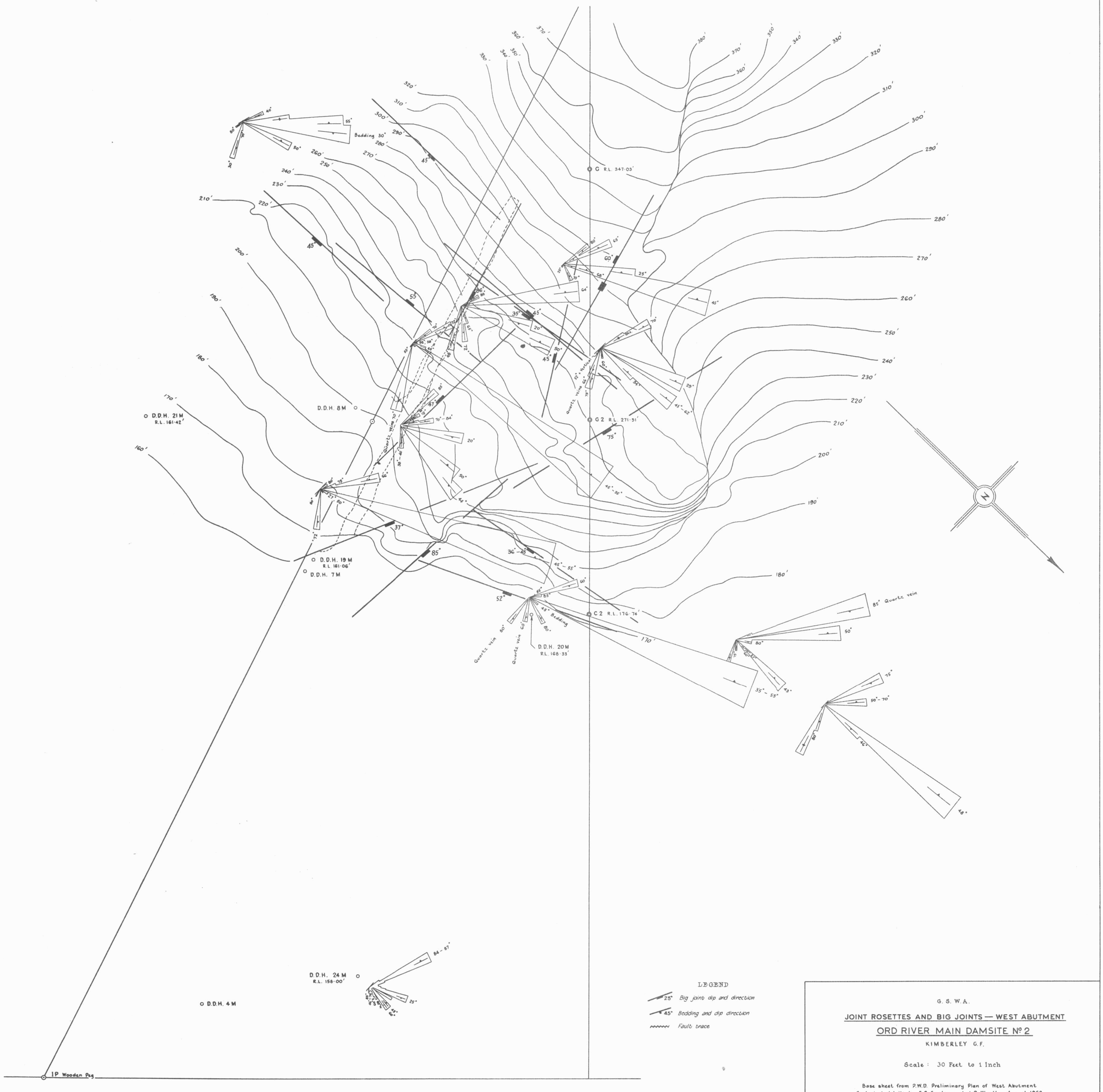
PROPOSED CONCRETE DAM AND ANCILLARY WORKS

KIMBERLEY GOLDFIELD

SCALE : 200 FEET TO AN INCH

100 0 100 200 300 400 500

Based on P.W.D. Contour Plan 34959
As to 30. 4. 62.



G. S. W. A.

JOINT ROSETTES AND BIG JOINTS — WEST ABUTMENT

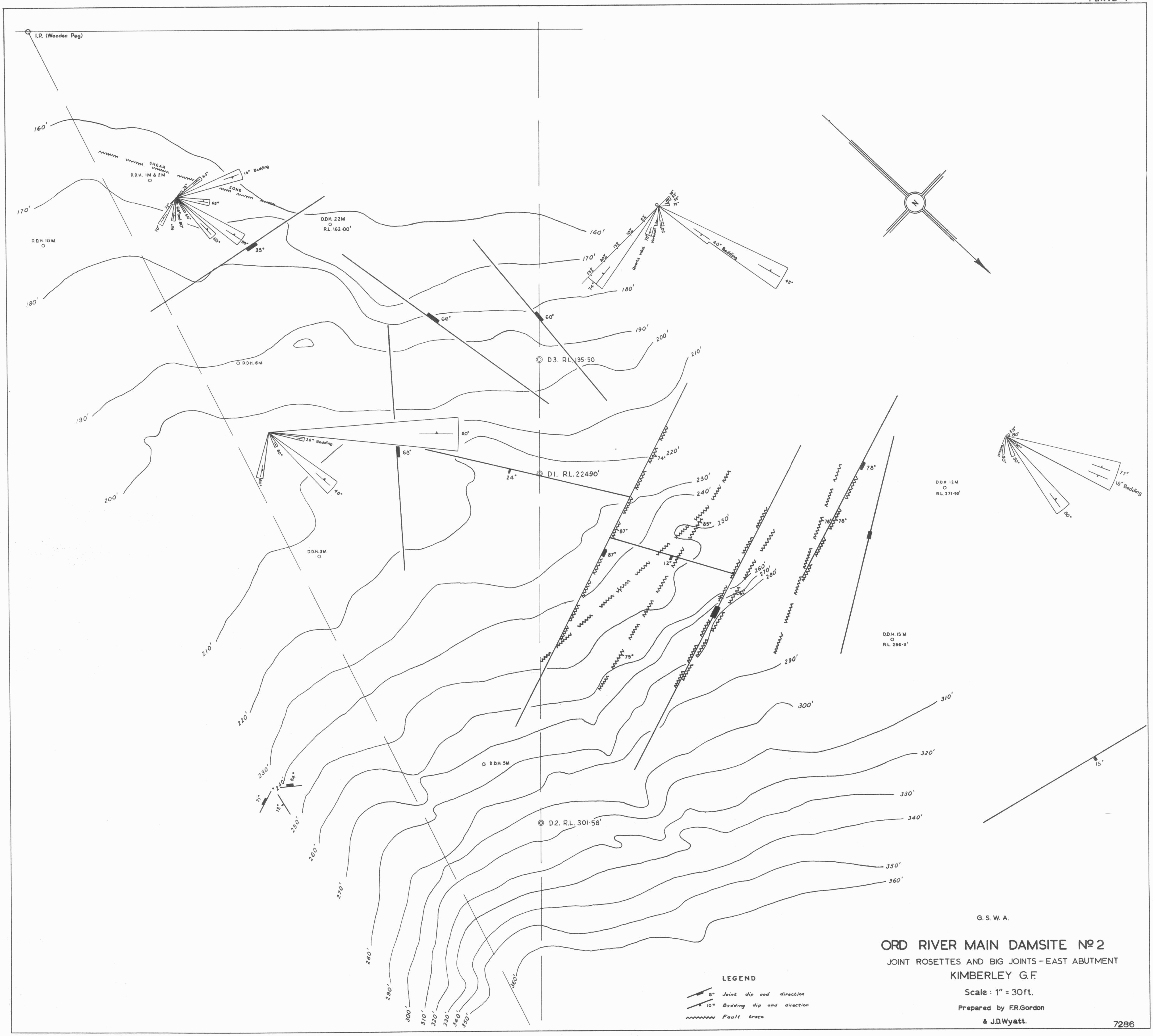
ORD RIVER MAIN DAMSITE No 2

KIMBERLEY G.F.

Scale: 30 Feet to 1 Inch

Base sheet from P.W.D. Preliminary Plan of West Abutment
Geological details by F.R. Gordon and J.D. Wyatt, August 1962

7285



G. S. W. A.

ORD RIVER MAIN DAMSITE Nº 2

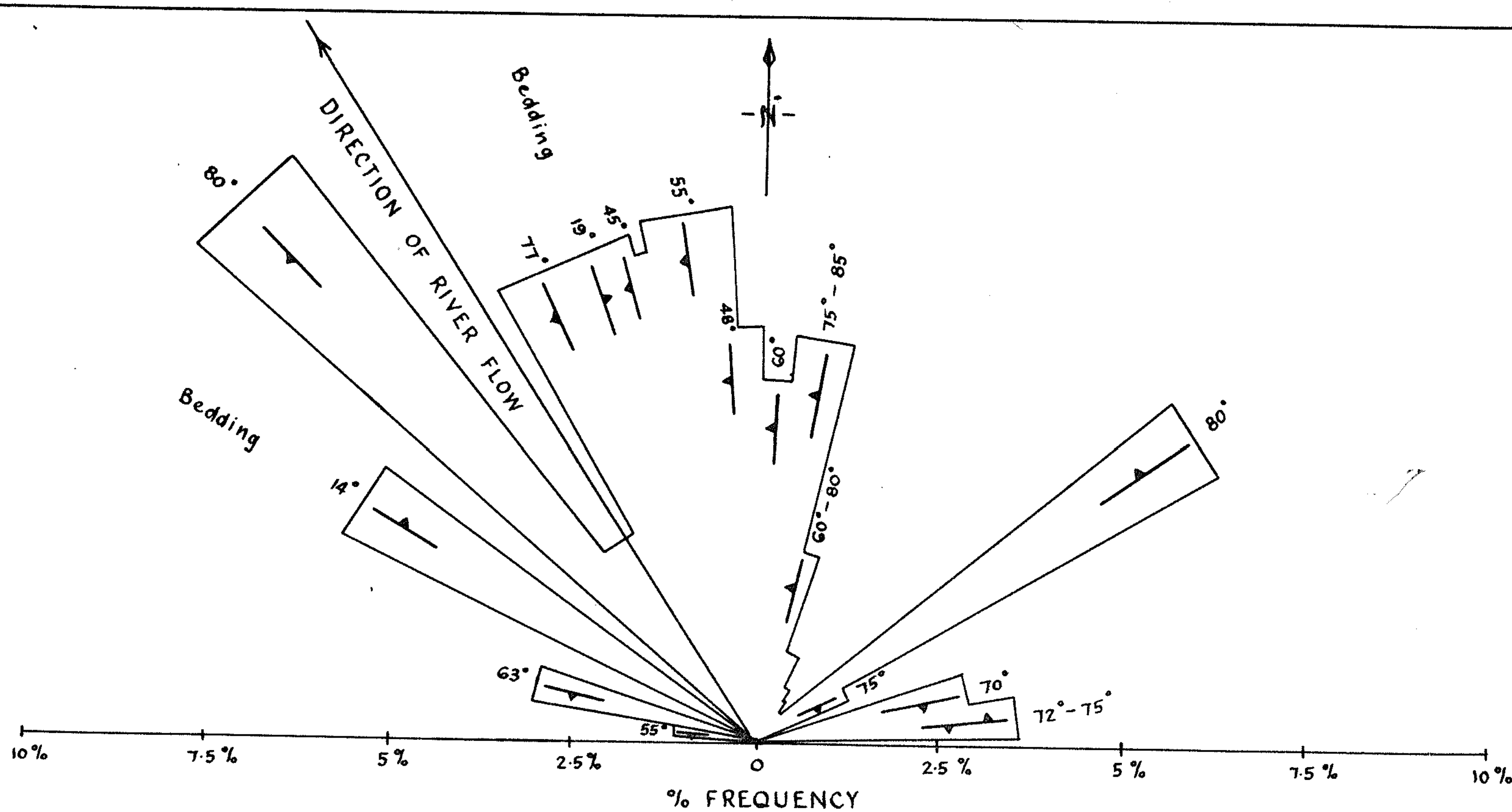
JOINT ROSETTES AND BIG JOINTS – EAST ABUTMENT

KIMBERLEY G.F.

Scale : 1" = 30 ft.

Prepared by F.R.Gordon & J.D.Wyatt.

7286



G. S. W. A.

COMPOSITE JOINT ROSETTE

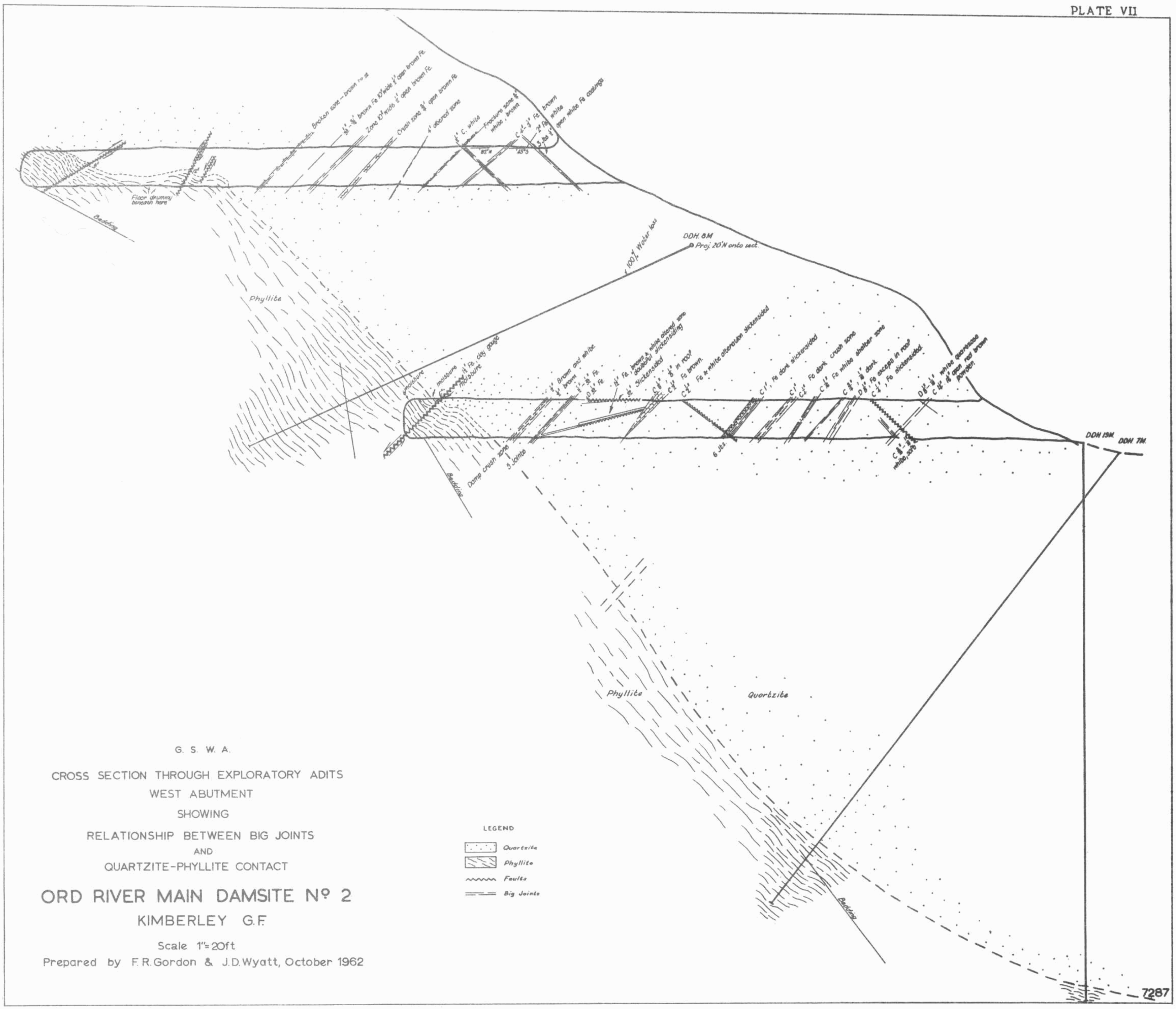
EAST ABUTMENT

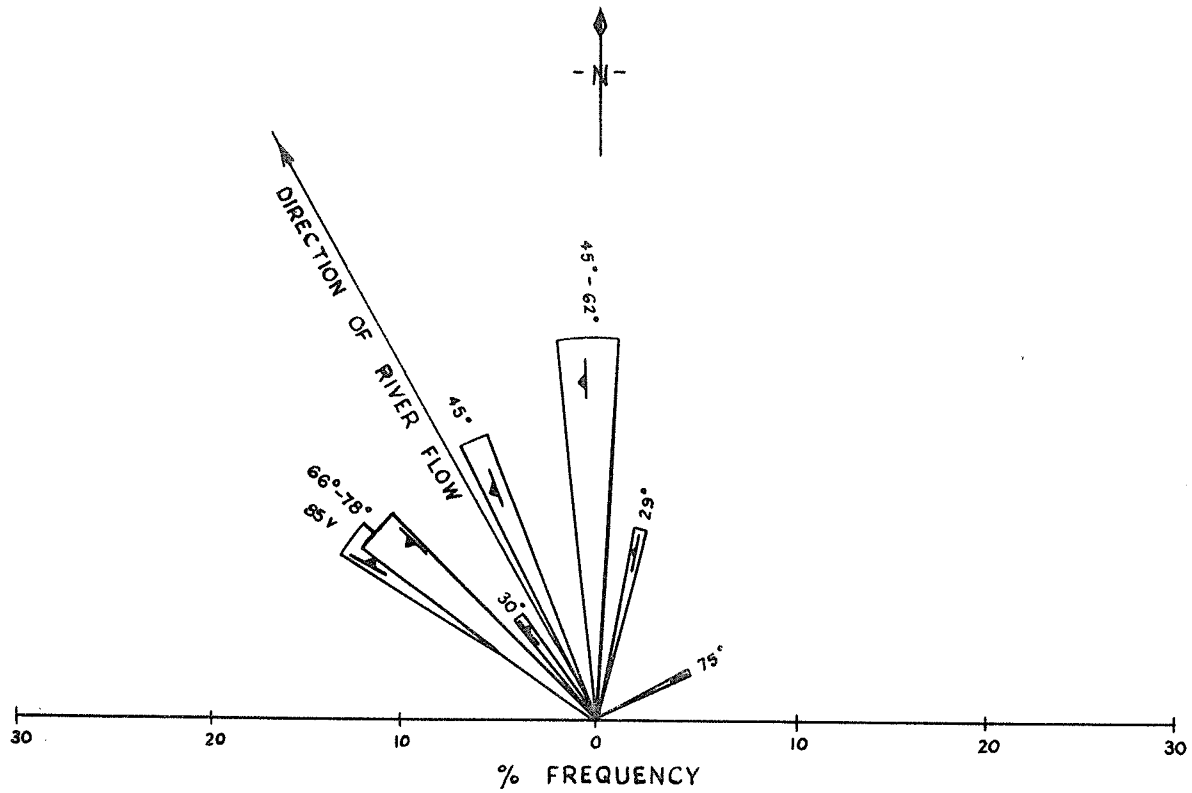
ORD RIVER No. 2 MAIN DAMSITE

KIMBERLEY G. F.

J. D. Wyatt, Aug. 1962.

7288


Broken zone – brown
Crush zone
altered zone
C. white
Fracture zone
white, brown
Fe brown
Fe white
open white Fe coatings
82°N
45°S
Floor drummy beneath here
Bedding
DDH. 8M
Proj. 20'N onto sect.
100% Water loss
Phyllite
moisture
Fe, clay gouge
Brown and white
brown
Fe.
Fe, brown & white altered zone
doubtful slickensiding
Slickensided
in roof
Fe brown.
Fe & white alteration slickensided
C 1', Fe dark slickensided
Fe dark crush zone
Fe white shatter zone
dark
Fe except in roof
Fe slickensided
white quartzose
open red brown powder
white, soft
6 Jts.
Damp crush zone
5 Joints
Bedding
DDH. 19M.
DDH. 7M.
Phyllite
Quartzite
Bedding
G. S. W. A.
CROSS SECTION THROUGH EXPLORATORY ADITS
WEST ABUTMENT
SHOWING
RELATIONSHIP BETWEEN BIG JOINTS
AND
QUARTZITE-PHYLLITE CONTACT
ORD RIVER MAIN DAMSITE Nº 2
KIMBERLEY G.F.
Scale 1" = 20ft
Prepared by F.R.Gordon & J.D.Wyatt, October 1962
LEGEND
Quartzite
Phyllite
Faults
Big Joints
7287



G.S.W.A.

COMPOSITE JOINT ROSETTE

WEST ABUTMENT

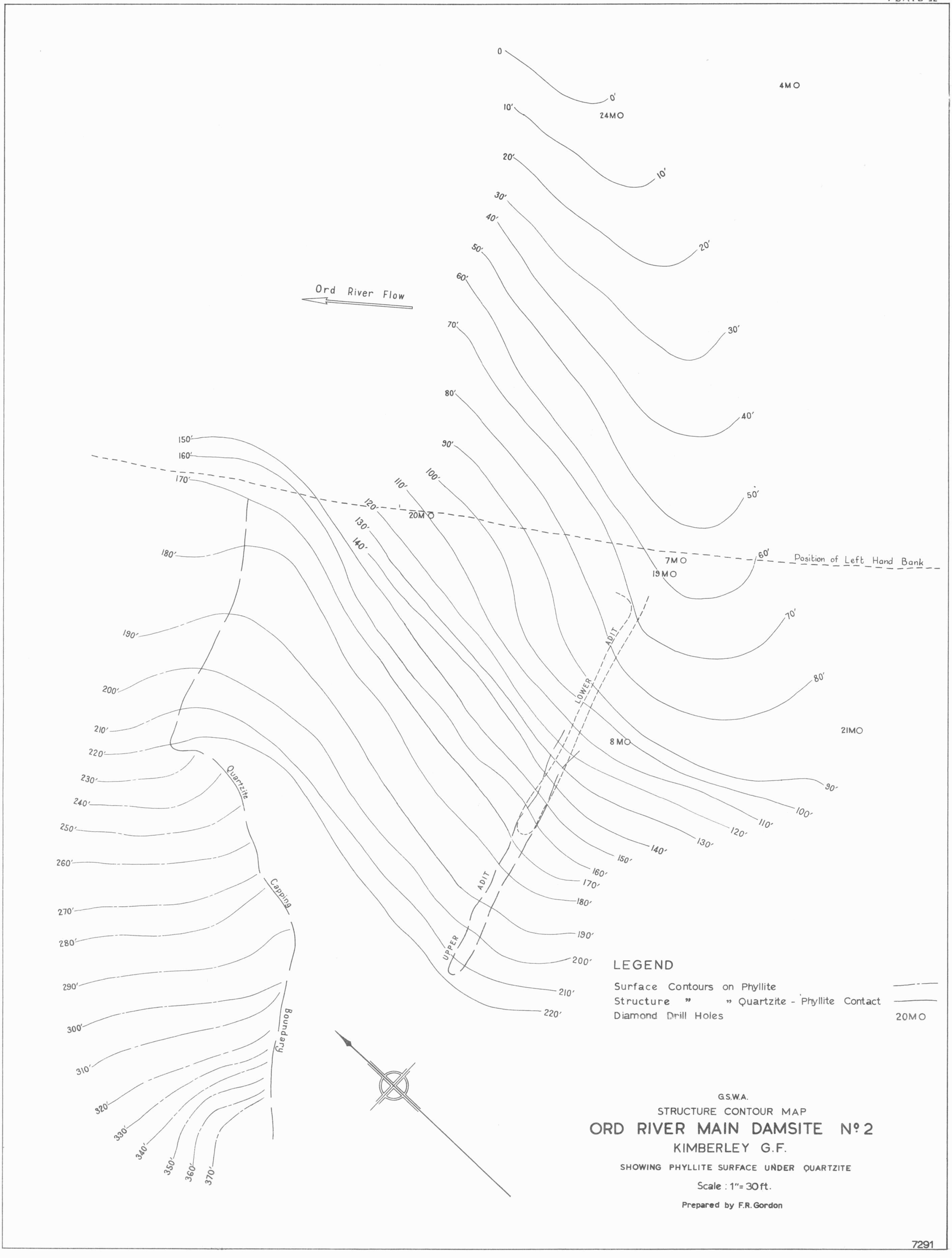
ORD RIVER No 2 MAIN DAMSITE

KIMBERLEY G.F.

F.R.Gordon, Aug. 1962

7289

Top Level of Dam
WEST
EAST
PARTIALLY FILLED AND CLOSED JOINTS
UPPER ADIT
LOWER ADIT
D.D.H. 8M (Proj 8' onto section) Bearing 263° M. Dep. 25°
100% W.L. 14'
Grey/Cream/Red phyllite (oxidised)
Bedding
D.D.H. 19M Vertical
D.D.H. 7M Bearing 260° Mag. Angle of dep 52°
90% W.L. 23'
ORD RIVER
Sand Surface
Silt, sand and gravel
D.D.H. 4M Bearing 243° mag. Angle of dep -40°
D.D.H. 2M. Bearing 237½ M Angle of dep -45°
At 20', 50% Water loss
At 33', 100% Water loss
BROKEN OPEN JOINTS
Ferruginous quartzite 48' Caved
At 55' Caving
BADLY BROKEN AND WEATHERED
D.D.H. 6M. Vertical
FAIRLY BROKEN
OPEN JOINTED
FILLED & CLOSED JOINTS
100% W.L.
D.D.H. 3M Vertical
HIGHLY BROKEN OPEN JOINTED
Bedding Trace
Jointing Trace
Ferruginous and non-ferruginous quartzite
101' temporary W.L.
Quartz injection
151' 0"
100% Water loss
OPEN JOINTS
OPEN JOINTS WEATHERED
Ferruginous quartzite
FILLED & CLOSED JOINTS
Massive, white quartzite
Grey phyllite
most prominent fracture joints
100% W.L.
Bedding and cleavage
Joints trace
Jointing trace
240'
220'
200'
180'
160'
140'
120'
100'
80'
60'
40'
20'
LEGEND
Quartzite
Phyllite
Fault zone
Quartz vein
W.L. Water loss
Core loss or zone of breakage.
G.S.W.A
PHYSICAL DIVISIONS OF BEDROCK
ORD RIVER MAIN DAMSITE Nº2
KIMBERLEY G.F.
CROSS SECTION THROUGH D.D.H.'s 8M, 7M, 4M, 2M, 6M, 3M
LOOKING NORTH – ALONG ORIGINAL CENTRE LINE
Scale 1inch to 30 Feet
Prepared by F.R. Gordon & J.D. Wyatt. Aug. 1962.
7290


Ord River Flow
Position of Left Hand Bank
Quartzite Capping Boundary
UPPER ADIT
LOWER ADIT
4MO
24MO
20MO
7MO
19MO
8MO
21MO
LEGEND
Surface Contours on Phyllite
Structure " " Quartzite - Phyllite Contact
Diamond Drill Holes
20MO
G.S.W.A.
STRUCTURE CONTOUR MAP
ORD RIVER MAIN DAMSITE Nº 2
KIMBERLEY G.F.
SHOWING PHYLLITE SURFACE UNDER QUARTZITE
Scale : 1" = 30 ft.
Prepared by F.R. Gordon

G.S.W.A.

GEOLOGIC SETTING OF UNDERGROUND STRUCTURES

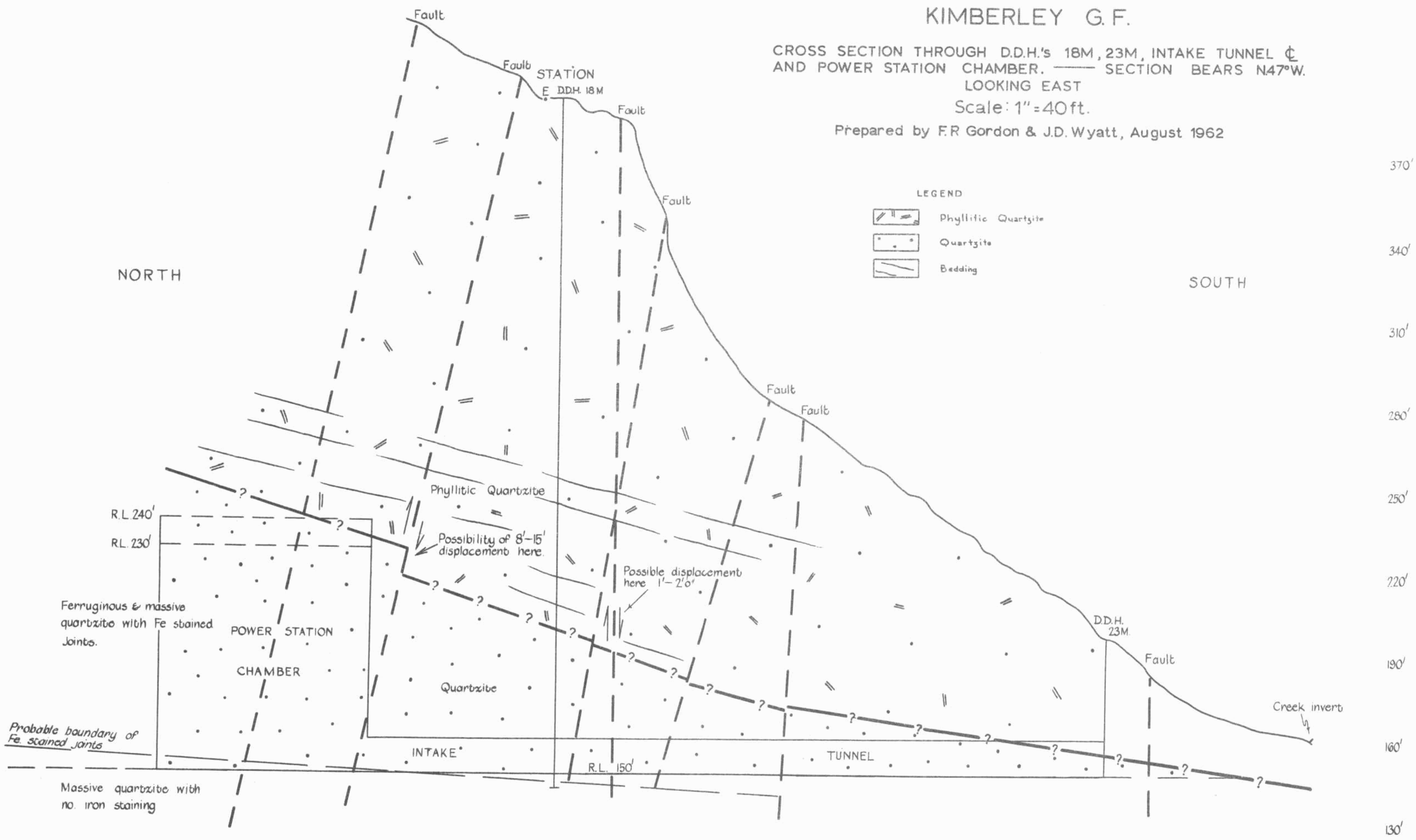
ORD RIVER MAIN DAMSITE N° 2

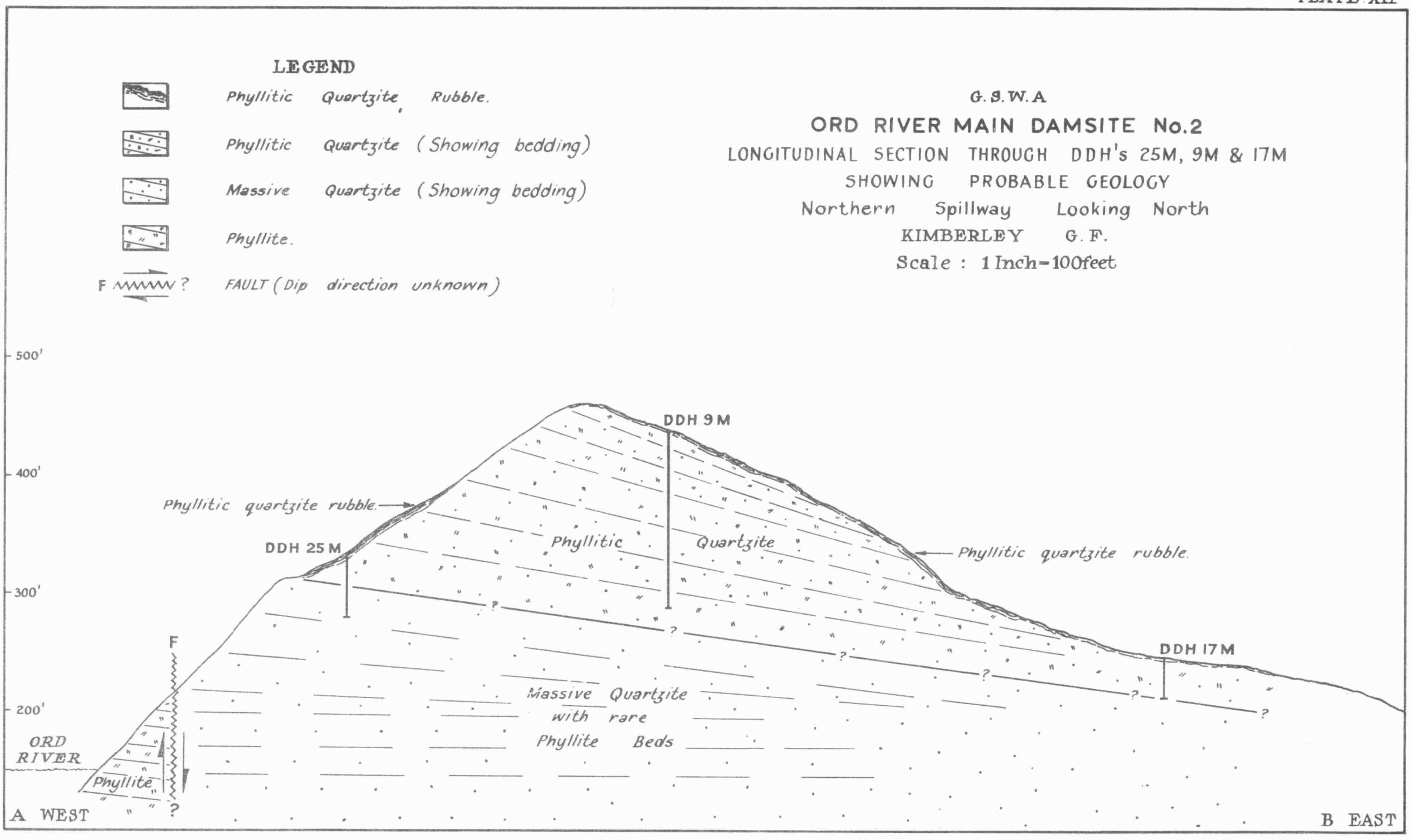
KIMBERLEY G.F.

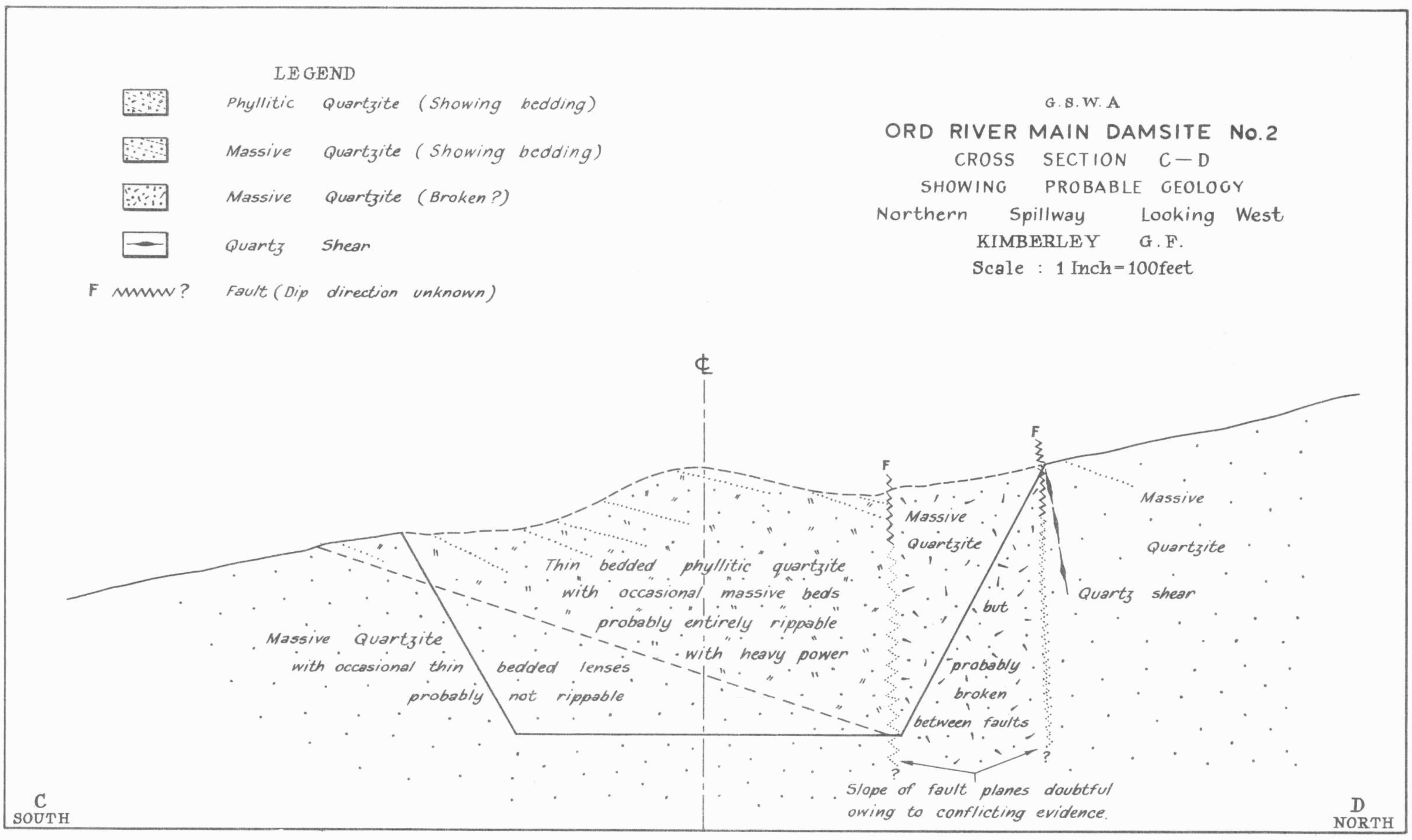
CROSS SECTION THROUGH D.D.H.'s 18M, 23M, INTAKE TUNNEL ℄ AND POWER STATION CHAMBER. —— SECTION BEARS N47°W. LOOKING EAST

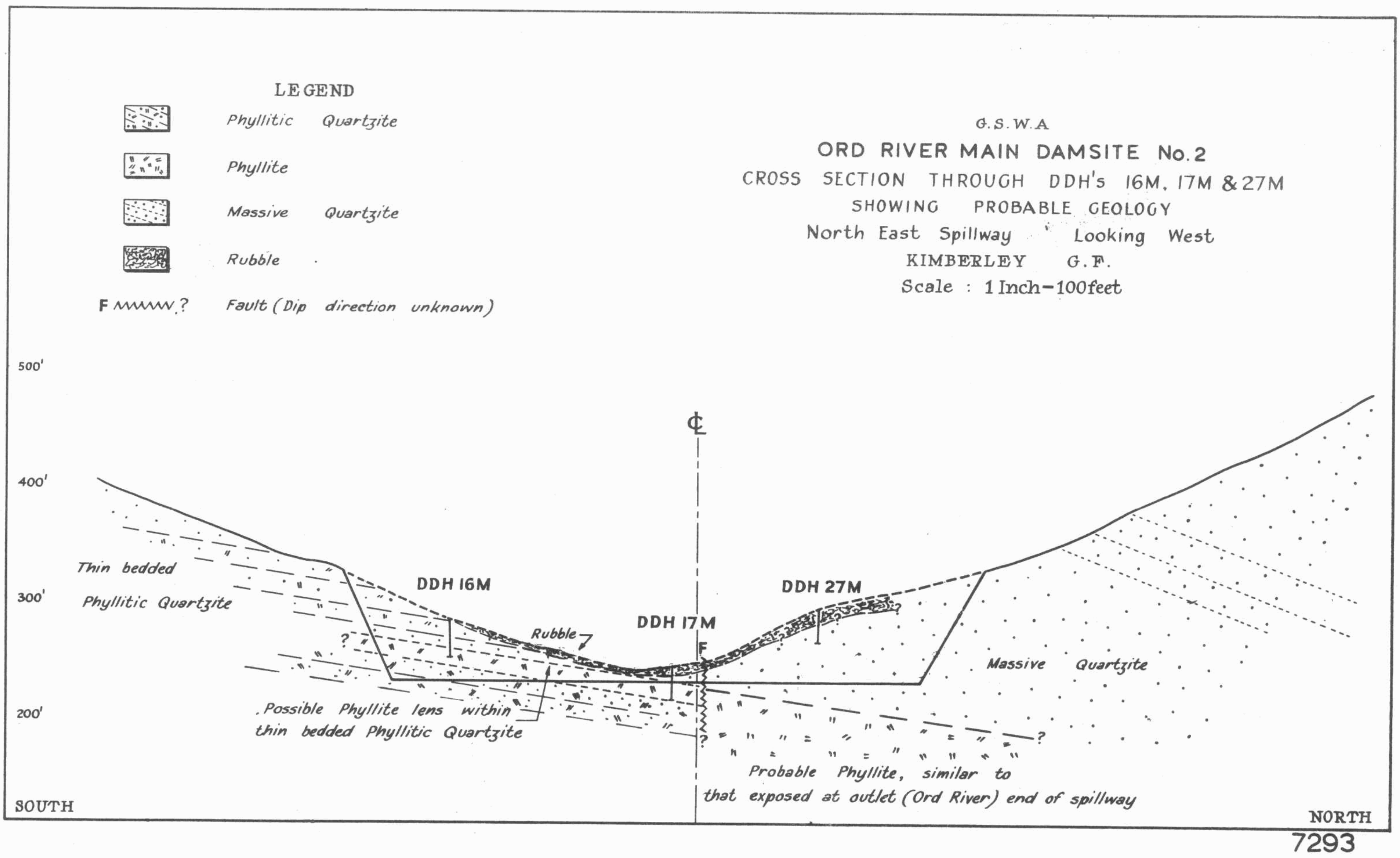
Scale: 1" = 40 ft.

Prepared by F.R. Gordon & J.D. Wyatt, August 1962




LEGEND
Phyllitic Quartzite Rubble.
Phyllitic Quartzite (Showing bedding)
Massive Quartzite (Showing bedding)
Phyllite.
F FAULT (Dip direction unknown)
G.S.W.A
ORD RIVER MAIN DAMSITE No.2
LONGITUDINAL SECTION THROUGH DDH's 25M, 9M & 17M
SHOWING PROBABLE GEOLOGY
Northern Spillway Looking North
KIMBERLEY G.F.
Scale : 1 Inch-100feet
500'
400'
300'
200'
DDH 9M
DDH 25M
DDH 17M
Phyllitic quartzite rubble
Phyllitic Quartzite
Phyllitic quartzite rubble.
Massive Quartzite with rare Phyllite Beds
ORD RIVER
Phyllite
F
A WEST
B EAST


LEGEND
Phyllitic Quartzite (Showing bedding)
Massive Quartzite (Showing bedding)
Massive Quartzite (Broken ?)
Quartz Shear
F Fault (Dip direction unknown)
G.S.W.A
ORD RIVER MAIN DAMSITE No.2
CROSS SECTION C—D
SHOWING PROBABLE GEOLOGY
Northern Spillway Looking West
KIMBERLEY G.F.
Scale : 1 Inch-100feet
℄
F
F
Thin bedded phyllitic quartzite with occasional massive beds probably entirely rippable with heavy power
Massive Quartzite with occasional thin bedded lenses probably not rippable
Massive Quartzite but probably broken between faults
Massive Quartzite
Quartz shear
Slope of fault planes doubtful owing to conflicting evidence.
C SOUTH
D NORTH


LEGEND
Phyllitic Quartzite
Phyllite
Massive Quartzite
Rubble
F Fault (Dip direction unknown)
G.S.W.A
ORD RIVER MAIN DAMSITE No.2
CROSS SECTION THROUGH DDH's 16M, 17M & 27M
SHOWING PROBABLE GEOLOGY
North East Spillway Looking West
KIMBERLEY G.F.
Scale : 1 Inch-100feet
500'
400'
300'
200'
℄
Thin bedded Phyllitic Quartzite
DDH 16M
Rubble
DDH 17M
DDH 27M
F
Massive Quartzite
Possible Phyllite lens within thin bedded Phyllitic Quartzite
Probable Phyllite, similar to that exposed at outlet (Ord River) end of spillway
SOUTH
NORTH

G.S.W.A.

ORD RIVER MAIN DAMSITE No 2

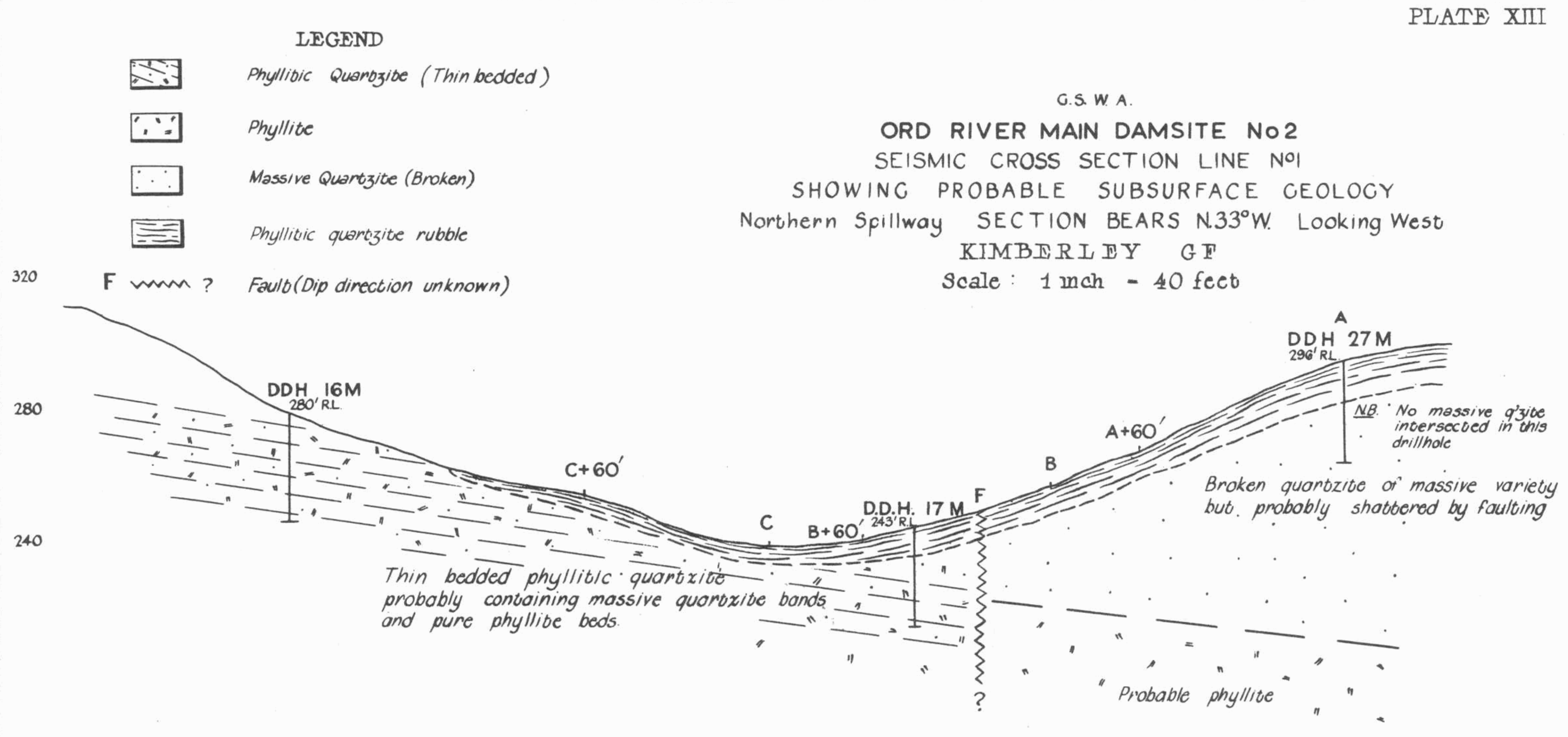
SEISMIC CROSS SECTION LINE No 1

SHOWING PROBABLE SUBSURFACE GEOLOGY

Northern Spillway SECTION BEARS N.33°W. Looking West

KIMBERLEY G.F.

Scale: 1 inch – 40 feet



G.S.W.A.

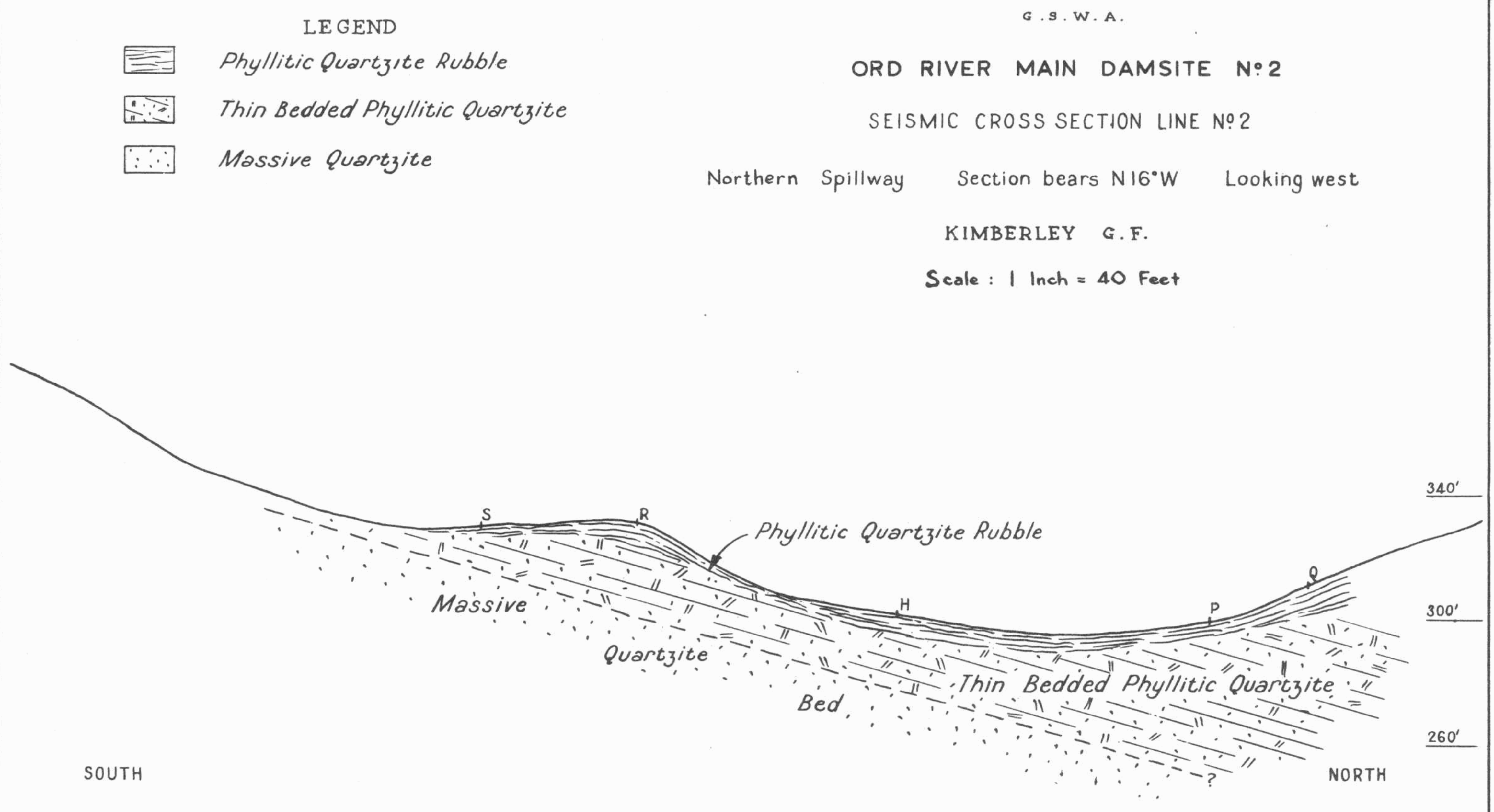
ORD RIVER MAIN DAMSITE No 2

SEISMIC CROSS SECTION LINE No 2

Northern Spillway Section bears N16°W Looking west

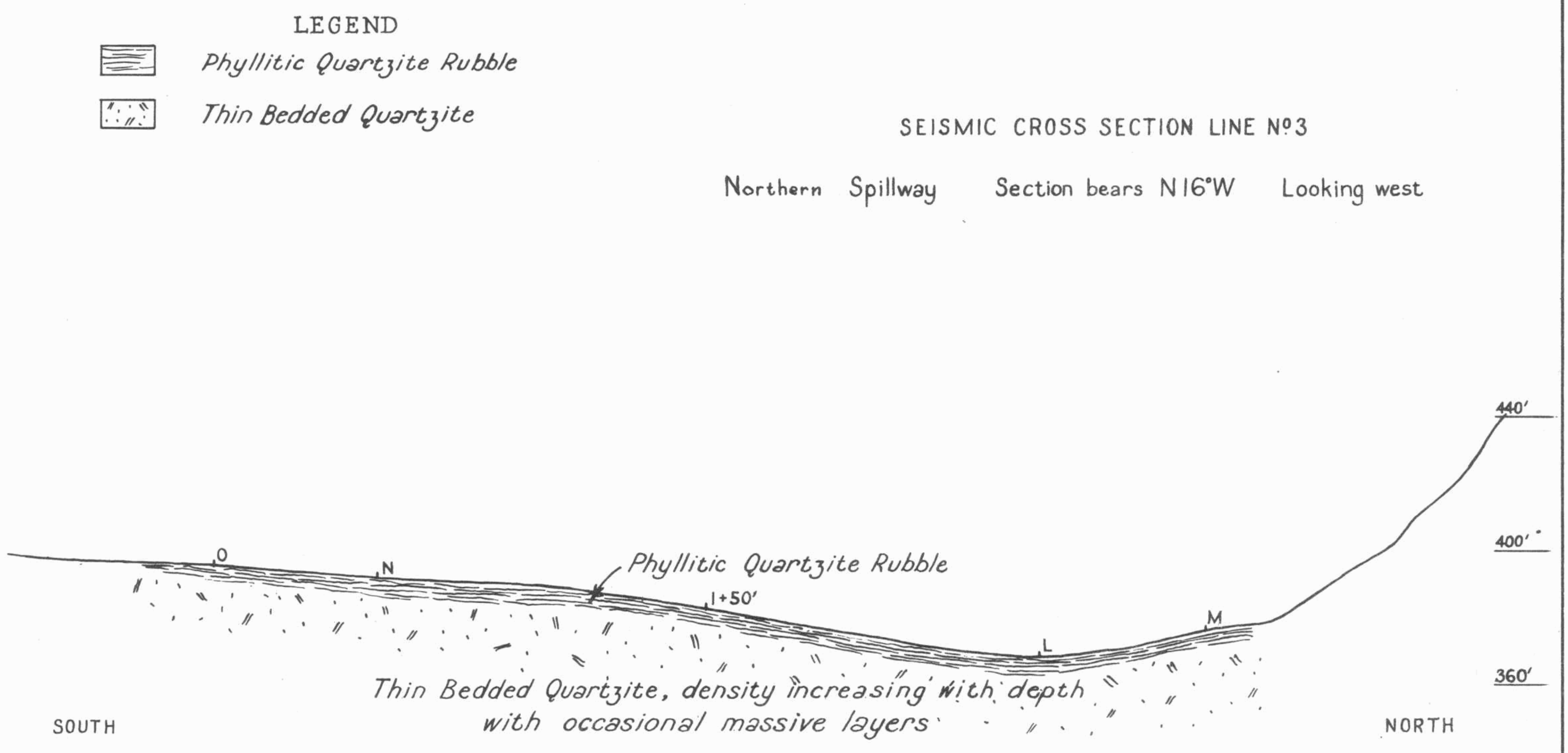
KIMBERLEY G.F.

Scale: 1 Inch = 40 Feet



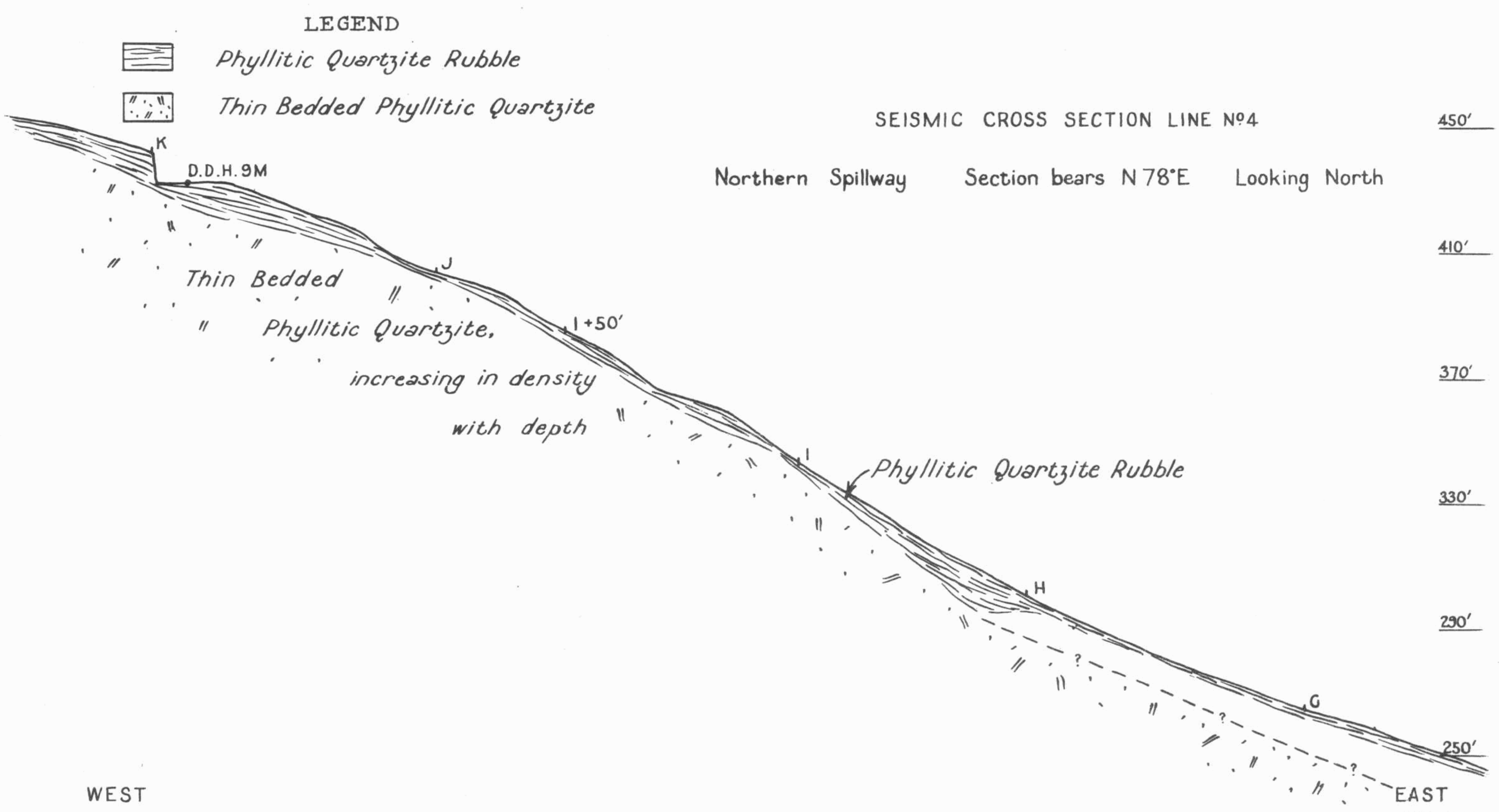
SEISMIC CROSS SECTION LINE No 3

Northern Spillway Section bears N16°W Looking west

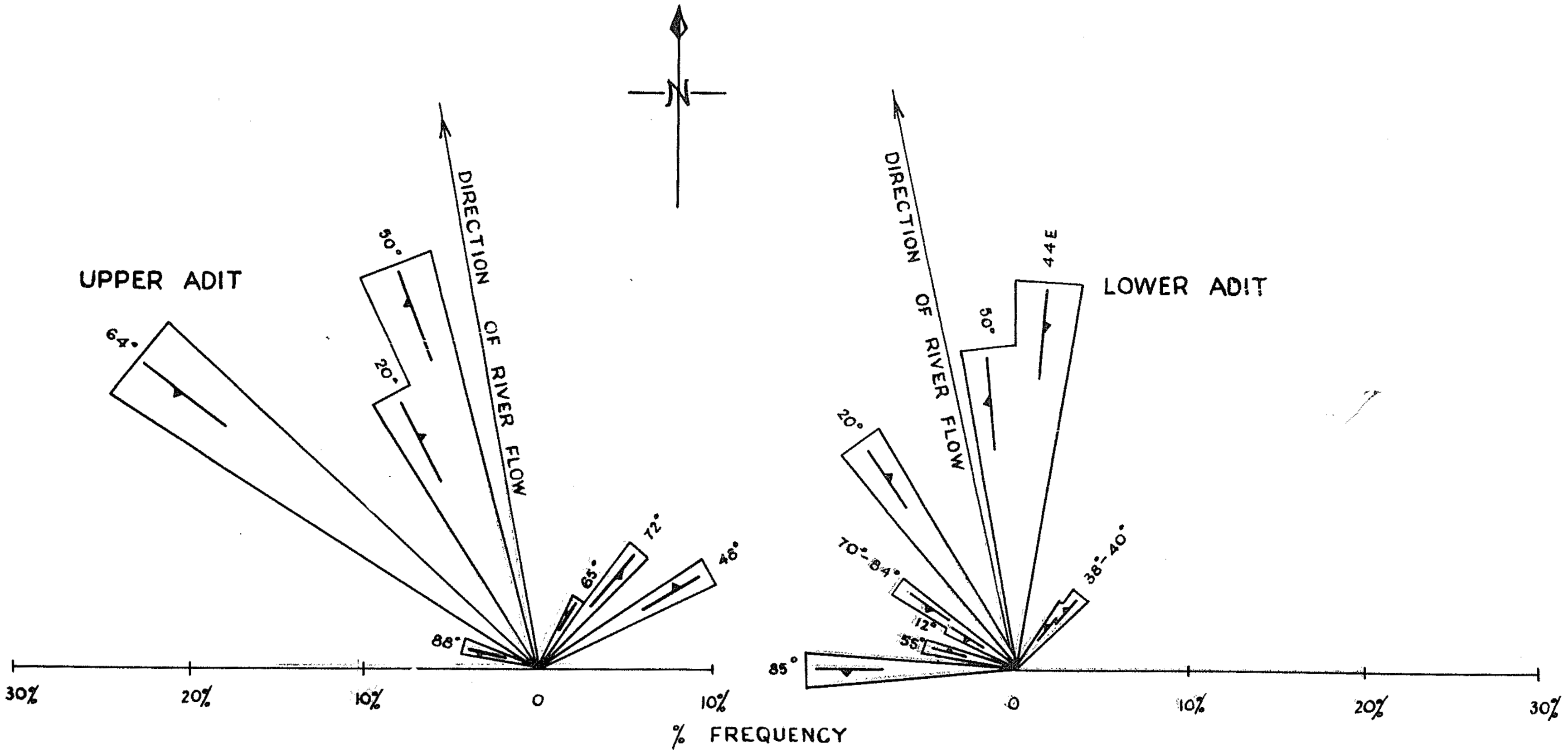


SEISMIC CROSS SECTION LINE No 4

Northern Spillway Section bears N78°E Looking North



7294

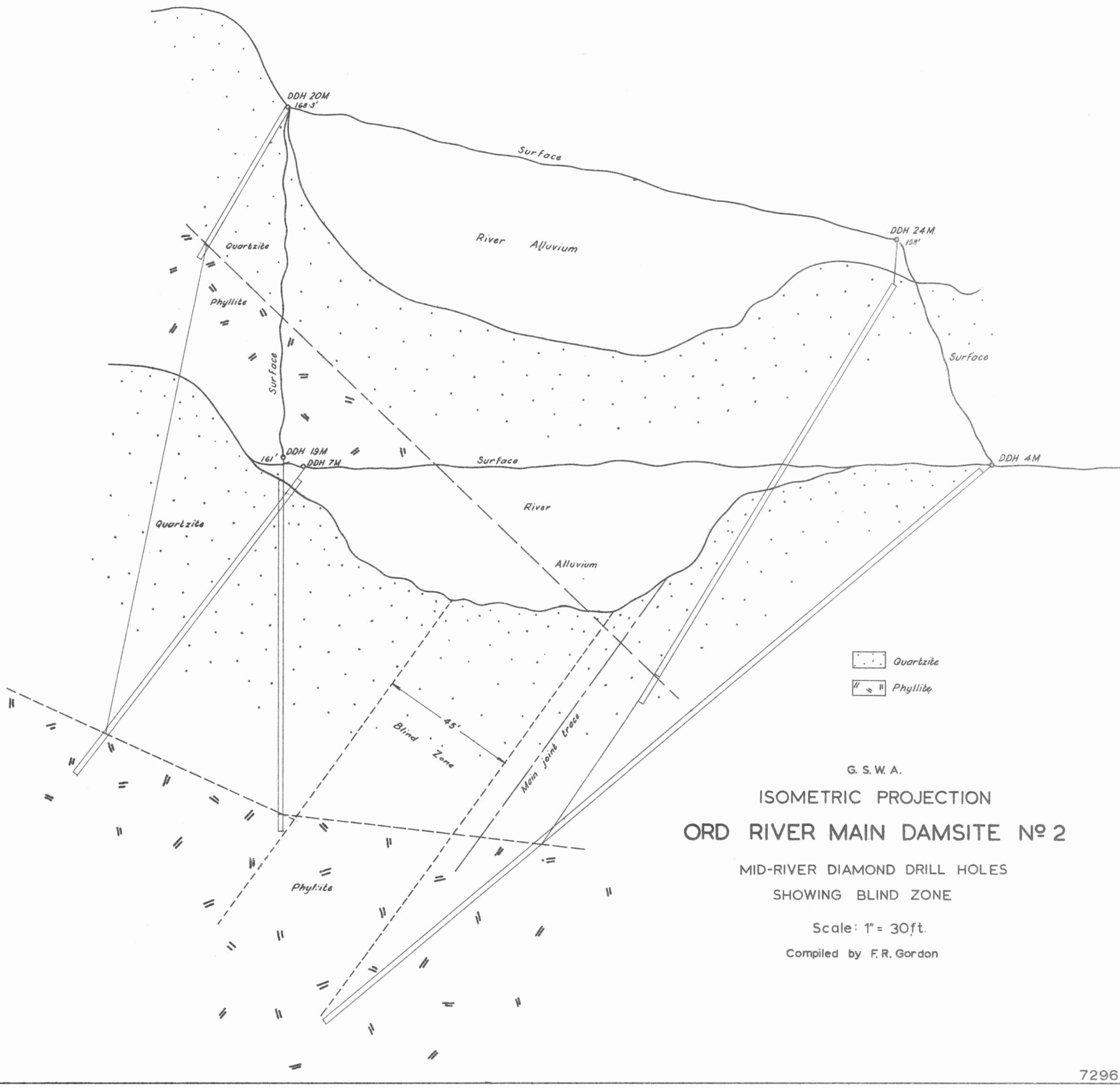


G. S. W. A.

JOINT ROSETTES IN EXPLORATORY ADITS ORD RIVER No.2 MAIN DAMSITE

KIMBERLEY G.F.

J.D.Wyatt, August 1962



G. S. W. A.

ISOMETRIC PROJECTION

ORD RIVER MAIN DAMSITE № 2

MID-RIVER DIAMOND DRILL HOLES

SHOWING BLIND ZONE

Scale: 1" = 30ft.

Compiled by F. R. Gordon

7296

photos indicated the centre line for the length of Contract 2, and a line on a topographic plan along with some survey tangent lines, cut on the ground, was all that was available for most of Contract 3. As this was an area of largely uniform, rugged topography, in places heavily bush-covered, location, and especially level location, was most difficult.

The writer was assisted in the field by Geologist J. D. Wyatt and, for a brief period, by Geologist I. Gemuts. About 4 months was spent in field work, involving route examination and ballast sources.

GEOLOGICAL SETTING.

Historical.

From the 1870s, when the proposal was first made to link the Goldfields to the coast, it was realised that the Swan Valley afforded a unique natural route through the dissected topography of the Darling Ranges. In 1880 the Government Engineer estimated the cost of a railway up the river route as £256,500 as against £190,000 for the direct line over the hills. The cost of the river route was beyond the means of the Government at that time and as a result the 3 ft. 6 in. line was laid down between Midland and Northam by way of the direct line up the Darling Scarp, with very steep grades and tight curves avoiding cuttings. This economy was of course illusory, and with the necessity for long fast trains, this section of the line became a bottleneck, and operation and maintenance costs were extreme.

An agreement between the State of Western Australia and B.H.P. Ltd. for the latter to establish an integrated iron and steel industry at Kwinana required that the State should construct a standard gauge (4 ft. 8½ in.) railway between Kwinana and major iron ore deposits at Koolyanobbing. A parallel agreement between the Commonwealth Government and the State has laid down that standard gauge should be carried from Kalgoorlie to Fremantle. This proposed Standard Gauge Railway with an obligation for flat grades, was of necessity routed through the Swan-Avon Valley, from near Midland Junction to Northam, thus forming the Avon Valley Deviation (see Plate XVI).

Previous Geological Investigations.

Small areas of the Swan-Avon Valley have been geologically surveyed in detail but no large scale or comprehensive geological investigation has been published. However, background information was readily made available by Professor R. T. Prider of the University of Western Australia, and considerable assistance in the investigation of ballast and borrow materials was gained from the maps of the Metropolitan Survey, published by the Geological Survey of Western Australia in 1951.

Physiography.

From west to east the following broad and contrasting elements are found in the Perth metropolitan area:—

(i) Recent sand dunes and beaches.

(ii) Coastal limestone belt.

(iii) Vegetated sand dunes.

(iv) Piedmont alluvials—sand, lateritic gravels, etc.

(v) The Darling Scarp, possibly a fault scarp.

(vi) The Darling Ranges—a dissected plateau about 800 feet above sea level formed on a complex of granites and granite-gneisses, with subordinate epidiorite and quartz dolerite intrusives.

The Swan-Avon River system displays relatively subdued upper valleys (mature) with the valleys parallel to the strike of the rocks, and the structure is followed faithfully except in the gorge area where there is control by the major joint pattern or along shear zones. The principal gorges are thus in west running valleys while the N.W. and S.E. valleys are generally mature. The general maturity of the valley means that a natural transportation is available, and the fact that only one major river tributary has to be crossed (Wooroloo Brook) is of great advantage to any construction. With a fall of about 450 feet in the distance of 60 miles between Midland and Northam, first class grades are possible.

Areal Geology.

There are two main elements to be considered:—

(a) The Precambrian basement complex of the Darling Peneplain (or range) and the Darling Scarp.

(b) The superficial deposits of Tertiary and Recent Age, covering the sedimentary basin of the Coastal Plain, and mantling the weathered Precambrian rocks.

The Precambrian rocks consist of a complex of crystalline igneous and metamorphic rocks, dominantly granites and gneisses, with minor amounts of basic igneous and schistose metasedimentary formations.

Above the 700 foot contour, the Precambrian rocks are covered by a layer, up to 20 feet thick, of massive and pisolitic laterite ("ironstone gravel"). The laterite usually overlies highly weathered country rock, which may extend to as deep as 100 feet before fresh unweathered basement rock is encountered. The sediments of the Coastal Plain close to the Scarp consist of alluvial clays and loams, along with river deposits of sand and alluvium in the Swan-Avon valley.

ROUTE DETAILS.

Introduction.

The geological appraisal of an engineering project such as the Avon Valley Deviation involves the accumulation of a mass of detail concerning depth and nature of overburden over bedrock; the relationship of rock to the railroad structure, the quantity and workability of the rock, areas of undesirable material, and the location of borrow pits or waste areas. In addition, the stability of the materials encountered, both of the back slopes and of the subgrade, and seepage possibilities must be considered along the route. Much of this information can be shown on geological plans and sections, and typical compilations are shown in Plates XVII and XVIII.

More localised topics concern the effect of gross geologic features such as faulting, the existence or possibility of sliding and bridge site appraisal, and certain of these features are detailed in this report. Description of some of these geologic features formed the basis of the Reports on Site Investigations provided by the Consulting Engineers (G. Maunsell and Partners) for the general guidance of tenderers for each of the contract sections.

Rock Excavation.

The cost of rock excavation is one of the few items in modern construction work that has decreased, and this is largely due to the greater power available from excavating machinery and more efficient drilling and blasting techniques. This means that deeper cuts are economically feasible and that cutting for river or route diversion is often preferable to bridging.

The original design proposals for the Avon Valley Deviation envisaged seven major bridges, consisting of three double crossings of the Swan-Avon largely in order to avoid tight curves, and a bridge crossing Wooroloo Brook. Alternative proposals for each of the double crossings were accepted because the low unit cost of rock excavation, accentuated by competitive tendering, revealed substantial economies for deep rock cuttings as opposed to the proposed bridging programme.

Each of the six abandoned bridge sites showed unusual geological features, and some of the wider applications of these are worthy of record.

Bridge Site 1 (Plate XVII).

A large exfoliating boss of granite gneiss forms most of the left-hand-bank of the Swan, with the exfoliation joints giving onion-skin layers of rock about 8 feet thick. The river direction appears to be controlled by a prominent joint-set in the quartzose granite of the bed with the dip about 60 degrees to the North. The right-hand-bank shows a 15-foot high alluvial terrace with horizontally banded sands, silts and humus. No solid rock shows in the bank and the terrace extends for 2½ chains where a granite spur is encountered. However, site investigations have disclosed the presence of a buried river channel 17 feet below the level of the existing channel. This former waterway is about 120 feet wide and about 10 feet of the channel bottom is filled with cobbles and small boulders. This buried river course indicates a Recent 20 feet depression, which is also shown by the drowned flood plains of the Lower Swan.

Bridge Site No. 2 (Plate XVII).

At the No. 2 site the river is running along the strike of a succession of altered sediments, and this southerly direction is also one of prominent shearing and jointing. The metasediments dip at 80 to 85 degrees to the west, and consist of hornblende and mica schists and highly siliceous cherty banded rocks. An exceedingly hard quartzose granite also forms part of the sequence, thus giving considerable relief to the channel cross-section as some of the schists are fissile and easily eroded. The most prominent joint-set in the area is at right angles to the river direction, and although of low frequency, is strongly developed. A notable trough, 40 feet wide, formed by plucking from between two of these big joints, crosses the bridge site near the right hand bank and the effect of the joint trough and the continuously varying rock types across the site meant that care was necessary in locating the five piers in order to avoid differential settlement.

Bridge Site 3 (Wooroloo Brook) (Plate XIX).

The South Gatta or Wooroloo Brook rises some considerable distance inland, and flows through a fairly steep sided valley, while in the last 1½ miles before the Swan Junction there is a fall of 100 feet, which is much greater than the drop in the Swan Valley itself. The stream finally flows through a deep trench with steep sides, contrasting with the flatter nature of the stream bed higher up the valley. At the junction of the Swan and Wooroloo there is a considerable amount of recent alluvium, and the Swan has been partially diverted with the formation of a steep cliff on the west bank.

The Swan flows in a remarkably straight course above the Wooroloo Junction, and a pool of considerable length remains during the summer. This is obviously in a sheared zone, easily eroded.

Drilling Results.—Four drill holes were put down at pier and abutment positions with a Gemco drill and a further hole was positioned between the Midland abutment and first pier in order to complete the site appraisal. Condensed logs, derived from the driller's log and examination of the core recovered, are given here:—

(a) *Borehole 25.13.1:*

0-10 feet: Boulders and clay (recent stream action).

10-20 feet: Clay, sand gravel.

20-51 feet: Boulders, stone, sand, in old river deposit some boulders highly weathered.

(b) *Borehole 25.13.8:*

0-10 feet: Cobbles, clay and gravel, recent stream deposit.

10-19 feet: Clays, sandy and gravelly.

19-26 feet: Clay sand with weathered stones.

26-30 feet: Clay with sand and gravel.

30-45½ feet: Stones up to 1 ft. 6 in. in clay and sand—old river deposit.

45½-50 feet: Highly weathered granite.

(c) *Borehole 25.14.6:*

0-8 feet: Surface boulders in stream bed.

8-15 feet: Clay.

15-34 feet: Sand with organic fragments.

34-35 feet 9 inches: Schist lens.

35 feet 9 inches-44 feet: Granite, slightly weathered.

(d) *Borehole 25.16.1:*

0-25 feet: Cobbles, sand and clay.

25 feet: Granite shattered near surface, improving immediately to solid rock.

(e) *Borehole 25.17.6:*

0-23 feet: Clay and sands.

23-30 feet: Weathered dolerite.

30 feet: Relatively fresh dolerite.

Foundation Appraisal.—The local geology in relation to the original bridge site is shown on the accompanying sketch plan and section (Plate XIX). The most striking feature is the fact that the shear zone controlling the Swan Valley and the granite/gneiss junction passes through the proposed bridge site. This is reflected in the great depth of alluvium in the bores at the Midland end. Undoubtedly this represents an older buried channel of the Swan, as the Wooroloo is rock bound about 100 yards upstream. The Swan was displaced from this channel by the debris brought down by the Wooroloo, and also the base level of erosion must have been lowered by a depression of the order of 20 feet. This accords with the fact that there is a buried channel at the 1st Bridge site, 17 feet below the existing stream bed.

There would be no particular merit in moving the bridge along the proposed line as heavy cutting costs would be involved to realign the Wooroloo Channel in the dolerite upstream. Shifting the bridge up the Wooroloo was undoubtedly the best solution, and this was adopted. If the bridge had been left on the original alignment, steel H piles would have been necessary to obtain foundation in the old river levels. The possible foundation depth at the new site may vary between 30 feet and surface exposures. Steel H piles would undoubtedly penetrate or turn the weathered granite cobbles as disclosed in the cores, but the dolerite boulders may fill the web or turn the point of the pile.

Debris Slides.

There is an area of substantial cut commencing at the 27m. 01c. and extending through to 27m. 13c., with a maximum cut of 26 feet at 27m. 03c. The sections at the beginning of the cut area show a vertical or overhanging rock cliff above the river channel, then steep debris slopes (35°) which rise to a flat terrace, showing rock exposures 120 feet above the river. From 27 miles 5 chains to 7 chains there are signs of slow movement of the natural soil and rock detritus above granite bedrock of the debris slide type. In determining the stability of this area during and after construction, the critical factor is the depth of debris over granite, as the formation will be stable if the debris is no thicker than 10 feet, but unstable for greater thickness (Figure 8). Probing with hand augers proved ineffectual, and in an attempt to provide some data for design purposes a traverse was made with the Model R117 Seismic Timer. This work indicated a spoon-shaped depression in the granite with a maximum depth of 25 feet at 23 miles 4.5 chains, rising to about 15 feet from the surface, 60 feet on either side of that point. Seismic velocities indicate that there is about 10 feet of weathered granite at the Midland end, but this disappears in the middle of the rock depression. The bulk of the material filling the channel appears to be slide debris and the products of rock weathering under a soil and rubble cover. It would appear likely that the granite rises further, and almost reaches the surface in either direction.

On the basis of this evidence it would appear that only a small section of the cut would require special remedial treatment other than battering back and the provision of a bench in the solid. The area where the downhill part of the cut is entirely in debris, and thus the roadbed formation is liable to movement, may be from 23 miles 2 chains to 23 miles 5 chains. The most suitable form of protection would appear to be the provision of a rock buttress retaining wall, keyed into the solid rock.

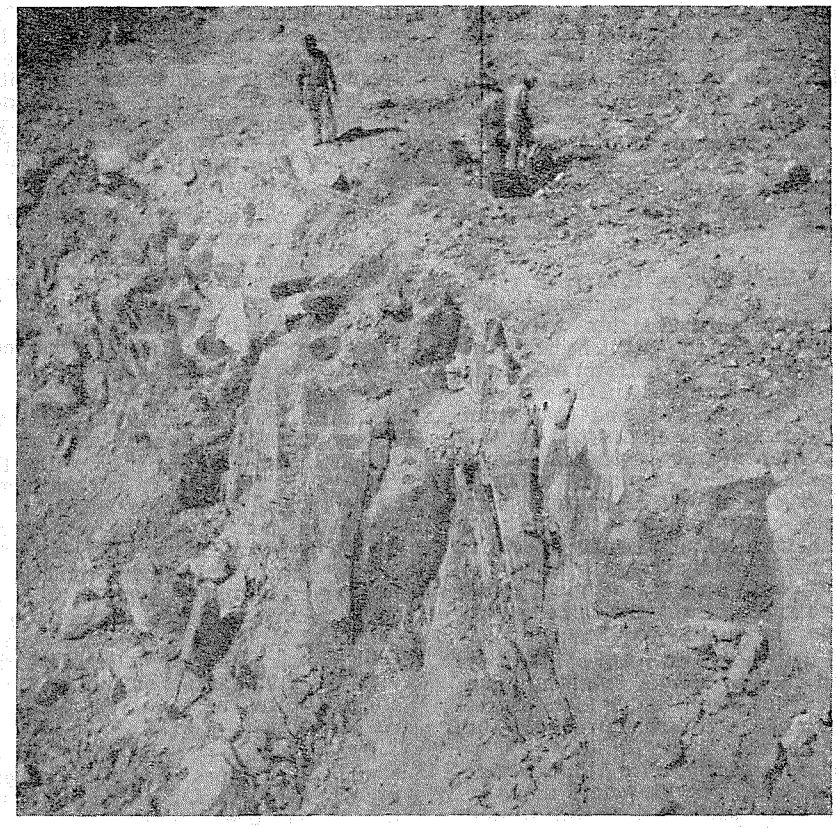


Fig. 8. Rock joints at 21m. 17ch., Avon Valley deviation.

Rock Cuttings.

The shape of a cutting in rock is governed by the required depth of cut, the local topography, and the required angle of slope. Soil-mechanics tests will readily give permissable slope angles for unconsolidated materials, whereas it is universal practice for slopes in rock to be decided empirically. The drawback of this procedure is that the inherent stability of the slope, and thus the degree of safety is not known. To keep a cutting absolutely safe, the high cost of flat batters must be faced. On the other hand if money is to be saved by using steep slopes, the risk of some undefinable danger is encountered. The newly developing field of rock-mechanics has now made it possible for rock to be described as a material with nearly the same accuracy that soil-mechanics achieves with clay and sand.

Rock stability and permissable slope angles of open cuts are governed by 9 main considerations:—

(1) Rock type.
(2) Rock strength etc.
(3) Stratification and foliation etc.
(4) Mechanical fragmentation etc.
(5) Chemical weathering.
(6) Positional relationship between the slope plane and structural elements.
(7) Time.
(8) The presence of water in joints.
(9) Vibrations during construction or from traffic.

The most important element is mechanical fragmentation, such as small joints, big joints, faults and fractured zones, and the mechanical behaviour of the rock is determined largely by the type, size and extent of these small tectonic elements, the condition of their surfaces, the width and filling of gaps, but most of all by their direction and location. The stability of rock formation is largely dependent on their structure, and only to a small extent on their material.

The various major rock cuts along the first and third contract sections have been examined, and an attempt has been made to assess the permissable slope angle. The final consideration of course, will be the engineer's decision on the rock face as exposed, but the estimated angles are applicable for design purposes. A firmer basis of calculation would have entailed the use of cored drill holes to enable an in situ view of the jointing and a detailed examination of fresh rock immediately on removal of overburden and cover. Additionally, the use of a seismic timer would also possibly assist in the determination of the degree of weathering and of joint penetration into the solid.

Two examples of the nature of the assessment involved are given.

(a) Rock cut from 22 miles 6 chains to 22 miles 19 chains, (old chainage) with a maximum cut of 41 feet at 22 miles 13 chains. The rock is characteristically a quartzose granite but some differences will be encountered along the cut, as minor schist and chert bands are locally prominent. Weathering extends largely along the joints which appear to be open well into the rock mass, and as all the vertical joint faces are iron stained, a certain amount of seepage may be expected in a wet season. The joint system as shown in Plate XX is fairly simple as the major joints are vertical or close to vertical. The dominant joint is at 35 degrees to the centre line and this is parallel with the foliation or major trend, while the second major set is at right angles to this direction with the dip ranging from 85 degrees to vertical, i.e., 80 degrees or vertical apparent dip when turned into the excavation. The third joint set is horizontal, and has rather feeble incidence and persistence, in marked contrast to the other two sets.

The degree of disintegration by chemical weathering is not high, but the rock is intensely jointed thus the rock may be classified on the third scale of breakdown. The interaction between the joints is negligible as they are at right angles, and the compound resistance of the rock will be of the steps-of-joints type where most of the breakage will be along the pre-existing 105 degree joint, with short connecting fractures in the solid rock. In effect the permissable angle of slope may be as high as 75 degrees overall, and a factor of safety may be introduced by the cutting of two benches, with the rock slope between the benches near the dip of the main joint into the excavation.

The joint intersections tend to produce tabular blocks of rock nearly face-on to the length of the cutting, and shooting will be necessary for excavation.

When the alignment was altered to eliminate Bridges (1) and (2), a considerable amount of rock cutting was planned, including a new major cutting through the initial scarp, and lengthening and intensification of the cut formerly commencing at 22 miles 6 chains. This new work was not included in the route appraisal, and it was only after construction was well advanced that it was geologically examined in detail. The cutting extends from 21 miles 75 chains to 22 miles 14 chains involving a maximum cut of 85 feet at 22 miles 75 chains.

On opening up it was obvious that rock types other than granite were involved, and as highly jointed and weathered metasediments were revealed in the Midland end of the cut it became apparent that the proposed 1 : 4 batters would be too steep. The geology as exposed in the excavation on 17th December, 1962, revealed that from 21 miles 75 chains to 22 miles 6 chains the cutting would be in highly broken and weathered schists and cherts with granite-gneiss from 22 miles 6 chains to the end of the cut. The granite is in effect the same rock whose properties have been detailed from the abandoned cut 22 miles 6 chains to 22 miles 19 chains (old chainage). Thus the batter slope may be as steep as 75° as the slightly altered direction means practically the same spatial relationship between the joints and the cutting.

The cherts and schists are in places intensely jointed and sheared with breakages resulting from faulting and this, combined with the high degree of chemical weathering, has effectively reduced the rock strength. Against this is the fact that ridges of resistant quartzose rocks form topographic highs or spurs and these provide some measure of added stability. The combined chemical and mechanical breakdown indicates properties of the 5th order, and this in conjunction with the major joint (75°-80° at 45° to the cutting) indicates that the batter slope should be no steeper than 55° or $\frac{3}{4}$: 1.

There are some practical difficulties in having two different slopes in the cutting involving a transition but the appearance of a cutting briefly seen from a train, matters less than considerable economy of construction.

(b) Rock cut from 22 miles 67 chains. to 23 miles (old chainage) with a maximum of 24 feet of cut at 22 miles 78 chains. This cutting is situated on a curve and a considerable portion is traversed by a lens of basic material which lies along the line and then crosses it, over a distance of 5 chains. Otherwise the cut will be in granite-gneiss, and there is a cover of up to 10 feet of rock rubble over both types of rock. The dark coloured basic material has been less affected by weathering than the surrounding granite. The major joints in the basic lens are at 30° and 120° to the direction of the railway, and dip from 80° to 90°, and this would mean joints dipping at about 70° into the cut. In the deepest part of the cut, in granite-gneiss, the main joints are along the line and at right angles to it, while a minor joint at 25° to the line dips towards the river at 75° which would mean a 57° dip into the cut. As the major joint along the line has an angle of between 75° to 90°, it would appear that the limiting factor is the 57° into-the-cut-joint which shows openings of up to $\frac{1}{8}$ inch, is discontinuous, shows faces about 4 feet long and occurs once every 4 feet. There will be no inter-action between this fracture and the major joint at 75° into the cut, as the latter dips away from the river i.e. uphill, while the minor joints dip in the opposite direction. There will be interaction with the major joint at right angles to the line, as it dips 15° along the line and some rock falls are to be expected from wedges of rock of small size. It is considered that the type of fracture to be expected would be steps of fracture between pre-existing joint planes. The resistivity figure of the bonding shows that the permissible slope angle is of the order of 60°.

Abandoned Bridges Nos. 4, 5, 6 and 7.

Bridge Site 4.—Bridge Sites Nos. 4 and 5 are situated across a meander of the Avon in the vicinity of West Toodyay. The existing channel is in the middle of the proposed 700 feet structure of Bridge 4 and this is near the highest point of the bedrock surface, as under the Midland abutment there is a buried channel 50 feet deep and at least 250 feet wide, with boulders and cobbles in clay along with sands and clays filling to the surface. At the Northam end too, there is a former channel, now buried, with a depth of 22 feet and a width of 175 feet.

Bridge Site 5.—Here there are depressions in the granite-gneiss surface that correspond to former river courses—22 feet deep under the Midland Abutment, 50 feet deep in mid-channel, and 30 feet deep under the Northam abutment, although the drillers' log for the latter would fit for a decomposed granite sequence as ambiguous terms such as "clay" and "gravel" are used.

Bridge Site 6.—Four miles east of Toodyay the Avon swings in a large "S" bend round two parallel quartzite spur ends, with the river direction at either end faithfully following the strike direction of easily eroded mica-schist. The section across Bridge Site 6 is shown in Plate XX, and the succession is of soft quartzite, weathered to 40 feet; a band of hard quartzite forming a strike ridge; weathered mica schist; a fault zone; weathered hornblende schist; then soft mica schist followed by quartzite, forming the hill beyond the Northam abutment. Strong weathering in the schists has extended at least as deep as 60 feet, and the high angle of dip of the various layers (60°-80°) means that conditions are varied in the extreme.

Bridge Site 7.—This site exhibits a varied succession of rock types presenting no great foundation problems, however, there is the usual buried channel, 40 feet deep, in the centre of the site.

BALLAST AND BORROW MATERIALS.

Requirements for Railway Ballast.

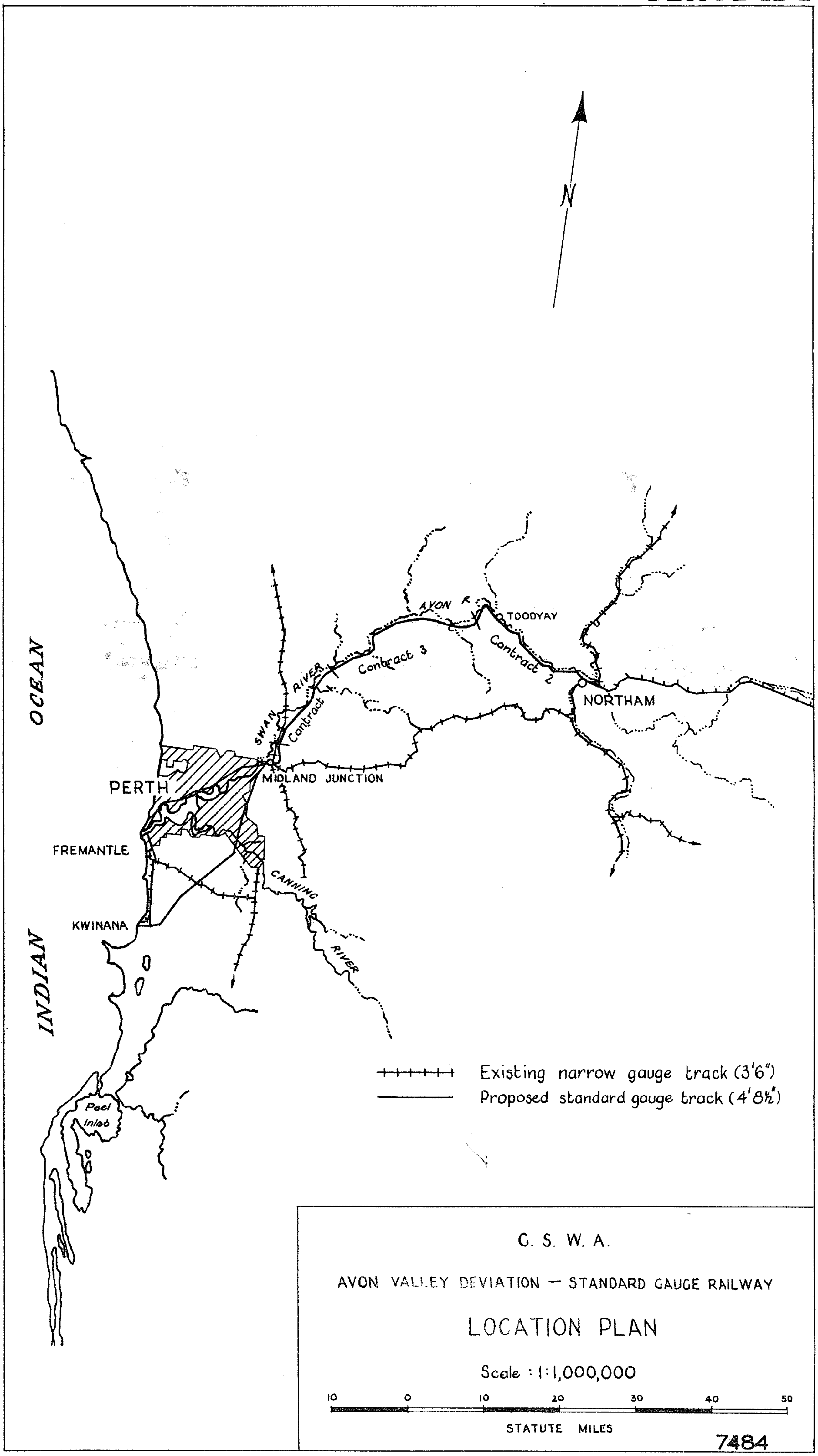
Ballast is the natural or artificial material that supports the railway sleepers in the permanent way and transfers the train loads to the subgrade. The type and thickness depend on traffic and, of course, on economic considerations. In addition, drainage conditions of the subgrade, climate, and the bearing properties of the subgrade have to be assessed. Ballast must be elastic in order that the ties and rails can return back to true line and grade after the passage of the train. Ballast also has to reduce dust and weed growth, and should permit satisfactory cleaning and repacking, and crushed stone is the best ballast-type from this point of view.

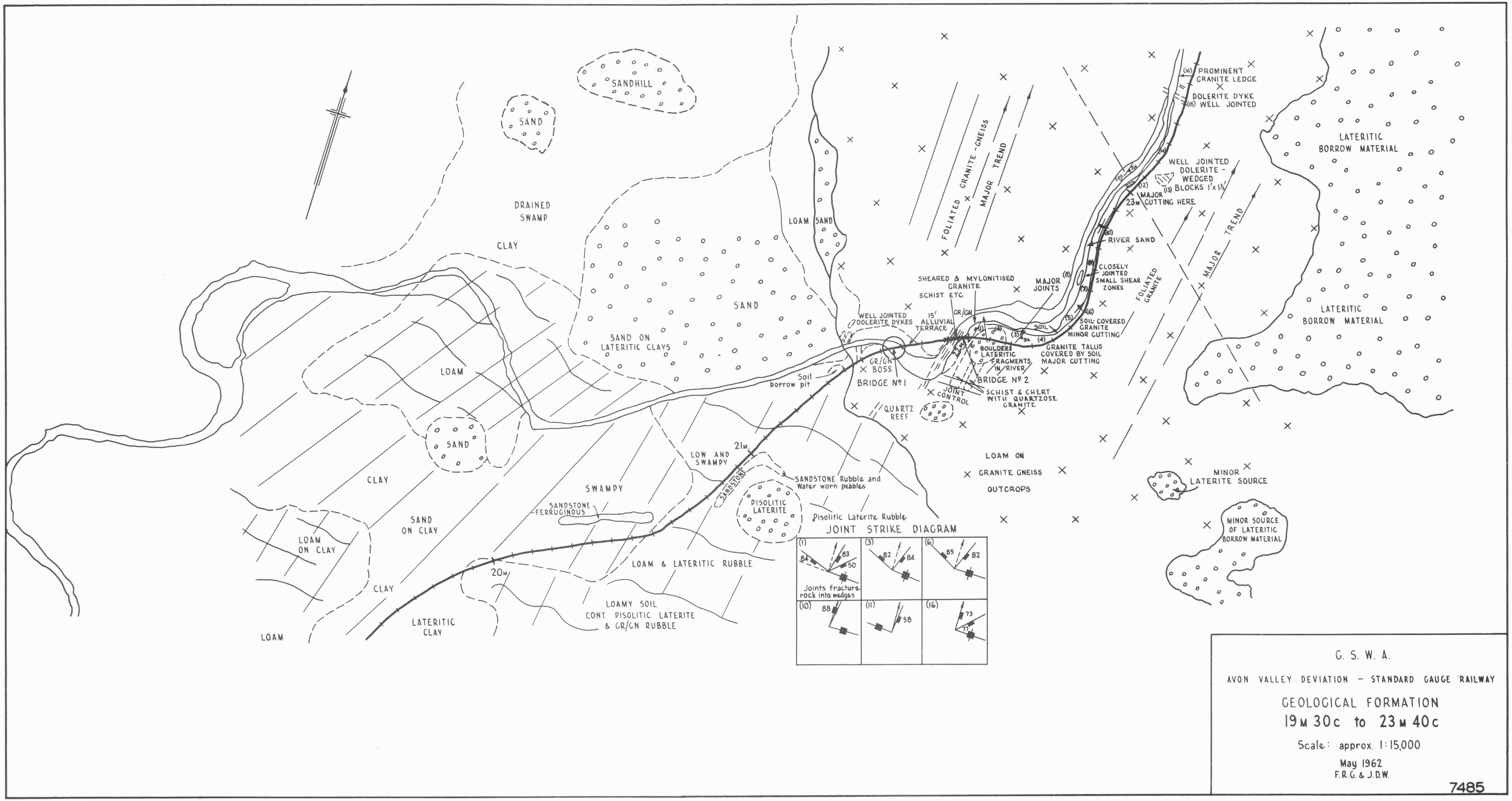
Ballast aggregate must be notably resistant to impact, as railway engines, in particular, impose heavy loads suddenly applied. Furthermore, the ballast particles must have a high resistance to abrasion, as movement induced by a series of cars tends to induce autogenous grinding.

Glassy or brittle rocks, e.g., those containing considerable amounts of quartz or mica, are usually not suitable because of poor impact resistance. The best rocks are those usually known as the "traprocks" or "bluemetal"—basalts, dolerites, diorites, etc. Granites are sometimes not desirable because of interlocking texture causing difficulty in crushing, and sometimes because of a low abrasion resistance. The "traprocks" on the other hand are naturally blocky and brittle enough to crush easily in mechanical crushers; but not under traffic conditions. Quartzites are also excellent sources of ballast if not excessively jointed.

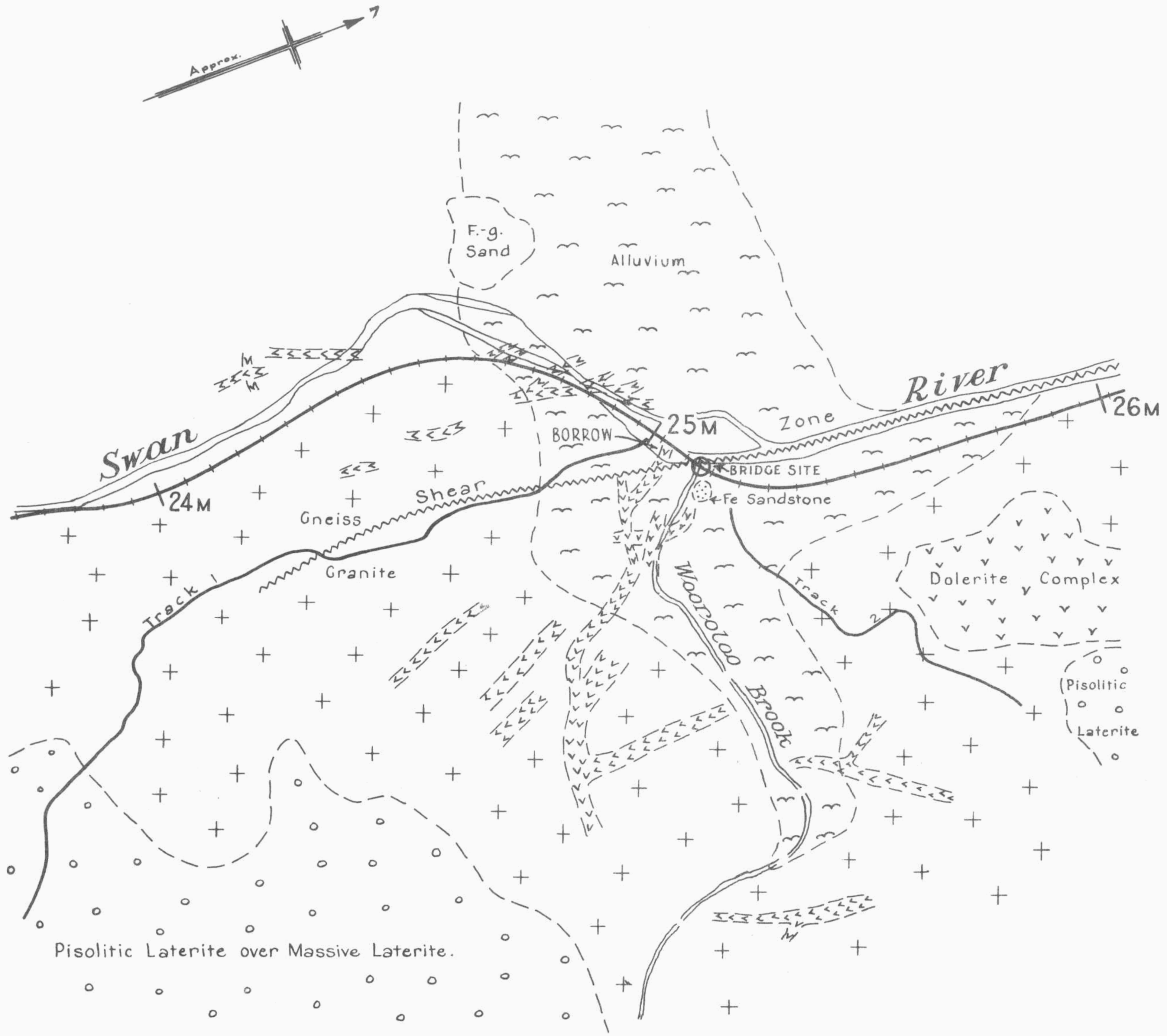
Rock Types.

Dolerites and Epidiorites.—These are dense, dark and fine grained igneous rocks which occur as minor intrusives, usually in the form of dykes, with a width varying from a few inches to over 200 feet and with a length of up to 3 miles. There is no preferred orientation, although many of the dykes in the Perth Metropolitan area lie either in the N.W. or N.E. directions with minor E.W. intrusives generally connecting the major units. Dyke intersections are common, and in some areas the dykes are so numerous and closely spaced as to constitute 80 per cent of the surface outcrop over an

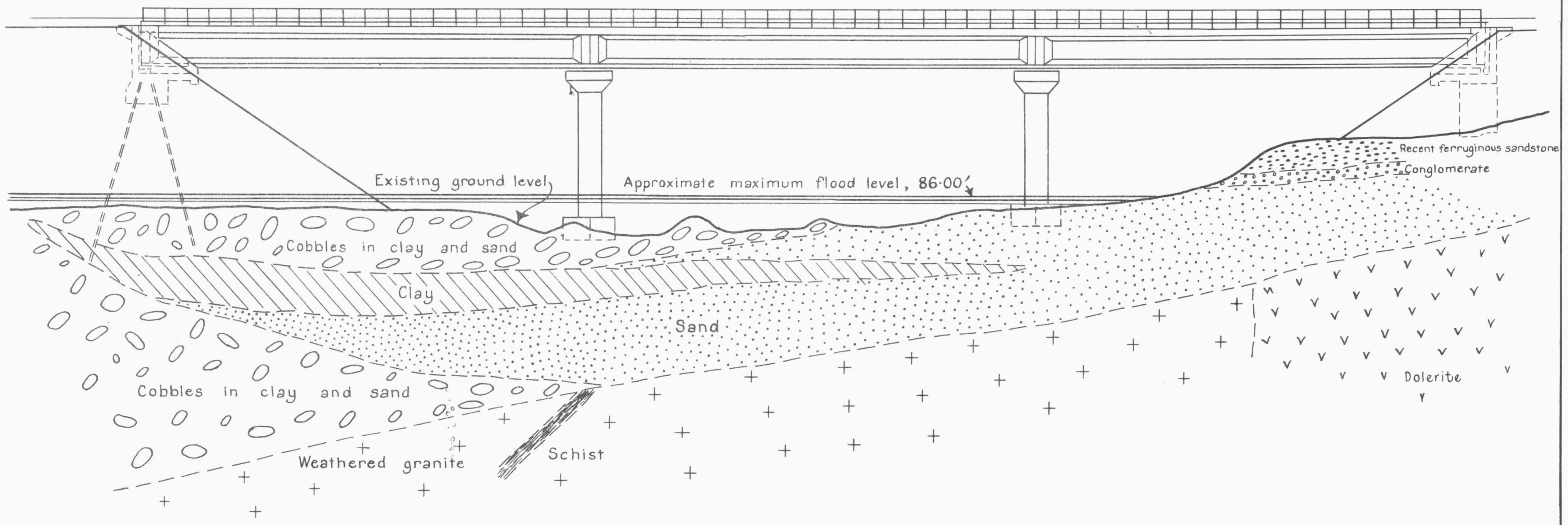

N
INDIAN
OCEAN
PERTH
MIDLAND JUNCTION
FREMANTLE
KWINANA
Peel Inlet
SWAN RIVER
AVON R
TOODYAY
NORTHAM
Contract
Contract 3
Contract 2
CANNING RIVER
Existing narrow gauge track (3'6")
Proposed standard gauge track (4'8½")
G. S. W. A.
AVON VALLEY DEVIATION — STANDARD GAUGE RAILWAY
LOCATION PLAN
Scale : 1:1,000,000
10 0 10 20 30 40 50
STATUTE MILES
7484


SANDHILL
SAND
DRAINED SWAMP
CLAY
LOAM
SAND
CLAY
SAND ON CLAY
LOAM ON CLAY
CLAY
LOAM
LATERITIC CLAY
SAND ON LATERITIC CLAYS
SAND
LOAM SAND
SWAMPY
SANDSTONE FERRUGINOUS
LOW AND SWAMPY
21M.
20M
SANDSTONE
Soil borrow pit
LOAM & LATERITIC RUBBLE
LOAMY SOIL CONT. PISOLITIC LATERITE & GR/GN RUBBLE
PISOLITIC LATERITE
SANDSTONE Rubble and Water worn pebbles
Pisolitic Laterite Rubble
QUARTZ REEF
GR/GN BOSS
BRIDGE No 1
WELL JOINTED DOLERITE DYKES
15' ALLUVIAL TERRACE
SHEARED & MYLONITISED GRANITE
SCHIST ETC.
GR/GN
BOULDERS LATERITIC FRAGMENTS IN RIVER
BRIDGE No 2
JOINT CONTROL
SCHIST & CHERT WITH QUARTZOSE GRANITE
SOIL
GRANITE TALUS COVERED BY SOIL MAJOR CUTTING
SOIL COVERED GRANITE MINOR CUTTING
MAJOR JOINTS
CLOSELY JOINTED SMALL SHEAR ZONES
RIVER SAND
23M
MAJOR CUTTING HERE
WELL JOINTED DOLERITE - WEDGED BLOCKS 1' x 1½'
PROMINENT GRANITE LEDGE
DOLERITE DYKE WELL JOINTED
FOLIATED GRANITE - GNEISS
MAJOR TREND
FOLIATED GRANITE
MAJOR TREND
LATERITIC BORROW MATERIAL
LATERITIC BORROW MATERIAL
LOAM ON GRANITE GNEISS OUTCROPS
MINOR LATERITE SOURCE
MINOR SOURCE OF LATERITIC BORROW MATERIAL
JOINT STRIKE DIAGRAM
(1) 84 83 50 Joints fracture rock into wedges
(3) 82 84
(6) 85 82
(10) 88
(11) 58
(16) 73 77
G. S. W. A.
AVON VALLEY DEVIATION - STANDARD GAUGE RAILWAY
GEOLOGICAL FORMATION
19M 30C to 23M 40C
Scale: approx. 1:15,000
May 1962
F.R.G. & J.D.W.
7485


G.S.W.A.
AVON VALLEY, DEVIATION — STANDARD GAUGE RAILWAY
GEOLOGICAL FORMATION
55M to 63M
Scale: approx 1:15,000
MAY 1962
F.R.G. & J.D.W.
N
CULTIVATED SOIL COVER
55M
GRANITIC RUBBLE AND SOIL
STRONG FOLIATION LINES
CLAY SOIL
MINOR CUTTING ALONG HILL SLOPE
89
56M
MINOR FILL
CREEK
57M
TOODYAY TOWNSITE
APPROXIMATE BUILT UP
BOUNDARIES
GRANITE GNEISS
MICA SCHIST
MICA SCHIST
58M
MINOR FILL
CREEK
GRANITE GNEISS
SOIL AND GRANITE GNEISS RUBBLE
CULTIVATED SOIL
59M
MINOR CUTTING
SOIL AND RUBBLE
MINOR FILL
CREEK
MICA SCHIST AND QUARTZITE CLAY SOIL
88
CLAY SOIL OVER MICA SCHIST
87
LATERITE 6' ROCK RUBBLE
60M
BRIDGE SITE 6
UNDER ALLUVIAL COVER 20'-30'
RIVER TERRACES
MICA SCHIST
HORNBLENDE SCHIST
WELL JOINTED
QUARTZITE
85
QUARTZITE
MICA SCHIST
BRIDGE SITE 7
RIVER 30' DEEP SAND BOTTOM
LATERITE PIT
A84
89
86
PROBABLE BORROW SOURCE LATERITE UP TO 15' THICK
QUARTZITE RUBBLE
JOINTED QUARTZITE
HORNBLENDE SCHIST
WINDMILL HILL
SOIL AND QUARTZITE RUBBLE
82
GRANITE GNEISS
MICA SCHIST
M/S
62M(o.c.)
SOIL COVER
QUARTZITE
HORNBLENDE SCHIST
MICA SCHIST
QUARTZITE
QUARTZITE
GRANITE GNEISS
63M
JOINT STRIKE DIAGRAM
N
52°
S70E
80°
S80W
N50E
N40W
50
7486



SITE PLAN
Scale : 20 chains to 1 Inch



GEOLOGICAL SECTION ALONG CENTRE LINE
Scale : 20 feet to 1 Inch

G. S. W. A.
AVON VALLEY DEVIATION - STANDARD GAUGE RAILWAY
SITE GEOLOGY - BRIDGE No 3 - WOOROLOO BROOK

SCALES { SITE PLAN 20 Chains to 1 Inch; SECTION 20 Feet to 1 Inch

May, 1962
F.R.G., J.D.W.

7487

G.S.W.A.

AVON VALLEY DEVIATION - STANDARD GAUGE RAILWAY

SITE INVESTIGATION - BRIDGE Nº 6

60M 45·8c TO 60M 59·3c

SCALES - Horizontal : 30feet to an Inch
Vertical : 10feet to an Inch

Prepared by F.R.G.
January, 1963

Based on 6102/P172
G. Maunsell and Partners

7488

area, say, of a mile square. The dykes can usually be identified on airphotos as discontinuous, dark, thick, lines contrasting with the lighter coloured surrounding granite. On the ground the dolerite is often more resistant to weathering than granite and the "backbone" of many spurs and ridges is doleritic. The dykes can be traced in the field by means of pieces of broken rock and by a characteristic dark red colouration of the residual soil lying on top of the basic dyke. Laterite exhibits a brick red colour over dolerite, but caution must be exercised here, as intense heat from a bush fire can cause a similar colouration. Where there is no surface outcrop due to the presence of a residual cover, the dykes can often be traced by the greater growth of larger trees on the richer soil derived from the dolerite.

The larger dykes show fine grained margins with crystal size increasing in towards the centre, in places giving a coarse-grained rock or gabbro, known to local quarrymen as "spotted dick." Some dykes show extensive shearing at the margins, especially so with the epidiorites or lighter hued varieties, and the production of dimension store from these is precluded.

Most of the local working quarries commenced operating on a dyke or dyke intersection, and the need to maintain an even quarry face has meant that the amount of dolerite has decreased as the face advanced (e.g. Boya).

Granites.—The granites comprise the greater portion of the Darling Range in the Metropolitan area. These acid rocks are usually white to grey in colour and are characteristically coarse grained, but no distinction is usually made between the various types: white granite, grey granite, gneissic granite and banded gneiss. Gneissic material is undesirable in a quarry and should be avoided due to poor particle shape and abrasion loss.

The granite may show weathering to considerable depths, and even in some operating quarries entirely fresh rock has not yet been reached at a distance of 200 feet into the hill. Some granites exhibit no defect in hand specimen, but a high Los Angeles abrasion test result may indicate partial crushing, a condition a petrological examination will quickly confirm. Quite often darker coloured lenses (basic) are encountered within the granite and these are sometimes coarse grained.

Joints are another main consideration in locating a quarry in granite, and massive jointing is necessary for an equidimensional product. Outcrop jointing generally reduces in incidence at depth, leaving usually a major joint parallel to the foliation or grain of the granite and another at right angles to this. Both these joints tend to be vertical, and the next most prominent joint is usually horizontal. Careful consideration of the outcrops is essential to establish if there is a local joint pattern, and if this is intense, further work is probably not warranted.

Many of the working and abandoned quarries in the vicinity of the railway were examined, and details have been reported in the Records of the Geological Survey of Western Australia.

Planning for Ballasting.

A ballast requirement of 2,900 cubic yards of rock to the mile over a distance of 63 miles of track will mean the provision of approximately 190,000 cubic yards of material. The various practical alternatives appear to be:—

(a) Provision of the whole quantity from a quarry near the middle of the run i.e. in the vicinity of the 40-50 mile pegs. This could be achieved from a possible site quarry near the 48 mile peg.

(b) Equal quantities could be provided from either end, from near Midland Junction and from the Northam area. An abandoned quarry on the Spencers Brook road, and Stathams (P.C.C.) abandoned Quarry, appear as the most desirable choices, with the possiblity of opening another quarry on the same dolerite dyke if Stathams is disposed of, before ballasting commences. This scheme would involve then the reopening of two existing quarries and thus the provision of 2 sets of crushing and screening plants.

(c) In order to reduce the capital outlay it may be felt desirable to only open (or reopen) one quarry, say at Northam, and to call for tenders for supply at the Midland end. For this alternative Spencers Brook Quarry, and the most economical price from the Darling Range quarries that produce satisfactory ballast will be preferred.

(d) From the point of view of railway engineering the most conventient situation would probably be the supply of ballast at one of the existing railroad sidings as close as possible to Midland Junction. This would enable ballasting and track laying to proceed up the Swan Avon Valley with the track materials following up the line from Perth. From this aspect a quarry situated between Bellevue and Chidlow, say, on the Great Eastern Railway or in the Darling Range would be in the optimum position. For that reason, a quarry near the railway at Greenmount Block must be considered. However, the fact that Stathams is already developed, and that a temporary track could be quickly laid on the old railway embankment running right into the quarry (a distance of 240 chains) is of major importance.

Borrow Materials.

The material most favoured for use in embankments and formation in the S.W. portion of the State is the weathering product known as laterite. Three forms may be distinguished:—

(i) Pisolitic laterite or "ironstone gravel" which occurs as a thin veneer and in small pockets on top of massive laterite. The reddish brown rock is composed of spherical pebbles loosely cemented together by a lighter coloured earthy matrix.

(ii) Massive laterite or "ironstone" has a wide distribution over the Darling Ranges, usually above the 690 feet contour, and occurs as a superficial layer usually be-between 10 and 15 feet thick.

(iii) Lateritic gravels are developed on the face of the Darling Scarp and as piedmont deposits at the foot of the scarp. The deposits are limited in extent and lenticular, and have been heavily exploited.

These three lateritic materials are formation-building soils of the highest quality.

WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA TO THE END OF 1962.

by P. E. Playford and D. C. Lowry.

INTRODUCTION.

A total of 57 oil-test wells have been completed in Western Australia. Of these, 30 are in the Canning Basin, 21 are in the Carnarvon Basin, five are in the Perth Basin, and one is in the Ord Basin. A further test well is currently being drilled in the Perth Basin. In addition, some 56 wells have been drilled for stratigraphic and structural information in connection with oil exploration in the Canning, Carnarvon, Perth and Eucla Basins, and another is now being drilled in the Perth Basin. No wells have yet been drilled in the Officer Basin, nor in that part of the Bonaparte Gulf Basin lying in Western Australia.

The positions of wells drilled to the end of 1962 are shown on the accompanying map (Plate XXI) and summary information on each well is given in the accompanying table.

HISTORICAL REVIEW.

The first wells drilled for oil in this State were put down in 1902-04 near the Warren River, in the southern part of the Perth Basin. They were drilled following the discovery of small quantities of bitumen washed up on the coast in this area, and because the local residents had noticed that their tea had a strong flavour of "kerosene" when made from water obtained in certain localities. The ensuing "oil boom" was not followed by the discovery of any oil.

In 1919 intense interest was aroused by the report of traces of oil in a water bore being drilled on Gogo Station in the Kimberley District. The report was confirmed by a geologist, and as a result the Freney Kimberley Oil Company was formed. This company drilled a number of wells in the Canning Basin in the years 1922 to 1941, but without success. The interests of the company were taken over by Associated Freney Oilfields N.L. in 1954, and this organization has since drilled three test wells in the Canning Basin.

The first large-scale exploration in this State employing modern geophysical and drilling techniques began in 1952, when West Australian Petroleum Pty. Ltd. (Wapet) commenced operations in the Carnarvon Basin. This company had spectacular success in 1953 with its first well, Rough Range No. 1. This well produced oil at a rate of 500 barrels per day from Lower Cretaceous sands of the Birdrong Formation, at a depth of 3,602 feet. Since then the company has drilled a total of 35 test wells without further success, other than in Rough Range No. 1A, which was drilled a few yards from the discovery well. The company holds exploration permits covering most of the Canning, Carnarvon, and Perth Basins, and it is continuing with active exploration in each.

For more detailed information on the status of oil exploration in Western Australia the reader is referred to publications by Hobson (1936), Playford and Johnstone (1959), Bureau of Mineral Resources (1960), McWhae (1960), and Playford (1962).

EUCLA BASIN.

The only wells drilled for oil exploration in the Eucla Basin were put down in 1960 by Exoil Pty. Ltd. to obtain stratigraphic information. These two wells, Eyre No. 1, and Gambanga No. 1, entered Precambrian basement rocks at shallow depths.

PERTH BASIN.

Five oil-test and seven stratigraphic wells have been completed in the Perth Basin. With the exception of three shallow test wells drilled by the Westralian Mining and Oil Corporation in 1902-04 near the south coast, drilling has been concentrated in the north-central part of the basin. Two test wells and five stratigraphic holes have been drilled by Wapet, and two stratigraphic holes by the Bureau of Mineral Resources. Wapet is currently drilling oil-test and stratigraphic wells at Woolmulla and Eganu respectively, but the greater part of the basin remains untested.

CARNARVON BASIN.

All the test wells drilled to date in the Carnarvon Basin have been put down by Wapet. Most are concentrated in the Exmouth Gulf area, where a total of 17 have been drilled. In addition, several of the Tertiary anticlines outside this area have been tested, but there are no test wells in the central and eastern parts of the basin.

Wapet has completed 30 stratigraphic and structure holes in the Carnarvon Basin, and a further five have been put down by the Bureau of Mineral Resources. Most of the Wapet holes were drilled for structural information on the Rough Range and Dirk Hartog Anticlines.

Although the initial success at Rough Range Nos. 1 and 1A has not been followed by further oil discoveries, some of the other test wells have had showings of oil or gas, especially Cape Range Nos. 1 and 2, which recorded substantial gas showings.

CANNING BASIN.

In the Canning Basin, exploratory drilling has been restricted to the northern part and the coastal strip, where a total of 30 test wells and 8 stratigraphic holes have been drilled. A huge area, covering the central and western parts of the basin, remains untested, mainly because of its inaccessible and inhospitable nature.

Wapet has drilled more holes (14 oil-test and 3 stratigraphic holes) in the Canning Basin than any other organization. The rest have been put down by the Freney Kimberley Oil Company (13 oil-test holes), Associated Freney Oilfields N.L. (3 oil-test holes) and the Bureau of Mineral Resources (5 stratigraphic holes).

Traces of oil and gas have been reported from a number of wells drilled in the Canning Basin, and one, Meda No. 1, produced a few gallons of oil from the Lower Carboniferous sequence.

ORD BASIN

In 1920 bitumen was discovered at two localities in the Ord River area, in jointed and vesicular basalts underlying Lower Cambrian limestones. This discoverey led to the formation of the Okes Durack Kimberley Oil Company, which drilled one dry hole in 1924. Since then there has been no serious oil exploration in the basin.

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WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALA. TO THE END OF 1962

Name	Type	Location		Depth (feet)	Bottomed in	Drilled for	Year completed	Remarks
		Lat. (S.)	Long. (E.)					
Eucla Basin.								
Eyre No. 1	Strat.	32° 07′	126° 58′	1,718	Precambrian	Exoil	1960	
Gambanga No. 1	Strat.	32° 16′	124° 50′	1,282	Precambrian	Exoil	1960	

WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA. TO THE END OF 1962—*continued.*

Name	Type	Location		Depth (feet)	Bottomed in	Drilled for	Year completed	Remarks
		Lat. (S.)	Long. (E.)					
				Perth Basin.				
Abbarwardoo No. 1	Strat.	28° 35′ 10″	115° 09′ 35″	2,000	L. Permian	WAPET	1962	
B.M.R. No. 10 (Beagle Ridge)	Strat.	29° 49′ 38″	114° 58′ 30″	3,910	L. Permian	B.M.R.	1959	Minor oil shows.
B.M.R. No. 10A (Beagle Ridge)	Strat.	29° 49′ 38″	114° 58′ 30″	4,862	Precambrian	B.M.R.	1960	Minor oil shows.
Eganu No. 1	Strat.	29° 59′ 05″	115° 49′ 35″	....	....	WAPET	....	Drilling.
Eneabba No. 1	Oil test	29° 34′ 14″	115° 19′ 56″	13,712	L. Triassic	WAPET	1961	Minor oil and gas shows.
Hill River No. 1	Strat.	30° 16′	115° 18′	1,900	L. Jurassic	WAPET	1962	Five coal seams, 2 to 3 feet thick.
Hill River No. 2	Strat.	30° 11′	115° 14′	1,620	L. Jurassic	WAPET	1962	Minor lignite.
Hill River No. 3	Strat.	30° 00′ 32″	115° 11′ 13″	865	U. Triassic	WAPET	1962	
Hill River No. 4	Strat.	30° 23′ 24″	115° 13′ 49″	1,010	U. Triassic	WAPET	1962	
Jurien No. 1	Oil test	30° 08′ 40″	115° 02′ 54″	3,366	Precambrian	WAPET	1962	Minor gas shows.
Warren River No. 1	Oil test	34° 34′ (app.)	115° 55′ (app.)	81	U. Jurassic	W.M. & O.	1902	Dry.
Warren River No. 2	Oil test	34° 35′ (app.)	115° 54′ (app.)	504	U. Jurassic	W.M. & O.	1902	Dry.
Warren River No. 3	Oil test	34° 37′ (app.)	115° 51′ (app.)	1,719	U. Jurassic	W.M. & O.	1904	Dry.
Woolmulla No. 1	Oil test	30° 01′ 24″	115° 11′ 28″	....	....	WAPET	....	Drilling.
				Carnarvon Basin				
B.M.R. No. 5 (Giralia)	Strat.	22° 39′ 15″	114° 14′ 25″	2,070	L. Permian	B.M.R.	1958	
B.M.R. No. 6 (Muderong)	Strat. & Struct.	24° 05′ 55″	114° 46′ 30″	1,002	L. Permian	B.M.R.	1958	
B.M.R. No. 7 (Muderong)	Strat. & Struct.	24° 05′ 55″	114° 46′ 30″	1,997	L. Permian	B.M.R.	1958	
B.M.R. No. 8 (Mt. Madeline)	Strat. & Struct.	25° 44′ 50″	115° 40′ 40″	3,004	L. Permian	B.M.R.	1959	
B.M.R. No. 9 (Daurie Creek)	Strat. & Struct.	25° 32′ 20″	115° 52′ 50″	2,299	L. Permian	B.M.R.	1959	
Cape Cuvier No. 1	Strat.	24° 13′ 30·3″	113° 23′ 43·6″	1,500	Devonian	WAPET	1955	
Cape Range No. 1	Oil test	22° 05′ 56·5″	114° 00′ 32·5″	8,019	M. Jurassic	WAPET	1954	Minor gas shows.
Cape Range No. 2	Oil test	22° 05′ 50·5″	113° 59′ 41·2″	15,170	L. Jurassic	WAPET	1956	Gas, non-commercial
Cape Range No. 3A	Oil test	22° 08′ 42·9″	113° 59′ 54·2″	3,737	U. Jurassic	WAPET	1956	Dry.
Cape Range No. 4	Oil test	22° 19′ 26·5″	113° 56′ 09·1″	3,858	U. Jurassic	WAPET	1956	Dry.
Dirk Hartog Nos. 1–16	Struct.	25° 42′ 00″–25° 57′ 45″	112° 58′ 20″–113° 09′ 20″	778–1,500	Eocene	WAPET	1955–1956	
Dirk Hartog No. 17B	Oil test	25° 51′ 58″	113° 04′ 40·5″	4,998	L. Silurian	WAPET	1957	Dry.
Exmouth No. 1	Struct.	22° 23′ 01″	114° 06′ 38·5″	1,759	U. Cretaceous	WAPET	1956	
Exmouth No. 2	Struct.	22° 21′ 25″	114° 08′ 17″	2,029	U. Cretaceous	WAPET	1956	
Giralia No. 1	Oil test	22° 59′ 35″	114° 14′ 20″	4,080	L. Permian	WAPET	1955	Dry.
Grierson No. 1	Strat. & Struct.	24° 12′ 00″	113° 46′ 20″	1,437	Devonian	WAPET	1955	
Grierson No. 2	Strat. & Struct.	24° 12′ 00″	113° 47′ 05″	1,478	Devonian	WAPET	1955	
Grierson No. 3	Strat. & Struct.	24° 12′ 02″	113° 45′ 30″	1,450	Devonian	WAPET	1955	
Learmonth No. 1	Oil test	22° 10′ 58·5″	114° 03′ 31·2″	7,636	L. Permian	WAPET	1958	Minor gas show.
Rough Range No. 1	Oil test	22° 25′ 06·6″	114° 04′ 54·4″	14,607	Devonian	WAPET	1955	Oil saturated 3,602–3,628 feet.
Rough Range No. 1A	Oil test	22° 25′ 06″	114° 04′ 55″	3,657	U. Jurassic-L. Cretaceous	WAPET	1955	Oil saturated 3,604–3,628 feet.
Rough Range No. 2	Oil test	22° 25′ 50″	114° 04′ 05″	4,079	U. Jurassic	WAPET	1954	Dry.
Rough Range No. 3	Oil test	22° 24′ 40″	114° 05′ 09″	3,915	L. Cretaceous	WAPET	1954	Dry.
Rough Range No. 4	Oil test	22° 25′ 23″	114° 04′ 54″	3,760	L. Cretaceous	WAPET	1954	Dry.
Rough Range No. 5	Oil test	22° 25′ 07″	114° 04′ 33″	3,772	L. Cretaceous	WAPET	1954	Dry.
Rough Range No. 6	Oil test	22° 25′ 12·7″	114° 04′ 48·8″	3,697	L. Cretaceous	WAPET	1955	Dry.
Rough Range No. 7	Oil test	22° 26′ 40″	114° 04′ 06″	4,281	U. Jurassic-L. Cretaceous	WAPET	1955	Dry.
Rough Range No. 8	Oil test	22° 26′ 46″	114° 03′ 44″	3,919	L. Cretaceous	WAPET	1955	Dry.
Rough Range No. 9	Oil test	22° 26′ 50″	114° 04′ 22″	3,844	U. Jurassic-L. Cretaceous	WAPET	1955	Dry.
Rough Range No. 10	Oil test	22° 25′ 04·6″	114° 05′ 02·4″	3,739	U. Jurassic-L. Cretaceous	WAPET	1957	Minor oil shows.
Rough Range South No. 1	Struct.	22° 37′ 17·5″	113° 57′ 37·6″	2,866	L. Cretaceous	WAPET	1956	
Rough Range South No. 2	Struct.	22° 23′ 48·2″	114° 00′ 20·4″	1,523	L. Cretaceous	WAPET	1956	
Rough Range South No. 3	Struct.	22° 30′ 08·7″	114° 02′ 29·5″	1,900	U. Cretaceous	WAPET	1956	
Rough Range South No. 4	Struct.	22° 32′ 00″	114° 01′ 28·4″	2,289	U. Cretaceous	WAPET	1956	
Rough Range South No. 5	Oil test	22° 34′ 24·6″	113° 59′ 16·5″	4,760	L. Permian	WAPET	1956	Dry.
Rough Range South No. 6	Struct.	22° 32′ 22″	114° 00′ 42·4″	1,594	U. Cretaceous	WAPET	1956	
Wandagee No. 1	Strat.	23° 53′ 15″	114° 23′ 51″	3,520	L. Silurian	WAPET	1962	Minor gas show.
Wandagee No. 2	Strat.	23° 53′ 13″	114° 31′ 38″	1,013	L. Permian	WAPET	1962	
Wandagee No. 3	Strat.	23° 49′ 43″	114° 20′ 03″	730	pre-Cretaceous	WAPET	1962	
Warroora No. 1	Oil test	23° 30′ 30·1″	113° 52′ 48·1″	5,992	Carboniferous	WAPET	1955	Minor oil show.
Yanrey No. 1	Oil test	22° 15′ 15·7″	114° 34′ 56·8″	1,413	Precambrian	WAPET	1957	Dry.
				Canning Basin.				
Babrongan No. 1	Oil test	18° 23′ 23″	123° 35′ 37″	6,395	U. Devonian	WAPET	1962	Dry.
Barlee No. 1	Oil test	17° 48′ 25″	122° 42′ 40″	8,101	U. Carboniferous	WAPET	1960	Minor gas show.
B.M.R. No. 1 (Jurgurra Creek)	Strat.	18° 19′ 49″	123° 42′ 45″	1,680	L. Permian	B.M.R.	1955	
B.M.R. No. 2 (Laurel Downs)	Strat.	18° 07′ 06·1″	125° 20′ 05·1″	4,000	U. Devonian	B.M.R.	1956	
B.M.R. No. 3 (Prices Creek)	Strat.	18° 39′ 40″ (app.)	125° 54′ 05″ (app.)	694	Precambrian	B.M.R.	1956	
B.M.R. No. 4 (Wallal)	Strat.	19° 44′ 12″	120° 44′ 28″	1,410	Jurassic	B.M.R.	1958	
B.M.R. No. 4A (Wallal)	Strat.	19° 44′ 12″	120° 44′ 28″	2,223	Precambrian	B.M.R.	1958	
Dampier Downs No. 1	Strat.	18° 18′ 00″	123° 06′ 00″	3,028	L. Ordovician	WAPET	1956	
Fraser River No. 1	Oil test	17° 25′ 04″	123° 09′ 39″	10,144	post-Carboniferous gabbro	WAPET	1956	Dry.
Frome Rocks No. 1	Oil test	18° 11′ 48″	123° 38′ 42″	4,003	Rock salt	WAPET	1959	Dry.
Frome Rocks No. 2	Oil test	18° 15′ 15″	123° 39′ 35″	7,504	U. Devonian	WAPET	1959	Minor oil shows.
Goldwyer No. 1	Oil test	18° 22′ 47″	122° 22′ 58″	4,720	Precambrian	WAPET	1958	Minor oil shows.
Grant Range No. 1	Oil test	18° 01′ 00″	124° 00′ 25″	12,915	U. Carboniferous	WAPET	1955	Dry.
Hawkstone Peak No. 1	Oil test	17° 14′ 45″	124° 24′ 26″	3,897	Precambrian	WAPET	1962	Dry.
Langoora No. 1	Oil test	17° 18′ 07″	124° 06′ 48″	5,299	Precambrian	WAPET	1962	Dry.
Meda No. 1	Oil test	17° 24′ 00″	124° 11′ 30″	8,809	Precambrian	WAPET	1958	Oil and gas shows.
Meda No. 2	Oil test	17° 24′ 36″	124° 11′ 23″	7,628	U. Devonian	WAPET	1959	Oil and gas shows.
Mount Wynne No. 1	Oil test	18° 05′ 35″ (app.)	124° 23′ 44″ (app.)	896	L. Permian	F.K.O.	1923	Minor bitumen present.
Mount Wynne No. 3	Oil test	18° 05′ 35″ (app.)	124° 23′ 44″ (app.)	2,154	L. Permian	F.K.O.	1925	Minor oil shows.
Myroodah No. 1	Oil test	18° 16′ 15″	124° 11′ 27″	6,001	L. Permian	A.F.O.	1956	Dry.
Nerrima No. 1 (A.F.O.)	Oil test	18° 26′ 55″	124° 22′ 17″	9,072	U. Carboniferous	A.F.O.	1955	Minor oil shows.

WELLS DRILLED FOR PETROLEUM EXPLORATION IN WESTERN AUSTRALIA TO THE END OF 1962—*continued.*

Name	Type	Location		Depth (feet)	Bottomed in	Drilled for	Year completed	Remarks
		Lat. (S.)	Long. (E.)					
			Canning Basin—continued.					
Nerrima No. 1 (F.K.O.)	Oil test	18° 28′ 16″	124° 24′ 02″	4,271	L. Permian	F.K.O.	1941	Dry.
Poole Range No. 3	Oil test	18° 53′ 06″ (app.)	125° 47′ 20″ (app.)	3,264	L. Permian	F.K.O.	1930	Minor oil shows.
Poole Range No. 5	Oil test	18° 52′ 27″ (app.)	125° 49′ 02″ (app.)	1,545	L. Permian	F.K.O.	1933	Dry.
Prices Creek No. 1	Oil test	18° 40′ 30″ (app.)	125° 55′ 00″ (app.)	1,008	Ordovician	F.K.O.	1922	Minor oil shows.
Prices Creek No. 2	Oil test	18° 40′ 40″ (app.)	125° 55′ 55″ (app.)	340	Ordovician	F.K.O.	1923	Minor oil shows.
Prices Creek No. 3	Oil test	18° 41′ 25″ (app.)	125° 55′ 15″ (app.)	809	Ordovician	F.K.O.	1923	Minor oil shows.
Prices Creek No. 4	Oil test	18° 40′ 55″ (app.)	125° 54′ 05″ (app.)	444	L. Permian	F.K.O.	1923	Dry.
Roebuck Bay No. 1	Strat.	18° 09′ 33·9″	122° 27′ 27·8″	4,000	L. Ordovician	WAPET	1956	
Samphire Marsh No. 1	Oil test	19° 31′ 07·6″	121° 10′ 50·8″	6,664	Precambrian	WAPET	1958	Dry.
Sisters No. 1	Oil test	17° 43′ 31″	124° 25′ 09″	9,828	Devonian	A.F.O.	1957	Dry.
Thangoo No. 1	Oil test	18° 22′ 06″	122° 53′ 22″	3,475	L. Ordovician	WAPET	1959	Minor oil shows.
Thangoo No. 1A	Oil test	18° 21′ 52″	122° 53′ 09″	5,429	Precambrian	WAPET	1960	Minor oil shows.
Wallal No. 1	Strat.	19° 51′ 45·5″	120° 37′ 58·5″	1,014	Jurassic	WAPET	1957	
			Ord Basin.					
Okes Durack	Oil test	17° 16′ (app.)	128° 57′ (app.)	1,196	L. Cambrian basalt	O.D.K.	1924 (app.)	Dry.

Abbreviations :
Strat. = Stratigraphic Hole.
Struct. = Structure Hole.
app. = Approximately.

L. = Lower.
M. = Middle.
U. = Upper.

A.F.O. = Associated Freney Oilfields N.L.
B.M.R. = Bureau of Mineral Resources.
F.K.O. = Freney Kimberley Oil Co.
WAPET = West Australian Petroleum Pty. Limited
W.M. & O. = Westralian Mining and Oil Corporation.
O.D.K. = Okes Durack Kimberley Oil Co.
Exoil = Exoil Pty. Ltd.

THE SEARCH FOR OIL IN WESTERN AUSTRALIA IN 1962.

by P. E. Playford.

INTRODUCTION.

The rate of oil exploration in Western Australia increased considerably during 1962. This was not associated with any new oil discovery in this State, but it followed the Australia-wide trend towards increased exploration resulting from the Moonie discovery in Queensland.

During the year, four oil-test and eight stratigraphic wells were completed, and a further oil-test and a stratigraphic well were still drilling at the end of the year. All were put down by West Australian Petroleum Pty. Ltd. (Wapet) in the Perth, Carnarvon, and Canning Basins.

Geophysical operations totalling some 37 party-months of seismic work, 15 party-months of gravity work and 1½ months of aeromagnetic work, were conducted in the Perth, Carnarvon, Canning, Bonaparte Gulf, and Officer Basins. Surface geological mapping was undertaken by Wapet in the Perth Basin, and by the Geological Survey of Western Australia in the Perth and Canning Basins.

OIL HOLDINGS.

The positions of Permits to Explore and Licenses to Prospect current in Western Australia at the end of 1962 are show on the accompanying map (Plate XXII). Details regarding each permit and license are shown on the following table:

OIL HOLDINGS IN WESTERN AUSTRALIA ON DECEMBER 31st, 1962.

Permits to Explore.

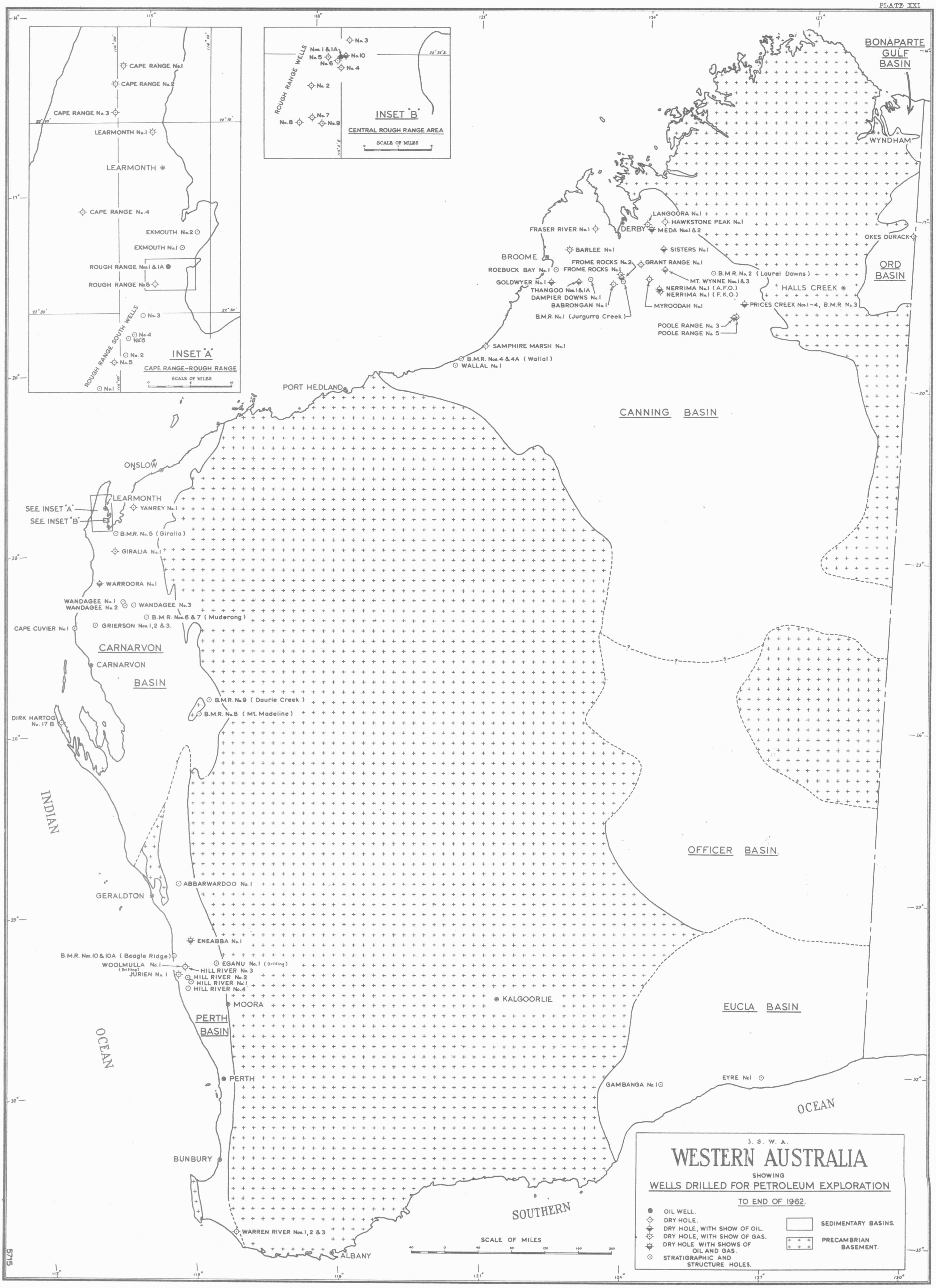
No.	Name of Holder	Area in Square Miles	Date of Expiry of Current Tenure
27H	West Australian Petroleum Pty. Ltd.	52,000	22/10/63
28H	do. do. do.	51,000	22/10/63
29H	do. do. do.	31,100	22/10/63
30H	do. do. do.	151,600	22/10/63
106H	Westralian Oil Ltd.	11,800	28/9/63
127H	Oil Development N.L.	13,800	28/3/63

Permits to Explore—continued.

No.	Name of Holder	Area in Square Miles	Date of Expiry of Current Tenure
133H	Jackson Explorations	15,750	2/9/62 Application for Renewal still under consideration
134H	Exoil Pty. Ltd.	12,600	9/12/63
135H	do.	12,600	9/12/63
136H	do.	12,450	9/12/63
142H	Hawkstone Oil Company Limited	5,200	8/4/63
147H	Hunt Oil Company ; Placid Oil Company	12,850	16/8/63
148H	do. do. do.	12,600	16/8/63
151H	Hackathorn Oils Pty. Ltd.	14,200	7/2/63
152H	do. do.	11,650	7/2/63
153H	do. do.	13,050	7/2/63
156H	Hunt Oil Company ; Placid Oil Company	12,450	10/7/63
157H	do. do. do.	12,600	10/7/63
158H	do. do. do.	12,800	10/7/63
159H	do. do. do.	12,800	10/7/63
161H	do. do. do.	12,900	24/8/63
165H	Vickers, Victor Ivor	13,700	19/12/63
166H	do. do.	5,315	19/12/63
167H	do. do.	13,550	27/12/63
171H	Turnbull, James	8,050	2/8/64
172H	Joice, James Matthew	6,150	30/7/64
173H	do. do.	12,250	30/7/64
174H	do. do.	6,100	30/7/64
175H	do. do.	6,000	30/7/64
177H	do. do.	6,050	30/7/64
178H	Australian Oil Corporation	12,300	29/8/64
179H	Byre Oil Exploration Syndicate	4,850	31/7/64
189H	Kalgoorlie Goldfields Petroleum N.L.	12,950	31/7/64
190H	Textralian Oil Pty. Ltd.	11,300	5/9/64
193H	Hawkstone Oil Company Limited	2,700	5/8/64
197H	Pilbara Exploration N.L.	6,900	15/8/64
199H	do. do.	11,950	15/8/64
203H	Australian Oil Corporation	18,000	29/8/64
209H	do. do.	12,200	30/8/64
210H	do. do.	12,050	29/8/64
211H	do. do.	5,975	28/8/64

Licenses to Prospect.

54H	West Australian Petroleum Pty. Ltd.	197·9	7/5/63
55H	do. do. do.	196·0	14/7/63
56H	do. do. do.	200	22/2/63
57H	Westralian Oil Ltd.	195·9	29/9/63
58H	Associated Freney Oil Fields N.L.	120	27/10/62 Application for Renewal still under consideration
59H	do. do. do.	113·4	do.
60H	do. do. do.	113·2	do.
61H	do. do. do.	112·5	do.
62H	do. do. do.	112·5	do.


G. S. W. A.
WESTERN AUSTRALIA
SHOWING
WELLS DRILLED FOR PETROLEUM EXPLORATION
TO END OF 1962.
OIL WELL.
DRY HOLE.
DRY HOLE, WITH SHOW OF OIL.
DRY HOLE, WITH SHOW OF GAS.
DRY HOLE WITH SHOWS OF OIL AND GAS.
STRATIGRAPHIC AND STRUCTURE HOLES.
SEDIMENTARY BASINS.
PRECAMBRIAN BASEMENT.
SCALE OF MILES
INSET "A"
CAPE RANGE-ROUGH RANGE
SCALE OF MILES
CAPE RANGE No. 1
CAPE RANGE No. 2
CAPE RANGE No. 3
LEARMONTH No. 1
LEARMONTH
CAPE RANGE No. 4
EXMOUTH No. 2
EXMOUTH No. 1
ROUGH RANGE Nos. 1 & 1A
ROUGH RANGE No. 8
ROUGH RANGE SOUTH WELLS
No. 3
No. 4
No. 6
No. 2
No. 5
No. 1
INSET "B"
CENTRAL ROUGH RANGE AREA
SCALE OF MILES
ROUGH RANGE WELLS
Nos. 1 & 1A
No. 5
No. 6
No. 3
No. 10
No. 4
No. 2
No. 7
No. 8
No. 9
BONAPARTE GULF BASIN
WYNDHAM
OKES DURACK
ORD BASIN
HALLS CREEK
LANGOORA No. 1
HAWKSTONE PEAK No. 1
MEDA Nos. 1 & 2
DERBY
FRASER RIVER No. 1
BARLEE No. 1
SISTERS No. 1
BROOME
GRANT RANGE No. 1
FROME ROCKS No. 2
FROME ROCKS No. 1
ROEBUCK BAY No. 1
B.M.R. No. 2 (Laurel Downs)
MT. WYNNE Nos. 1 & 3
GOLDWYER No. 1
THANGOO Nos. 1 & 1A
DAMPIER DOWNS No. 1
BABRONGAN No. 1
NERRIMA No. 1 (A.F.O.)
NERRIMA No. 1 (F.K.O.)
MYROODAH No. 1
PRICES CREEK Nos. 1-4, B.M.R. No. 3
B.M.R. No. 1 (Jurgurra Creek)
POOLE RANGE No. 3
POOLE RANGE No. 5
SAMPHIRE MARSH No. 1
B.M.R. Nos. 4 & 4A (Wallal)
WALLAL No. 1
PORT HEDLAND
CANNING BASIN
ONSLOW
LEARMONTH
SEE INSET "A"
SEE INSET "B"
YANREY No. 1
B.M.R. No. 5 (Giralia)
GIRALIA No. 1
WARROORA No. 1
WANDAGEE No. 1
WANDAGEE No. 2
WANDAGEE No. 3
B.M.R. Nos. 6 & 7 (Muderong)
CAPE CUVIER No. 1
GRIERSON Nos. 1, 2 & 3.
CARNARVON BASIN
CARNARVON
B.M.R. No. 9 (Daurie Creek)
B.M.R. No. 8 (Mt. Madeline)
DIRK HARTOG No. 17 B
INDIAN OCEAN
OFFICER BASIN
ABBARWARDOO No. 1
GERALDTON
ENEABBA No. 1
B.M.R. Nos. 10 & 10A (Beagle Ridge)
EGANU No. 1 (Drilling)
WOOLMULLA No. 1 (Drilling)
JURIEN No. 1
HILL RIVER No. 3
HILL RIVER No. 2
HILL RIVER No. 1
HILL RIVER No. 4
MOORA
KALGOORLIE
EUCLA BASIN
PERTH BASIN
PERTH
GAMBANGA No. 1
EYRE No. 1
SOUTHERN OCEAN
BUNBURY
WARREN RIVER Nos. 1, 2 & 3
ALBANY
5715

Licenses to Prospect—continued.

No.	Name of Holder	Area in Square Miles	Date of Expiry of Current Tenure
63H	West Australian Petroleum Pty. Ltd.	117·7	29/9/63
66H	do. do. do.	200	18/1/63
67H	do. do. do.	199·4	20/4/63
68H	do. do. do.	195·1	17/5/63
69H	do. do. do.	175·1	17/5/63
70H	do. do. do.	192·8	17/5/63
71H	do. do. do.	187·1	17/5/63
72H	do. do. do.	194·7	17/5/63
73H	do. do. do.	188·7	17/5/63
74H	do. do. do.	186·0	17/5/63
75H	do. do. do.	190·8	17/5/63
76H	do. do. do.	192·9	17/5/63
77H	do. do. do.	196·2	17/5/63
78H	do. do. do.	189·7	17/5/63
79H	do. do. do.	198·7	17/5/63
80H	do. do. do.	188·9	17/5/63
81H	do. do. do.	193·3	17/5/63
82H	do. do. do.	198·1	17/5/63
83H	do. do. do.	193·1	17/5/63
84H	do. do. do.	187·4	17/5/63
85H	do. do. do.	187·0	17/5/63
86H	do. do. do.	188·9	17/5/63
87H	do. do. do.	189·0	5/1/63
88H	Hawkstone Oil Company Limited	189	28/2/63
89H	West Australian Petroleum Pty. Ltd.	192	27/2/63
90H	do. do. do.	160·5	27/2/63
91H	do. do. do.	133·8	27/2/63
92H	do. do. do.	180·1	27/2/63
93H	do. do. do.	195·4	27/2/63
94H	do. do. do.	186·5	27/2/63
95H	do. do. do.	200	12/6/63
96H	do. do. do.	100	18/3/64
97H	do. do. do.	196	26/7/64
98H	do. do. do.	200	26/7/64
99H	do. do. do.	190·5	4/12/64
100H	do. do. do.	200	4/12/64
101H	do. do. do.	193·6	17/12/64
102H	do. do. do.	196	13/1/65

DRILLING.

Permit to Explore 27H.

Permit to Explore 27H is held by West Australian Petroleum Pty. Ltd., and covers the Perth Basin. The company completed one oil-test well (Jurien No. 1) and five stratigraphic holes (Hill River Nos. 1-4, and Abbarwardoo No. 1) in the permit area during 1962, and a further test well (Woolmulla No. 1) and a stratigraphic hole (Eganu No. 1) were still being drilled at the end of the year. Details of each are as follows:—

Jurien No. 1:

Type: Oil-test.
License to Prospect: 98H.
Latitude and Longitude: 30° 8′ 40″ S., 115° 2′ 54″ E.
Elevation: Ground = 30 feet, derrick floor = 39 feet.
Date commenced: July 9th, 1962.
Date completed: August 28th, 1962.
Total depth: 3,366 feet.
Bottomed in: Precambrian gneiss.
Remarks: Minor showing of gas and traces of fluorescence present in the Lower Triassic sequence.

Woolmulla No. 1:

Type: Oil-test.
Latitude and Longitude: 30° 1′ 24″ S., 115° 11′ 28″ E.
Elevation: Ground = 382 feet, derrick floor = 394 feet.
Date commenced: November 3rd, 1962. Drilling ahead on December 31st, 1962, at 5,400 feet.
Remarks: Minor showings of oil and gas recorded in the Lower Cretaceous sequence.

Hill River No. 1:

Type: Stratigraphic.
Latitude and Longitude: 30° 16′ S., 115°18′ E.
Elevation: Ground=363 feet, Kelly bushing=368 feet.
Date commenced: April 2nd, 1962.
Date completed: April 25th, 1962.
Total depth: 1,900 feet.
Bottomed in: Lower Jurassic.
Remarks: Thin coal seams present in the lower Jurassic sequence.

Hill River No. 2:

Type: Stratigraphic.
Latitude and Longitude: 30° 11′ S., 115° 14′ E.
Elevation: Ground=620 feet, Kelly bushing= 625 feet.
Date commenced: May 6th, 1962.
Date completed: May 24th, 1962.
Total depth: 1,620 feet.
Bottomed in: Lower Jurassic.

Hill River No. 3.

Type: Stratigraphic.
Latitude and Longitude: 30° 00′ 32″ S., 115° 11′ 13″ E.
Elevation: Ground=408 feet, Kelly bushing=413 feet.
Date commenced: August 12th, 1962.
Date completed: August 27th, 1962.
Total depth: 865 feet.
Bottomed in: Upper Triassic.

Hill River No. 4:

Type: Stratigraphic.
Latitude and Longitude: 30° 23′ 24″ S., 115° 13′ 49″ E.
Elevation: Ground=305 feet, Kelly bushing=309 feet.
Date commenced: 19th June, 1962.
Date completed: 30th June, 1962.
Total depth: 1,010 feet.
Bottomed in: Upper Triassic.
Remarks: Four additional shallow holes were drilled in the vicinity of Hill River No. 4, to obtain structural information. They are—

- Hill River No. 4/1, drilled at a shot-point AD-102 to 500 feet, bottoming in Lower Jurassic;
- Hill River No. 4/2, drilled at shot-point AD-104 to 510 feet, bottoming in Upper Triassic;
- Hill River No. 4/3, drilled at shot-point V-106 to 510 feet, bottoming in Upper Triassic; and
- Hill River 4/4, drilled to 510 feet at shot-point Q-89, bottoming in Upper Triassic.

Abbarwardoo No. 1:

Type: Stratigraphic.
Latitude and Longitude: 28° 35′ 10″ S., 115° 09′ 35″ E.
Elevation: Ground=720 feet, Kelly bushing=725 feet.
Date commenced: December 12th, 1962.
Date completed: December 22nd, 1962.
Total depth: 2,000 feet.
Bottomed in: Lower Permian.

Eganu No. 1:

Type: Stratigraphic.
Latitude and Longitude: 29° 59′ 05″ S., 115° 49′ 35″ E.
Elevation: Ground=772 feet, Kelly bushing=777 feet.
Date commenced: December 30th, 1962. Preparing to drill ahead at 67 feet on December 31st, 1962.

Permit to Explore 28H.

Permit to Explore 28H is held by West Australian Petroleum Pty. Ltd., and covers the Carnarvon Basin. Three stratigraphic holes (Wandagee Nos. 1, 2, and 3) were drilled in this permit area during 1962. Details of each are as follows:—

Wandagee No. 1:

Type: Stratigraphic.
Latitude and Longitude: 23° 53′ 15″ S., 114° 23′ 51″ E.
Elevation: Ground=225 feet, derrick floor=234 feet.

Date commenced: 25th April, 1962.
Date completed: 17th June, 1962.
Total depth: 3,521 feet.
Bottomed in: Lower Silurian.
Remarks: Completed as a water bore. This well was put down on the site of the earlier Wandagee corehole No. 1, which was drilled to a depth of 721 feet from 6th January 1962 to 14th January, 1962, bottoming in Upper Devonian strata.

Wandagee No. 2:

Type: Stratigraphic.
Latitude and Longitude: 23° 53′ 13″ S., 114° 31′ 38″ E.
Elevation: Ground=338 feet.
Date commenced: 16th January, 1962.
Date completed: 25th January, 1962.
Total depth: 1,013 feet.
Bottomed in: Lower Permian.

Wandagee No. 3:

Type: Stratigraphic.
Latitude and Longitude: 23° 49′ 43″ S., 114° 20′ 03″ E.
Elevation: Ground = 183 feet.
Date commenced: 30th January, 1962.
Date completed: 2nd February, 1962.
Total depth: 730 feet.
Bottomed in: Pre-Cretaceous rocks.

Permit to Explore 30H.

Permit to explore 30H is held by West Australian Petroleum Pty. Ltd., and covers the Canning Basin. Three oil-test wells (Babrongan No. 1, Langoora No. 1, and Hawkstone Peak No. 1) were drilled in this permit area during 1962. Details of each are as follows:—

Babrongan No. 1:

Type: Oil-test.
License to Prospect: 96H.
Latitude and Longitude: 18° 23′ 23″ S., 123° 35′ 37″ E.
Elevation: Ground = 350 feet, derrick floor = 360 feet.
Date commenced: 29th May, 1962.
Date completed: 6th August, 1962.
Total depth: 6,395 feet.
Bottomed in: Upper Devonian.
Remarks: No signs of oil or gas were encountered. The well was abandoned because of stuck drill-pipe, following the collapse of the mast.

Langoora No. 1:

Type: Oil-test.
Latitude and Longitude: 17° 18′ 7″ S., 124° 6′ 48″ E.
Elevation: Ground = 69 feet, derrick floor = 80 feet.
Date commenced: 25th August, 1962.
Date completed: 6th October, 1962.
Total depth: 5,279 feet.
Bottomed in: Precambrian schist.
Remarks: No significant signs of oil or gas were encountered.

Hawkstone Peak No. 1:

Type: Oil-test.
License to Prospect: 101H.
Latitude and Longitude: 17° 14′ 45″ S., 124° 24′ 26″ E.
Elevation: Ground = 161 feet, derrick floor = 170 feet.
Date commenced: 17th October, 1962.
Date completed: 2nd December, 1962.
Total depth: 3,897 feet.
Bottomed in: Precambrian quartzite.
Remarks: No signs of oil or gas were encountered.

GEOPHYSICAL OPERATIONS.

Seismic.

During the year seismic operations were conducted in the Perth, Carnarvon, Canning, Bonaparte Gulf, and Officer Basins.

West Australian Petroleum Pty. Ltd. carried out operations totalling some 13 party-months in the Perth Basin (Permit 27H), 6½ party-months in the Carnarvon Basin (Permit 28H), and seven party-months in the Canning Basin (Permit 30H).

Associated Freney Oil Fields N.L., conducted a seismic survey of The Sisters Licenses to Prospect (61-62H) in the Canning Basin, which occupied about two weeks.

In the Bonaparte Gulf Basin (Permit 127H), Oil Development N.L., conducted some two party-months of seismic work.

Exoil Pty. Ltd., ran a regional seismic line along the Officer Basin extending from the South Australian part into Western Australia (Permit 135H), nearly one party-month being spent in this State.

The Bureau of Mineral Resources continued a regional seismic survey, commenced in 1961, between Giles weather station and Carnegie homestead, in the south-eastern part of the Canning Basin. This work occupied approximately two party-months. A contract seismic crew engaged by the Bureau carried out a seismic survey of the Poole Range Anticline, in the Canning Basin, over a period of nearly five months.

Gravity.

Gravity surveys were carried out during the year in the Perth, Carnarvon, and Canning Basins. Wapet conducted surveys amounting to some four party-months in the northern Perth Basin (Permit 27H), and some six party-months in the northern Canning Basin (Permit 30H). A brief reconnaissance gravity survey was also carried out by this company on Barrow Island (Part of Permit 29H), in the Carnarvon Basin.

The Hawkstone Oil Co. Ltd., and Oil Development N.L., conducted gravity surveys, each amounting to about one party-month, on Permits 142H and 106H, respectively near the northern margin of the Canning Basin.

A regional gravity survey of the south-eastern part of the Canning Basin was carried out by the Bureau of Mineral Resources, a total area of some 55,000 square miles being covered. Helicopters were utilized in this work, which occupied about three months. Additional gravity readings were made along the Bureau of Mineral Resources' seismic line between Giles and Carnegie.

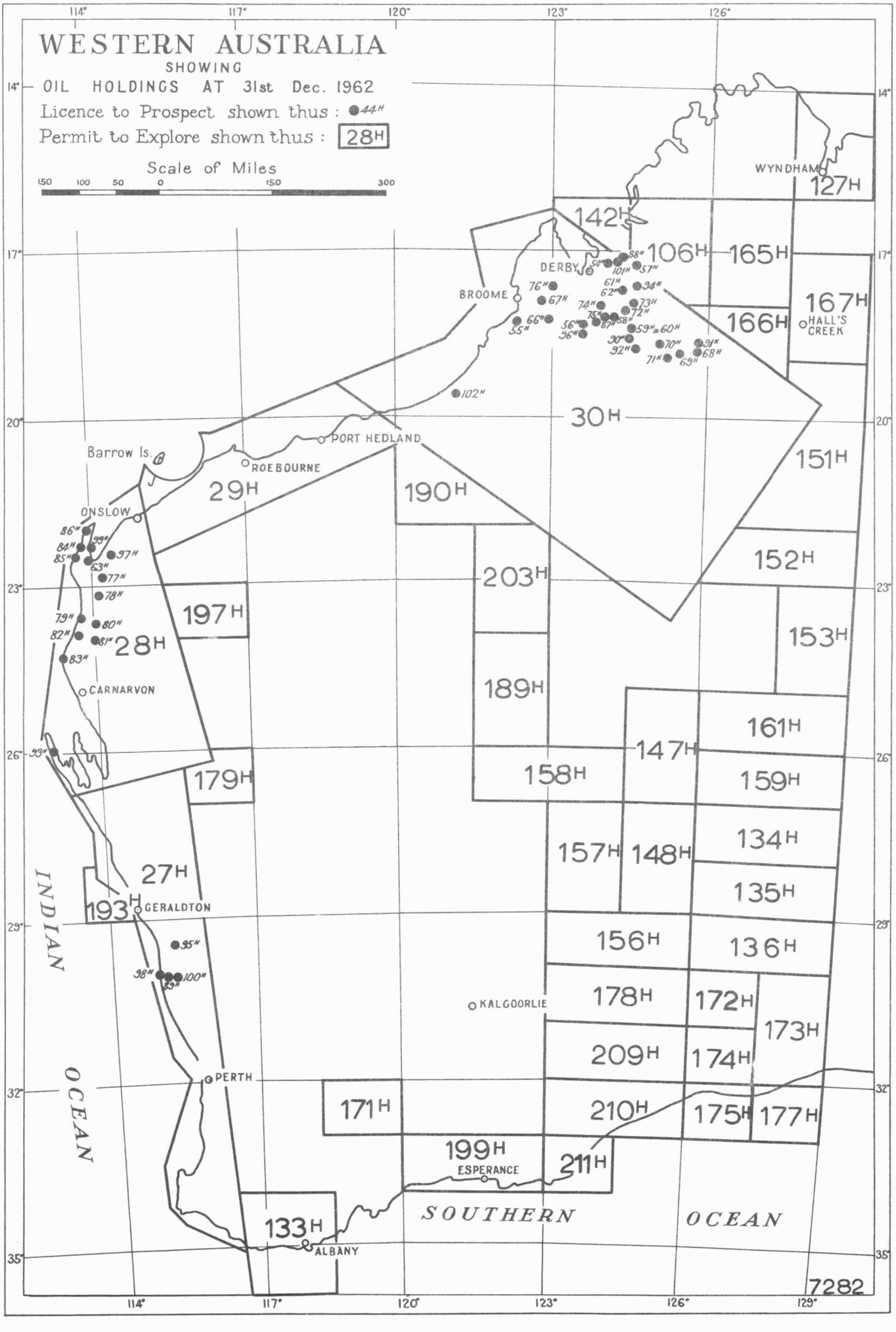
Aeromagnetic.

The only aeromagnetic work done in Western Australia during 1962 was in the Canning Basin, where Wapet conducted a survey extending previous aeromagnetic coverage to include about 160,000 square miles of the southern and eastern parts of the basin. This work occupied some 1½ months, and was incomplete at the end of the year.

GEOLOGICAL OPERATIONS.

Geological field investigations played only a small part in the exploration programmes of the various companies searching for oil in Western Australia. Wapet employed two geologists for two weeks in field work in the Hill River area of the Perth Basin, and other companies carried out even briefer field studies. Most geological activity was concerned with the collation of previously gathered information with the results of exploratory wells and geophysical investigations.

The Geological Survey of Western Australia conducted field studies, which are still incomplete, amounting to three months for two geologists on the Devonian reef complexes of the Canning Basin, and two months for one geologist in regional mapping of the southern part of the Perth Basin.


WESTERN AUSTRALIA
SHOWING
OIL HOLDINGS AT 31st Dec. 1962
Licence to Prospect shown thus : 44H
Permit to Explore shown thus : 28H
Scale of Miles
150 100 50 0 150 300
WYNDHAM
127H
142H
106H
165H
167H
166H
HALL'S CREEK
DERBY
BROOME
30H
151H
PORT HEDLAND
ROEBOURNE
Barrow Is.
29H
190H
ONSLOW
152H
203H
197H
153H
28H
CARNARVON
189H
161H
147H
158H
159H
179H
134H
157H
148H
27H
135H
193H
GERALDTON
156H
136H
178H
172H
KALGOORLIE
173H
209H
174H
PERTH
171H
210H
175H
177H
199H
ESPERANCE
211H
INDIAN OCEAN
SOUTHERN OCEAN
133H
ALBANY
7282

FACIES CHANGES IN THE ARCHAEAN OF THE ROEBOURNE AREA, WEST PILBARA GOLDFIELD.

by R. C. Horwitz.

Based on field work by W. Bock and the author early in 1962, the following conclusions on facies equivalence are presented.

In the Archaean rocks of the Nickol River area, north-west of Roebourne, coarse clastic rocks rest disconformably upon basic volcanic rocks. A dolerite which intrudes the volcanic rocks is truncated at this contact. This break in sedimentation does not persist along strike as the clastic and volcanic rocks pass laterally into an unbroken sequence of jaspilites and calcareous sediments. Still further along the strike, the jaspilites and calcareous sediments change facies to a sequence of bedded amphibolites with rare jaspilites. All these beds are overlain by basic volcanic rocks, which together with the volcanic rocks already mentioned, elsewhere form an apparently unbroken sequence consisting mainly of pillow lavas.

It is thus concluded that, in this region, in a part of this Archaean succession, basic lavas, an intrusive dolerite and sediments are all roughly contemporaneous. All these rocks form the lower part of the Archaean succession. The upper part, recently established by Ryan and Kriewaldt (1963), consists of banded iron, chert and shale with no record of lavas.

REFERENCE.

Ryan, G. R., and Kriewaldt, M., 1963, Archaean Stratigraphy in the Roebourne area, West Pilbara Goldfield: West. Australia Mines Dept. Ann. Rept. 1962.

THE STRATIGRAPHIC SEQUENCE IN THE WARBURTON RANGE, EASTERN DIVISION.

by R. C. Horwitz and J. Sofoulis.

During a short visit to the Warburton Range, a traverse was made across all the rocks that occur below the Permian glacials. This paper deals with these rocks on the Talbot One-Mile Military Sheet.

Talbot and Clarke (1917) gave an account of these rocks. They recognised a break in sedimentation, thus subdividing this sequence into two units—a complex lower unit, overlain by the Townsend Range "Series." They equated the basic rocks in the lower unit with the greenstones of the Kalgoorlie area, and the upper unit with the "Nullagine Series" which they tentatively assigned to the Ordovician.

F. G. Forman (1937) gave a summary of his previous investigations in the area (1932, 1933). He first recognised the presence of Nullagine-type rocks in the Warburton Ranges and suggested that:—"pending further investigations, the basal rocks of the Nullagine series in this area should be regarded as being the little altered sediments immediately underlying the Warburton Range Porphyries and that some, at least, of the greenstones and the altered sediments beneath the porphyries should be referred to the older Pre-Cambrian" (The older Pre-Cambrian here referred to the Kalgoorlie greenstones).

After a reconnaissance trip to the area, Sofoulis (1962) came to conclusions that agreed with Wilson, Compton and Jeffery (1961): that the oldest rocks exposed in the Warburton Ranges are younger than the greenstones of the Kalgoorlie region. He proposed a Lower Proterozoic age for all the Precambrian rocks of the Warburton Ranges and the Nullagine "System" and equated them with what is known as the "Archaean" in South Australia; one of the criteria used is the similarity between the acid igneous rocks in these three provinces. Because of a misinterpretation in structure, these igneous rocks were believed to be the youngest of all the rocks below the Permian in the Warburton Ranges.

Some of the conclusions reached in every one of the papers cited are considered correct and these are summarized below:—

(1) The Archaean (rocks broadly equivalent to the Kalgoorlie greenstones) is not represented in the Warburton Range, as suggested by Wilson, Compton and Jeffery (1961), and by Sofoulis (1962).

(2) The break in sedimentation established by Talbot and Clarke (1917) is considered valid: as noted by these authors, the base of the Townsend Range "Series" contains abundant reworked elements of the acid igneous rocks.

(3) The lower part of the Townsend Range "Series" (The Ainslie Volcanics of Sofoulis, 1962) is composed of basic volcanics, conglomerates, quartzites, and calcareous beds, which show copper mineralization. They rest on a unit with a characteristic acid igneous suite which is widespread in the "Archaean" of South Australian geologists. All the facies and characteristics of the lower part of the Townsend Range "Series" thus apply to the Willouran Series (basal unit of the Adelaide System, Mawson, 1927; Sprigg, 1949).

(4) The upper part of the Townsend Range "Series" (Townsend Quartzite of Sofoulis, 1962) is mainly composed of felspathic quartzite which is locally pebbly. Its lithology and distribution, as shown by Sofoulis (1962), suggest that it is unconformable on the Ainslie Volcanics. In a creek section nine miles south-east of Warburton Mission, felspathic gypsiferous silts, shales and limestones with quartzites are exposed. They are the highest beds observed in the Townsend Range "Series" and overlie the felspathic quartzites. The sediments of the upper half of the Townsend Range "Series" strongly resemble the beds of the passage from the Marinoan Series (upper part of the Adelaide System) to Lower Cambrian in South Australia.

(5) All these rocks are part of a south-west facing limb on the Talbot One-Mile Sheet as already recognised by Talbot and Clarke.

REFERENCES.

Forman, F. G., 1932, Preliminary Report on a Geological Reconnaissance between Laverton and Warburton Ranges: West. Australia Geol. Survey Ann. Rept. 1931.

—1933, Conclusions of Report on a Reconnaissance Survey of the Country Lying between Laverton and the Warburton Ranges: West. Australia Geol. Survey Ann. Rept. 1932.

—1937, A Contribution to our Knowledge of the Pre-Cambrian Succession in Some Parts of Western Australia (Presidential Address): Royal Soc. West. Australia Jour., v.23, 1936-1937.

Mawson, D., 1927, Geological Notes on an Area Along the North-Eastern Portion of the Willouran Ranges: Royal Soc. S. Australia Trans., v.51, 1927.

Sofoulis, J., 1962, Geological Reconnaissance of the Warburton Ranges Area, Western Australia: West. Australia Geol. Survey Ann. Rept. 1961.

Sprigg, R. C., 1949, Thrust Structures of the Witchelina Area, South Australia: S. Aust. Royal Soc. Trans., v.73, pt.1.

Talbot, H.W.B., and Clarke, E. de C., 1917, A Geological Reconnaissance of the Country between Laverton and the South Australian Border, Including Part of the Mount Margaret Goldfield: West. Australia Geol. Survey Bull. 75.

Wilson, A. F., Compston, W., and Jeffery, P. M., 1961, Radioactive Ages from the Pre-Cambrian Rocks of Australia (in Geochronology of Rock Systems): New York Acad. Sci. Annals, v.91, pt.2.

ARCHAEAN STRATIGRAPHY IN THE ROEBOURNE AREA, WEST PILBARA GOLDFIELD.

by G. R. Ryan and M. Kriewaldt.

Regional mapping of the Roebourne and Dampier 1:250,000 Sheets in the West Pilbara Goldfield, although not complete, has disclosed a definite succession in the Archaean rocks of the area.

Broadly, ignoring for the moment the many facies changes, the succession from top to bottom consists of five main units, as follows:—

(5) Banded iron, chert, and shale; fine grained purple and green clastic rocks; manganese staining.

(4) Basic volcanic rocks including pillow lavas.

(3) Chert and calcareous sediments; prase, fuchsite. Arenaceous sediments.

(2) Amphibolites, ultrabasic rocks, acid lavas; severely metasomatised.

(1) Gneiss, granite.

Granite has been seen to intrude all but the highest unit.

These rocks are folded into a series of generally broad anticlines and tight synclines, with gneiss in the cores of anticlines and the uppermost beds restricted in outcrop to the axes of the synclines. Foliation in the gneiss is in most cases parallel to the overlying strata.

The beds immediately above the gneiss have been severely metasomatised, with the production of a wide range of hybrid rocks ranging from ultrabasic to gabbroic and granitic in composition. Sporadic copper mineralization is found in this zone, and deposits of corundum, asbestos, and titaniferous magnetite are known.

This lower unit (2) includes calcareous rocks, and there is a gradation to the overlying unit (3) where calcareous and arenaceous sediments are now represented by amphibole schist and quartz-mica-schist. Above these rocks, banded chert and thin siltstone beds are interbedded with calcareous sediments; prase, fuchsite, and nickeliferous dolomite are developed locally. This horizon has been used with some success as a marker. Copper and gold mineralisation is also found in this succession.

Tough blue volcanic rocks and pillow lavas (4) overlie the chert horizon but are also present lower in the Archaean succession. Near the mouth of the Nickol River, chert and calcareous sediments pass laterally to volcanic rocks; arkose, conglomerate, and felspathic sandstone are found overlying a local disconformity (Horwitz, 1963). South of Roebourne the volcanic rocks, chert, and calcareous sediments (3 & 4) are represented by a very thick succession of red and green clastic rocks, massive chert beds, and volcanic rocks in which turbidites have been recognised.

A distinct change in environment is indicated by the beds of the uppermost unit (5), which consists of banded jaspilite, hematite, and chert with interlaminated shale, some thicker beds of red shale and siltstone, and sporadic manganese staining. This unit is well defined and consistent, and represents a marked change from the instability which prevailed during deposition of the lower units. Nowhere has granite been seen to intrude these upper beds.

The progression from basal gneiss in the anticlinal domes to manganiferous iron beds in the synclinal troughs provides a reliable facing throughout the area. This has greatly facilitated interpretation of the structure of the area.

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THE OCCURRENCE AND HYDROLOGICAL SIGNIFICANCE OF CALCRETE DEPOSITS IN WESTERN AUSTRALIA.

by J. Sofoulis.

INTRODUCTION.

The calcrete deposits are here referred to as an assemblage of surface limestone and opaline silica deposits that are generally associated with fine gravel beds of riverine origin. These formations occur in broad fossil valleys that still serve as trunk valleys for the present drainage systems.

The valley locations and physical characteristics presented by the calcrete deposits provide excellent conditions for ground water storage and aquifer recharge. Their distribution in the lower rainfall regions and utilization as shallow aquifers has been of valuable assistance to the State's pastoral development.

RECORDED DISTRIBUTION IN WESTERN AUSTRALIA.

Calcrete deposits are known in most trunk valleys of the major drainage systems in the North-West and Eastern Land Divisions. Those in the Oakover valley are referred to by Maitland (1904) and by Traves and others (1956) as the Oakover Beds. Similar deposits from this and other drainage systems of the North-West Division are described by Noldart and Wyatt (1963) and by de la Hunty (1960) as the Oakover Formation. Talbot (1920 and 1926) has referred to further deposits in the Ashburton drainage system as the Brumby Creek Beds.

Extensive developments of calcrete formations also occur throughout the Murchison District. Those of the Wiluna-Meekatharra area are described by C.S.I.R.O. Land Research Division as the Cunyu and Mileura Land Systems (Mabbutt and others, in press). The major occurrences known at Wiluna and at Lorna Glen have previously been referred to by Brookfield (in press), Chapman (1962), Morgan (1962), de la Hunty (1959), and by Ellis (1953).

Many of the deposits locally recorded in other parts of the State as kunkar, travertine, tufa, creek limestone, caliche, etc., are believed to be calcrete deposits. Traves and others (1956) consider that the Oakover Beds of the Pilbara area closely resemble the Tertiary deposits of the East Kimberley and Northern Territory. Recent investigations have also confirmed the presence of similar calcrete formations in the Eastern Division and in the Central Aborigines Reserve (Sofoulis, 1962a and 1962b).

Formations of this nature appear to be absent in the South-West and Eucla Land Divisions. A dissected remnant is recorded near Boorabbin (Sofoulis and Bock, 1962) but in general the trunk valleys in the southern part of the State are cut to basement or else they contain kunkarised earths. The kunkarised earths are believed to be unrelated to the calcrete deposits and rest directly on weathered basement without detrital fill.

The approximate area in which calcrete deposits are known to occur are shown on the accompanying sketch map (figure 9).

LITHOLOGY AND GENERAL DESCRIPTION.

The upper part of the calcrete deposits consists of limestones that contain thin detrital bands and cellular opaline silica layers. These form sequences that range from several feet to 100 feet thick but are usually of the order of 15 feet to 30 feet thick. The lower part of the deposit rarely exceeds a thickness of 50 feet and consists of gravels, sands and silts overlying an eroded surface of weathered rock. These detrital beds (subsequently referred to as fine gravels) are mainly unconsolidated although some sections show lime, silica and iron oxide indurations. Small pockets or bands of cellular opaline silica up to 10 feet or more thick

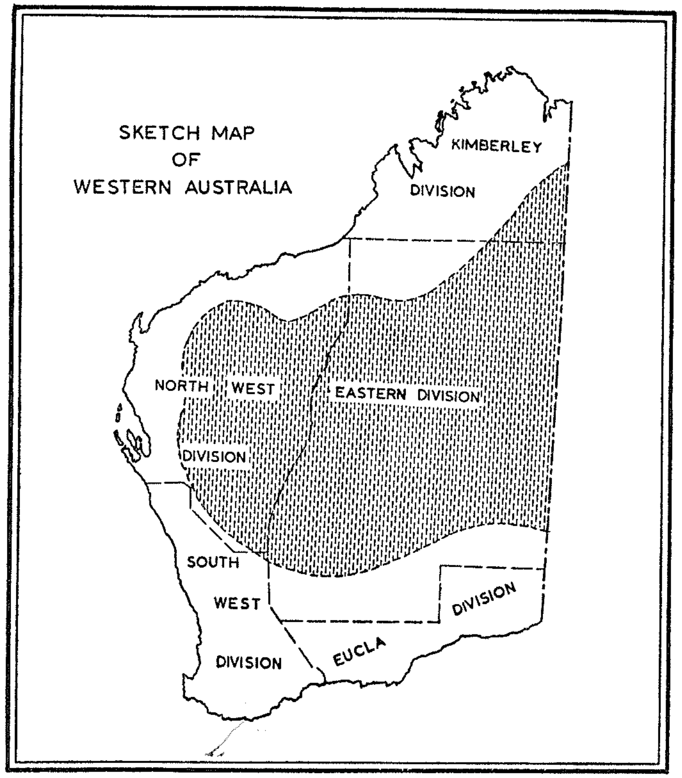
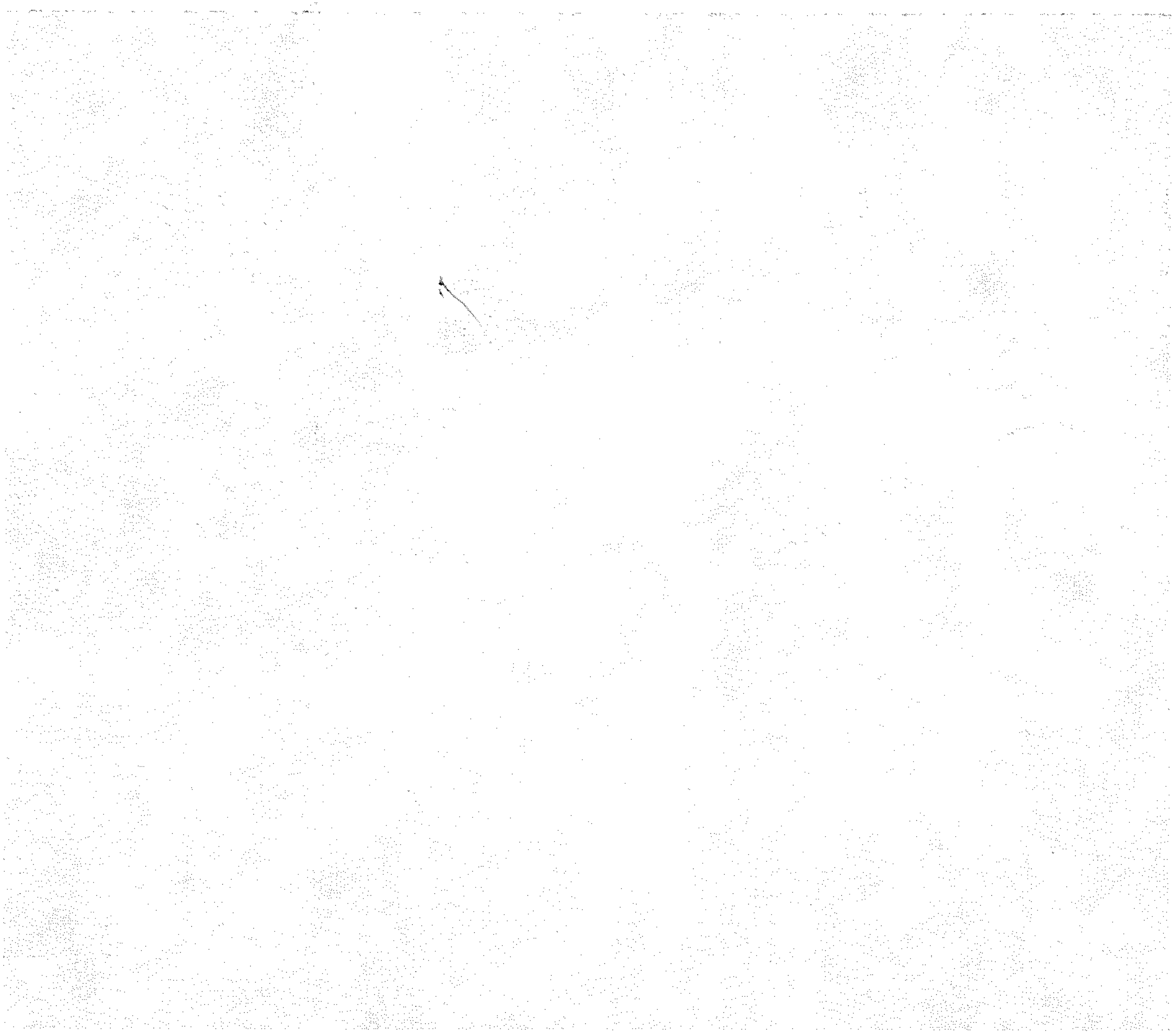


Fig. 9 (above). Sketch map of Western Australia showing the approximate area (shaded) within which calcrete deposits are known to occur.

Fig. 10 (right). Aerial photograph showing characteristic photo-pattern of calcrete deposits, Weeli Wolli Creek, North West Division. Photo illustrates how limestone platforms and kunkarised mounds (white pattern), alluviated trunk and tributary drainages and flanking outwash plains. Lands Dept. photo W.A.373 Roy Hill run 18, No. 5123. Approximate Scale: 50 chains to an inch.



are characteristically developed at the interface of fine gravels and limestone and often mark the present water table.

Opaline silica bands and fine gravels are exposed only in areas of greater dissection. Thus surface exposures are usually kunkarised limestone and consist of secondary lime cements, cappings, concretionary nodules, and powdery calcareous earths. Karst and sub-karst features are locally associated with these surfaces.

Extensive valley tracts of calcrete deposits are often continuous for distances up to 10 miles or more. These are usually of the order of 1 mile wide but locally may broaden to 4 miles or more, particularly in the larger drainage systems or in areas above stream constrictions or below confluent valleys. Smaller limestone developments usually appear as discontinuous valley trains separated by alluvium. Others occur as isolated pockets occupying restricted or perched basins eroded in weathered rock.

Valley side benches, breakaways, and flat-topped mesas (up to 80 feet high), composed of calcrete deposits are observed in some drainage systems of the North-West Division where the base level has been lowered (e.g. Oakover River, Weeli Wolli Creek). Most other drainages contain calcrete limestones at valley floor level where they appear as low limestone platforms, or kunkarised mounds, separated by a network of narrow alluviated channels (See figure 10). These are usually flanked or overlapped by extensive deposits of alluvium and fine outwash or are locally buried by aeolian sands.

In some instances, buried calcrete deposits are reflected by the vegetation and their extensions can be traced below soil covered areas. Calcrete deposits that locally appear in the desert areas are interpreted as relics of buried systems that drained internally or were tributary to major salt lake basins.

ORIGIN OF CALCRETE DEPOSITS.

Various authors have suggested that the limestone and opaline silica layers represent primary chemical deposits that were precipitated from solution in ground and surface waters. The nature and appearance of calcrete formations at different elevations along the same drainage system, together with broadening above valley constrictions or at confluent drainages, suggests that these formations could have been deposited in ponded sections of drainages following the cessation of a past period of higher rainfall.

Correlation between discontinuous outcrops in one or separate drainage systems is difficult as no fossils have been found. (These were probably inhibited by the concentration of salts.) However, it is assumed that the calcrete deposits are more or less contemporaneous and that their formation was governed by the same widespread climatic conditions. Since the calcrete deposits are locally underlain by a ferruginised layer and contain lateritic gravel bands, their formation is believed to date back to the period of lateritisation (Tertiary).

HYDROLOGICAL SIGNIFICANCE.

The calcrete deposits constitute important aquifers that are capable of providing a high density of watering points and are capable of yielding ground water of quantity and quality suitable for stock use and locally suitable for domestic, irrigation and town supply use.

The distinctive photo pattern (see figure 10) and pattern consistency over wide areas could provide a rapid means of assessing areas of possible aquifer potential. Their delineation could also assist in planning permanent watering points for pastoral extension as well as assist in the strategic selection of further watering points in remote regions.

Various factors influencing the economic usefulness of calcrete deposits in the Wiluna and Lorna Glen areas have been studied in detail by Chapman (1962) and by Brookfield (in press). These studies have included such aspects as porosity, permeability, storage capacity, flow rate, run off, recharge, yield, salinity, etc., and their resultant findings should be applicable to calcrete deposits of other parts of the State. Other aspects of regional significance are discussed below.

Formation Factors.

In addition to other factors, the aquifer potential of a calcrete deposit is influenced by its areal extent, thickness and state of dissection. The formations contain assemblages of varying porosities that in turn influence salinities and yields. Reductions in porosity are also effected by lime, silica and iron oxide indurations. In general the layers of greater aquifer potential are the unconsolidated coarse sands and gravel beds, cellular opaline silica bands, cavernous limestone, or basement rocks with high effective porosity.

Depth to Groundwater.

In most areas the water table in calcrete formations generally lies between 20 feet and 60 feet below the surface. Locally it can be as shallow as 5 feet or as deep as 100 feet or more. Low pressure waters, where present, are generally restricted to deeper aquifers. In some instances stream dissection or karstic phenomena may extend to water table level to provide a permanent spring, soak, or natural well. (e.g. Millstream Homestead, Weeli Wolli Spring, Wort Native Well.)

Quality and Yield.

The waters currently supplied from calcrete deposits are generally of good quality and excellent for stock purposes. Higher salinities are often associated with formations of lower effective porosity. In these areas the quality may show improvement towards the outer margins of the calcrete deposit particularly where these are flanked by extensive areas of alluvium or outwash. Highly saline sectors are generally restricted to the lower parts of valleys or to lower drainage reaches that are in close proximity to salt lakes. At Cue, Wiluna and Lorna Glen some calcrete aquifers yield good quality waters in amounts sufficient for irrigation and town supply use.

From a tabulation by Brookfield (in press), 74 per cent. of the watering points in calcrete formations of the Wiluna-Meekatharra area have salinities of less than 250 grains of sodium chloride per gallon. The tabulation also shows that 58 out of 124 watering points have yields greater than 4,000 gallons per day and that, of these, five have yields greater than 5,000 gallons per hour. In such pastoral areas, it is considered that the current supplies are mainly governed by equipment used and reflect demand rather than potential.

From these data, the quality and quantity of water available from calcrete deposits in other areas can be expected to show considerable fluctuations. It is also likely that some large untested deposits may be capable of providing good quality waters in amounts sufficient for restricted irrigation and town supply use.

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REPORT ON DIAMOND DRILLING ON THE PINNACLES GROUP OF LEASES, NEAR CUE, MURCHISON GOLDFIELD.

by J. H. Lord.

LOCALITY.

The Pinnacles leases are situated in the Murchison Goldfield, about 12 miles south-east of Cue. The distance is slightly longer by a graded gravel road.

Cue is connected to the ports at Geraldton and Perth by rail at distances of 263 and 533 miles respectively. The distances by road are 268 and 408 miles respectively.

HISTORY.

Gold was discovered at The Pinnacles or Jasper Hill and the first leases, the Comet (now Gold Mining Lease 676D) and the Eclipse (now G.M.L. 664D) were granted in November, 1913.

The Comet and adjoining leases were taken over by the Black Range Pinnacles Co. N.L. from the original owners Messrs. Phillips and Campbell. This company erected a small treatment plant, which operated until 1918. Over 90 per cent of the ore produced from the Comet lease was treated during this period.

As the only production, since that period, came from stripping the existing workings and from old dumps, the grade has been low.

The Eclipse lease, originally owned by Messrs. Harrison and Kelly, was investigated in 1914 by the Great Fingall Company, who apparently abandoned it. During the 1930s, a Mr. H. L. McGee, formerly of Bewick Moreing & Co. and the Great Fingall Company, operated the Eclipse, and an unsuccessful attempt was made to form a public company. Since World War II the only production has been low grade material from old dumps which have been treated at the State battery at Cue by the leaseholder.

The other leases on the line of mineralisation have been worked only on a small scale by prospectors.

In 1958, New Consolidated Gold Fields (Australia) Pty. Ltd., obtained an option over the area and put down five diamond drill holes (numbered 1 to 5 on Plates XXIII and XXIV). The three holes on the Comet leases (G.M.L. 676 and 670) showed interesting values, while the two holes on the Eclipse lease (G.M.L. 664) were disappointing. The company abandoned its option.

In 1959, a syndicate put down diamond drill hole No. 6 to intersect the lode on the Comet leases at a great depth, but the results were poor.

In 1961, another syndicate approached the Department of Mines and negotiated a subsidy on a pound-for-pound basis to carry out further drilling at Pinnacles. The location of the drill holes and examination of the core were undertaken by the Geological Survey.

The three drilling programmes were carried out by K. and W. H. McCallum, drilling contractors of Cue, in an efficient manner. Core recovery throughout was excellent. The author planned and examined the results of each programme.

PRODUCTION.

The Department of Mines' records show that prior to 1950, the Pinnacles group of leases now under consideration had produced 11,967 tons of ore for 5,715 fine ounces of gold (9.5 dwt. per ton). About 85 per cent. of this production occurred between 1913 and 1918 and it is doubtful whether all of the gold won from the tailings has been included in these figures.

The production from the Comet Lease (G.M.L. 676D) is as follows:—

Years	Tonnage	Grade	Grade
		fine oz.	dwts./ton
1913–1918	9,225	3,929·6	8·5
1932–1935	1,057	138·5	2·6
Total	10,282	4,068·1	8·0

The ore treated during the period 1932-1935 was obtained from old dumps and by stripping old workings. Some similar material has been treated in recent years, and no ore has been drawn from underground.

The production from the Eclipse lease (G.M.L. 664D) according to the Department of Mines is as follows:

Years	Tonnage	Grade	Grade
		fine oz.	dwts./ton
1913–1915	75	58·6	15·6
1935–1938	583	193·8	6·7
Total	658	252·4	7·7

MINE WORKINGS.

The most extensive underground workings, on the Comet lease, were done by the original Black Range Mining Co. The company sank a three-compartment inclined (45 degrees) shaft to a depth of 230 feet (vertical depth 160 feet), drove on the lode for nearly 800 feet, and some stoping was done.

On the Eclipse lease the chief workings are two inclined shafts (60 degrees), connected on the 71 foot level, and stoped above.

The line of lode can be traced for the full length of the leases and has been prospected at numerous points with small shafts, costeans and potholes.

GEOLOGY.

The regional geology of this area has been described fully by F. R. Feldtman in Bulletin 80, of the Geological Survey of Western Australia. A regional map and report of the Cue district by J. C. McMath appear in the Annual Report of the Geological Survey for 1950.

The leases are situated on an island or roof pendant of the Archaean greenstone series, surrounded by granite and granite-gneiss. The gold mineralization occurs along lines of weakness or shear lines. There are two major lines—the Comet and the Pinnacle. The former occurs within the area being considered (See Plates XXIII and XXIV).

The "greenstones" consist of basic lavas and dolerites, which have been subjected to low grade regional metamorphism producing hornblende and chlorite schists. Some massive epidiorites occur.

The country rock, for the sake of logging, has been termed "hornblende schist." The degree of alteration is variable and produces a rock which varies from quartz-actinolite schist to a chlorite-talc schist. The latter occurs on the hanging wall of the lode formation.

The Comet line can be traced for 2¼ miles and gold has been produced along the northern half. The general strike of this Comet lode formation is N. 30° E. and it dips at 40 to 60 degrees east at the northern end, steepening to 60 to 80 degrees east in the centre and southwards. On the Comet lease the lode formation is up to 20 feet in width with a footwall and hanging wall lode. The mining was done on the footwall lode, whereas on the adjoining lease (G.M.L. 670D) to the north, the hanging wall lode is said to have been worked, but this is doubtful. These lodes were supposed to vary in width up to 5 feet, being separated by a varying thickness of formation, consisting mainly of hornblende schist.

The drilling has been concentrated near the Comet mine (leases 676 and 670) and shows that the zone of shearing, which is silicified and mineralised in places, varies in width up to about 25 feet. Within this zone there are sections of unaltered hornblende schist. The gold mineralisation, shown on the core assays, occurs in the silicified zone of shearing, mainly near the footwall.

Although the Eclipse mine is on the same Comet line of lode formation about 50 chains to the south, there is no record of the existence of the hanging wall lode. The lode formation is said to be 12 feet wide.

The lode formation is oxidised to nearly 100 feet at the Comet mine but only to 71 feet at the Eclipse. The ore shoots, according to Feldtman, are erratic but at the Comet mine they appear to pitch at about 55 degrees to the north-east. From the drilling results the pitch appears to be much steeper. The ore shoots do not appear to be associated with any well-defined structural control along the shear line. They may be related to changes in dip of the lode formation.

DRILLING.

During these programmes five inclined and eleven vertical diamond drill holes were drilled. Nos. 1 to 3 and 6 to 15 were near the Comet Mine (leases 676 and 670), while Nos. 4, 5 and 16 were near the Eclipse Mine on lease 664. The position of the drill holes are shown on Plates XXIII and XXIV.

The detailed log of each hole, together with the full assay results of samples submitted to the Kalgoorlie School of Mines are on file at the Geological Survey. The summarized results of each hole are shown in the accompanying table.

It is interesting to note that the lode formation, with gold values, was encountered in all holes; however, the grade in many was low.

The earlier drilling (holes Nos. 1, 2 and 3) had shown that reasonable gold values occurred over a length of 900 feet at a vertical depth of about 250 feet. The continuation of these values to the north was tested with drill holes No. 7 and 8, which showed that, although mineralisation continued, values over a workable width were between only 2 and 3 pennyweights per ton.

Testing to the south showed values in drill hole No. 9 of 10.1 dwt./ton over 68 inches but further south in holes No. 11 and 14 the grade fell to 2 to 3 dwt./ton.

Three holes, Nos. 10, 11 and 13, were drilled to test the lode at a vertical depth of 500 to 600 feet. One hole, No. 10, showed two sections of good values, namely, 13.4 dwt./ton over 45 inches and 7.8 dwt./ton over 28 inches, but the remaining two holes Nos. 12 and 13 showed only low values. Hole No. 6, drilled by another syndicate to this depth, failed also to locate values of interest. It would appear that the possibility of workable values occurring at this depth are remote.

Hole No. 16 was drilled on the Eclipse Lease 664 but, as in earlier holes Nos. 4 and 5, it showed only low values.

ORE POTENTIAL.

Accurate ore reserves can not be assessed on this drilling programme, but some idea of the ore reserve potential can be gained.

Five holes have intersected values at a vertical depth of 200 to 250 feet which, when considered, represent a possible ore body. They are:—

		inches	dwts./long ton
D.D.H. No. 3	....	60	11.0
D.D.H. No. 1	....	90	13.0
D.D.H. No. 15	....	42	3.1
D.D.H. No. 2	....	48	6.7
D.D.H. No. 9	....	68	10.1

This is over a length of 800 feet and it is fair to assume that the ore body may extend beyond the holes at either end and result in an approximate length of 1,000 feet. It would indicate an ore potential of 620 tons per vertical foot averaging 9.9 dwt./long ton at this depth. This probably extends upwards to the old workings but apparently decreases with depth because, at a vertical depth of 550 to 600 feet, only one hole out of four intersected values. It is unknown whether this is only a barren horizon with values improving with depth or not.

TREATMENT.

It has been alleged that this ore is difficult to treat, but investigations by the Kalgoorlie Metallurgical Laboratory show that a 92 per cent extraction can be achieved with the normal amalgamation and agitation cyanidation method. Their report is Ore Dressing Investigation, Report No. 718.

CONCLUSION.

The drilling programmes were not entirely successful. They show an ore body at a vertical depth of 250 feet in the Comet leases of 620 tons per vertical foot averaging 9.9 pennyweights per long ton which, apparently, decreases in value with depth as only one hole located values at a vertical depth of 600 feet.

The values on the Eclipse lease were poor.

A considerable tonnage of ore may exist about the 500 feet vertical level, which should be tested further by underground development.

SUMMARISED DRILLING RESULTS AT PINNACLES, NEAR CUE, WESTERN AUSTRALIA.

Hole No.	Position	Bearing	Angle of Depression (degrees)	Total Depth (feet)	Assays of Interest: Depth (feet) From	Depth (feet) To	Estimated true width (inches)	Average Grade dwts./long ton	Remarks
1	200 feet on bearing 296° 40′ from N.E. corner G.M.L. 676D	N. 58° W.	50°	375	321	332	36	6·80	90″. 13·0 dwts./ton
					332	336½	54	17·00	
2	373 feet on bearing 244° from N.E. corner G.M.L. 676D	N. 58° W.	50°	375	314½	316½	24	4·10	48″. 6·65 dwts./ton
					316½	318½	24	9·20	
3	352 feet on bearing 356° from N.E. corner G.M.L. 676D	N. 58° W.	50°	397	366½	369	30	11·62	60″. 10·95 dwts./ton
					369	371½	30	10·28	
4	542 feet on bearing 146° from N.W. corner G.M.L. 664D	N. 51° W.	50°	350	294¾	298¾	48	1·17	
5	536 feet on bearing 114° from N.W. corner G.M.L. 667D	N. 51° W.	50°	320	297	300	36	0·21	
6	298 feet on bearing 010° from N.E. corner G.M.L. 676D	....	Vertical	648	....	....	....	....	Some low values
7	730 feet on bearing 355° from S.E. corner of G.M.L. 670D	....	Vertical	283	248	250	24	1·79	
					250	252	24	3·81	68″. 2·0 dwts./ton
					252	254	24	1·34	
					254	256	24	1·06	
8	985 feet on bearing 006° from S.E. corner G.M.L. 670D	....	Vertical	255	239	241	24	2·74	
					241	243	24	3·64	51″. 2·5 dwts./ton
					243	245	24	1·12	
9	692 feet on bearing 254° from N.E. corner G.M.L. 676D	....	Vertical	251	187	191	48	3·08	
					191	194½	42	7·22	102″. 7·7 dwts./ton
					194½	196	18	0·50	or
					196	199	36	18·20	68″. 10·1 dwts./ton
10	35 feet on bearing 254° from N.E. corner of G.M.L. 676D	....	Vertical	625	544	548	48	13·44	
					548	551	36	0·28	
					551	555	48	0·28	189″. 4·9 dwts./ton
					555	558	36	1·12	
					558	560½	30	7·78	
11	850 feet on bearing 245° 15′ from N.E. corner G.M.L. 676D	....	Vertical	225	178	180	24	2·69	48″. 3·0 dwts./ton
					180	183½	42	3·14	
					183½	186½	36	1·90	
					186½	190	42	0·62	
					196	201	60	2·13	68″. 2·7 dwts./ton
					201	204	36	3·70	
12	320 feet on bearing 213° 30′ from corner G.M.L. 676D	....	Vertical	642	584½	590	66	0·50	57″. 1·1 dwts./ton
					590	595½	66	1·12	
13	576 feet on bearing 031° from S.E. corner G.M.L. 670D	....	Vertical	701	610½	612½	24	1·34	
14	1,025 feet on bearing 239° 30′ from N.E. corner G.M.L. 676D	....	Vertical	271	211	215	48	1·29	68″. 2·5 dwts./ton
					215	219	48	3·92	
15	482 feet on bearing 281° 30′ from N.E. corner of G.M.L. 676D	....	Vertical	247	207	212	60	3·08	
16	515 feet on bearing 173° 15′ from N.W. corner G.M.L. 664D	....	Vertical	269	215	220	60	2·18	

A PRELIMINARY REPORT ON THE HAMERSLEY IRON PROVINCE, NORTH-WEST DIVISION.

by W. N. MacLeod, L. E. de la Hunty, W. R. Jones and R. Halligan.

INTRODUCTION.

A regional investigation of the newly discovered iron ore deposits of the Hamersley and Ophthalmia Ranges was commenced by the Geological Survey in May, 1962. The field team comprised Geologists L. E. de la Hunty, W. R. Jones and R. Halligan under the supervision of W. N. MacLeod, Senior Geologist. The field season was concluded at the end of October.

The investigation involved the resolution of the principal stratigraphic units of the region, the study of the relationship of the iron ore to the stratigraphic column and the examination and sampling of individual deposits. Approximately 11,000 square miles of the iron province has been mapped on a scale of 50 chains to the inch by ground traversing and photo interpretation and a further 10,000 square miles has been examined photogeologically. It is planned to complete the mapping of the province during the 1963 field season. The present report outlines the progress to date and is accompanied by a progress regional map on a scale of 15 miles to the inch (Plate XXV). A more detailed map is also being compiled and will be published when the investigation of the Iron Province is completed after the 1963 field season.

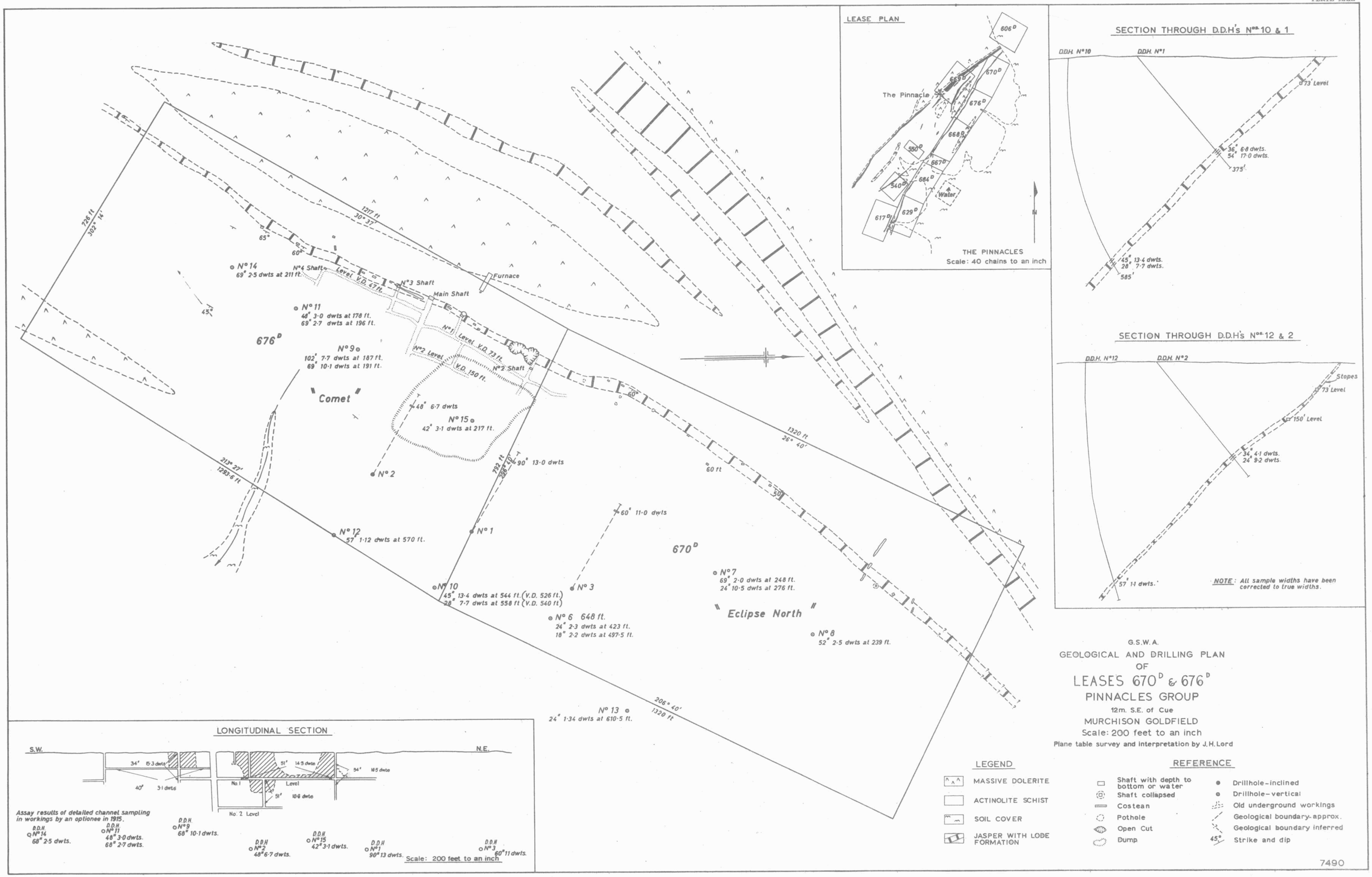
These deposits have been referred to as the "Pilbara Iron Ores". Investigation has shown that the deposits of the Hamersley and Ophthalmia Ranges constitute an integral mineral province related to a group of Proterozoic sediments. These deposits are quite distinct from those related to the Archaean jaspilites in the northern part of the Pilbara Goldfield, e.g., Mt. Goldsworthy. The term Hamersley Iron Province is accordingly introduced to cover the deposits associated with the Proterozoic sediments of the Hamersley and Ophthalmia Ranges. The deposits in the Archaean Jaspilites are referred to as the "North Pilbara Iron Province."

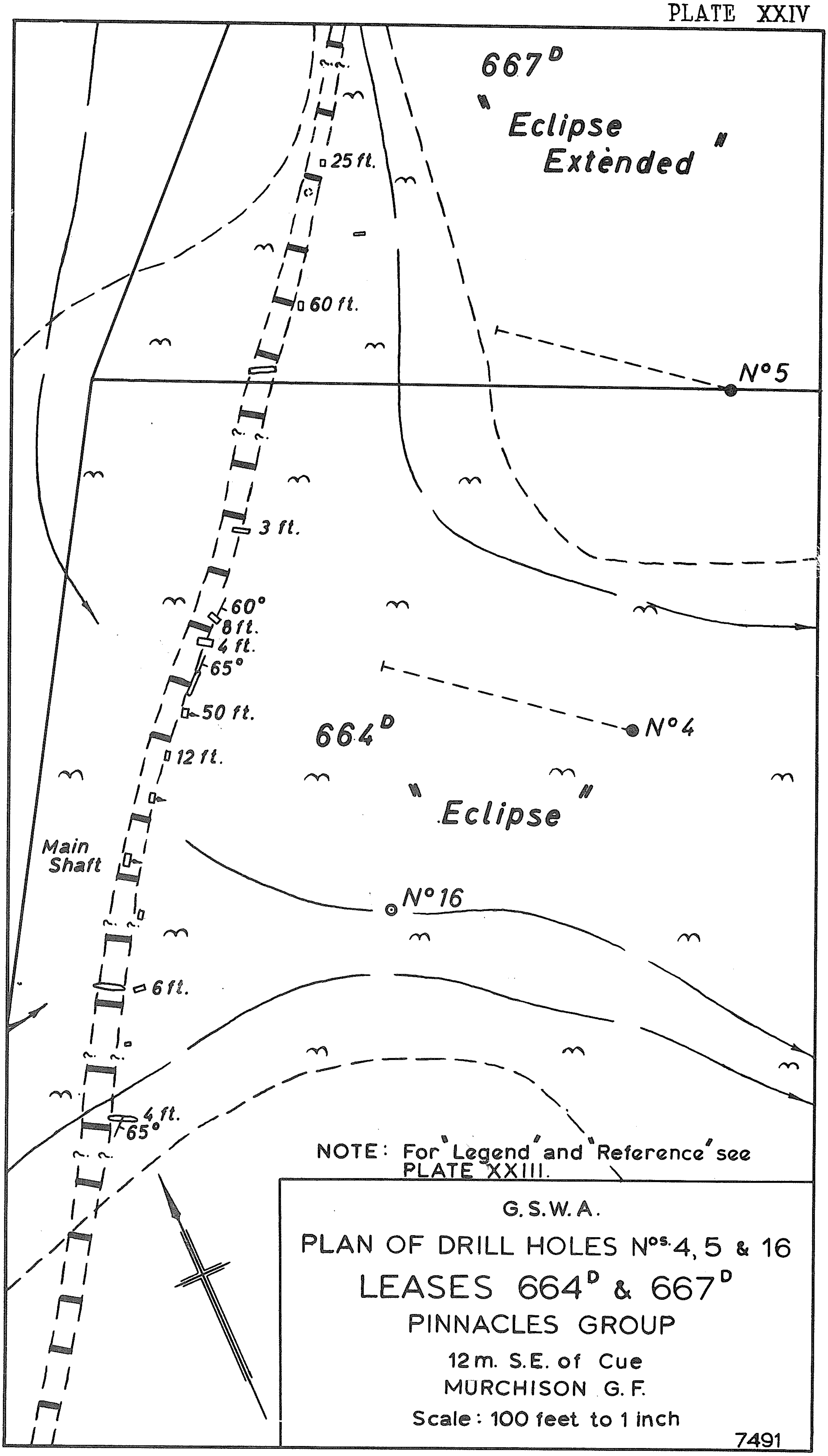
Close liaison has been maintained with prospectors and mining companies, who have been actively exploring for iron deposits in the Province since early 1961, and their confidential reports to the Department have been consulted. The courteous and wholehearted co-operation of the geologists of Conzinc Riotinto Australia Ltd., Broken Hill Pty. Co. Ltd. and Basic Materials Pty. Ltd. is gratefully acknowledged.

PHYSICAL FEATURES.

The Hamersley Iron Province covers an area of approximately 25,000 square miles between Latitude 21° S. and 23° 30′ S. and Longitude 116° E. and 120° E. This region of Western Australia includes the highest mountains of the State with many summits approaching 4,000 feet above sea level. The ranges lie astride the watershed of the important Fortescue and Ashburton drainage systems.

The region is semi-arid and sparsely inhabited. Owing to the rugged and deeply dissected nature of much of the terrain and the paucity of vegetation, large areas are unsuitable for grazing. Average temperatures during the summer months are the highest recorded throughout the entire conti-


LEASE PLAN
The Pinnacle
606D
669D
670D
676D
668D
550D
667D
540D
684D
Water
617D
629D
THE PINNACLES
Scale: 40 chains to an inch
SECTION THROUGH D.D.H's Nos 10 & 1
D.D.H. No10
D.D.H. No1
73' Level
36° 6·8 dwts.
54° 17·0 dwts.
375'
45° 13·4 dwts.
28° 7·7 dwts.
585'
SECTION THROUGH D.D.H's Nos 12 & 2
D.D.H. No12
D.D.H. No2
Stopes
73' Level
150' Level
34° 4·1 dwts.
24° 9·2 dwts.
57° 1·1 dwts.
NOTE: All sample widths have been corrected to true widths.
726 ft
302° 14'
1217 ft
30° 37'
65°
60°
No 14
69° 2·5 dwts at 211 ft.
No4 Shaft
Level V.D. 47 ft.
No3 Shaft
Main Shaft
Furnace
45°
No 11
48° 3·0 dwts at 178 ft.
69° 2·7 dwts at 196 ft.
676D
No 9
102° 7·7 dwts at 187 ft.
69° 10·1 dwts at 191 ft.
No1 Level V.D. 73 ft.
No2 Level V.D. 150 ft.
No2 Shaft
"Comet"
48° 6·7 dwts
No 15
42° 3·1 dwts at 217 ft.
792 ft
90° 13·0 dwts
No 2
213° 27'
1293·6 ft
60°
1320 ft
26° 40'
60 ft
50
60° 11·0 dwts
No 12
57° 1·12 dwts at 570 ft.
No 1
670D
No 10
45° 13·4 dwts at 544 ft. (V.D. 526 ft.)
28° 7·7 dwts at 558 ft (V.D. 540 ft)
No 3
No 7
69° 2·0 dwts at 248 ft.
24° 10·5 dwts at 276 ft.
No 6 648 ft.
24° 2·3 dwts at 423 ft.
18° 2·2 dwts at 497·5 ft.
"Eclipse North"
No 8
52° 2·5 dwts at 239 ft.
No 13
24° 1·34 dwts at 610·5 ft.
206° 40'
1320 ft
LONGITUDINAL SECTION
S.W.
N.E.
34° 6·3 dwts
40° 3·1 dwts
51° 14·5 dwts
54° 14·5 dwts
No 1 Level
51° 10·6 dwts
No. 2 Level
Assay results of detailed channel sampling in workings by an optionee in 1915.
D.D.H. No 14 68° 2·5 dwts.
D.D.H. No 11 48° 3·0 dwts. 68° 2·7 dwts.
D.D.H. No 9 68° 10·1 dwts.
D.D.H. No 2 48° 6·7 dwts.
D.D.H. No 15 42° 3·1 dwts.
D.D.H. No 1 90° 13 dwts.
D.D.H. No 3 60° 11 dwts.
Scale: 200 feet to an inch
G.S.W.A.
GEOLOGICAL AND DRILLING PLAN
OF
LEASES 670D & 676D
PINNACLES GROUP
12m. S.E. of Cue
MURCHISON GOLDFIELD
Scale: 200 feet to an inch
Plane table survey and interpretation by J.H. Lord
LEGEND
MASSIVE DOLERITE
ACTINOLITE SCHIST
SOIL COVER
JASPER WITH LODE FORMATION
REFERENCE
Shaft with depth to bottom or water
Shaft collapsed
Costean
Pothole
Open Cut
Dump
Drillhole-inclined
Drillhole-vertical
Old underground workings
Geological boundary-approx.
Geological boundary inferred
Strike and dip
7490



667^D
"Eclipse Extended"
25 ft.
60 ft.
N°5
3 ft.
60°
8 ft.
4 ft.
65°
50 ft.
12 ft.
N°4
664^D
"Eclipse"
Main Shaft
N°16
6 ft.
4 ft.
65°
NOTE: For "Legend" and "Reference" see PLATE XXIII.
G.S.W.A.
PLAN OF DRILL HOLES N^os. 4, 5 & 16
LEASES 664^D & 667^D
PINNACLES GROUP
12 m. S.E. of Cue
MURCHISON G.F.
Scale: 100 feet to 1 inch
7491

nent, but the winter months are mild and equable. The average annual rainfall amounts to about 10 inches, but there is a high variability and as most of the rain falls during the hot summer months its effectiveness is greatly reduced by excessive evaporation. Most of the watercourses are dry throughout the greater part of the year and flow briefly only after heavy summer thunderstorms.

In few areas of the State is the close correlation between geology and topography more strikingly demonstrated. The Hamersley and Ophthalmia Ranges both owe their existence and form to the presence of three thick, resistant jaspilite iron formations of wide lateral extent. These units are separated by dolomite, shale and volcanic rocks of much lower resistance to erosion and, in consequence, the stratigraphic and structural features of the region have been boldly outlined by erosion. The clear topographic expression of the major stratigraphic units has permitted accurate photogeological interpretation and the recognition of potential ore-bearing zones in the jaspilite. The northern escarpment of the Hamersley Range, which in places rises 2,000 feet above the Fortescue River plain, can be followed almost continuously for nearly 250 miles. It faithfully demarcates the northern limit of the Brockman Iron Formation which is the major jaspilite unit of the Hamersley succession.

In the northern zone of the Hamersley Range the rocks are almost flat lying with a gentle regional dip to the south. The topographic forms reflect these low dips with the development of broad plateaux, mesas, buttes and cuestaform ridges. In the central and southern sections of the ranges the rocks are much more strongly folded; in places with near vertical dips. Here the resistant jaspilites form bold and persistent hog backs in the limbs of the major folds and clearly define the broad geological structure of the region.

The majority of hill summits in the region, particularly those formed of the Brockman Iron Formation, have a gently domed form. The slopes of the domes are transgressive to the bedding of the jaspilite. These domes and cappings represent remnants of an older land surface, possibly of early Tertiary age, which has been strongly incised by more recent erosion. Recognition of this ancient surface is of paramount economic significance. Most of the major hematite ore bodies in the region are to be found immediately below this surface.

In the eastern section of the province, south and south-east of Wittenoom, this old surface is most extensively preserved in a terrain of low, domed hills separated by broad and shallow valleys in which there are thick detrital accumulations.

Elsewhere the old surface has been deeply eroded and in cross section most of the valleys have a characteristic "valley in valley" shape testifying to a vigorous cycle of erosion following stream rejuvenation. Active headward erosion by the rivers continues at the present time and most of the scenic attractions of the region such as Wittenoom Gorge, Joffre Falls and Dale's Gorge are products of this renewed erosion cycle.

STRATIGRAPHY.

Previous reconnaissance mapping has correlated the rocks of the Hamersley and Ophthalmia Ranges with those of the Proterozoic Nullagine Series which is widely distributed in the north-western portion of the State. (Maitland, 1909; Talbot, 1920b and Forman, 1938). There has been no systematic mapping or subdivision of these sediments prior to the present investigation.

The Proterozoic rocks of this region form a conformable succession which has been divided into three groups. The total thickness is about 33,000 feet. The upper part of the succession has not yet been completely examined and the total thickness could be much greater.

At the base, arkosic grits, sandstone and conglomerate unconformably overlie the Archaean basement. These sediments are followed by a thick and widespread succession of basaltic lava flows in which pillow lavas are abundantly represented. There are numerous sedimentary and pyroclastic intercalations within the lava sequence and these increase in thickness and proportion towards the upper part of the succession. This lowermost group of lavas and clastic sediments is termed the *Fortescue Group* and has a total thickness of about 14,000 feet.

The Fortescue Group is conformably overlain by a thick sequence of sediments which appear to be mainly of chemical origin. These comprise jaspilite, chert and dolomite with siltstone and shale. No coarse clastic sediments have been recorded in this part of the succession. These are interbedded with acid lavas and have been intruded by thick dolerite sills over a wide adea. This group is termed the *Hamersley Group*. Most of the iron ore deposits of the region occur within, or have been derived from, the thick jaspilite formations within this group. A striking feature of the group is the remarkable lateral persistence of the individual sedimentary units. The Hamersley Group is about 8,000 feet thick. The highly resistant jaspilite formations form most of the prominent topographic features of the Hamersley and Ophthalmia Ranges.

The chemical and fine clastic sediments of the Hamersley Group are conformably overlain by a thick sequence of sediments which are predominantly of clastic origin. These include greywacke, quartzite, conglomerate, phyllite, shale and interbedded vesicular basalt. A strong dolomite unit towards the upper part of the succession, the Duck Creek Dolomite, has been followed for over 200 miles. These later sediments have been termed the *Wyloo Group*. The upper limit of the group has not yet been determined but it is known to be at least 11,000 feet thick. Formal definition of the group and its component formations cannot be made at present. Some of the sediments which were formerly included within the Ashburton beds and correlated with the Mosquito Creek Series of the Archaean (Maitland, 1909) have been shown to belong to the Wyloo Group.

The Archaean basement rocks are exposed in the cores of structural domes at Rocklea, Milli Milli Spring and south of Mt. Newman. These include granite and granite gneiss, greenstone, schist and jaspilite and appear to be typical of the Warrawoona Series.

Superficial deposits in the iron province include thick deposits of valley fill of both Tertiary and Quaternary age, limestone and opaline silica of the Oakover Formation, limonitic iron ore deposits, thick river gravels, alluvium and soil cover. Much of the thick valley fill of Tertiary age has been dissected and redistributed in the present drainage system. Areas underlain by dolomite are sites of thick calcrete accumulations along the drainage channels.

The stratigraphic column is summarized in the following table:—

Stratigraphic Column of the Hamersley Iron Province.

Era	Period	Group	Formation	Lithology	Thickness
					Feet
CAINOZOIC	Recent			Soil cover	
				River gravel and alluvium	20
				Outwash	50
	Tertiary		Oakover Formation	Fill	100+
				Limestone and opaline silica	70
				Limonitic deposits	50av.
				Chert breccia	20
MESOZOIC	Jurassic		Yarraloola Conglomerate	Conglomerate, sandstone with fossil leaves and marine fossils	20
PROTEROZOIC		Wyloo	Duck Creek Dolomite	Greywacke	2,000
				Dolomite and chert	1,000
				Conglomerate (1)	1,300
				Dark shale	100
			Cheela Springs Basalt	Vesicular basalt	5,000
			Mt. McGrath Beds	Dark siltstone, quartzite and conglomerate	100
			Beasley River Quartzite	White quartzite	300
			Turee Creek Formation	Greywacke, conglomerate, shale and basalt	1,000
		Hamersley	Boolgeeda Iron Formation	Jaspilite, ferruginous shale....	700
			Woongarra Dacite	Dacite	1,900
			Weeli Wolli Formation	Jaspilite, dolerite and basalt	1,600
			Brockman Iron Formation....	Jaspilite, shale, chert	2,200
			Mt. McRae Shale	Shale, siltstone, dolomite, dolomitic shale, chert	300
			Mt. Sylvia Formation	Thin jaspilite with shale	110
			Wittenoom Dolomite	Dolomite and dolomitic shale	500
			Marra Mamba Iron Formation	Jaspilite, chert	600
		Fortescue	Jeerinah Formation	Jaspilite and shale with dolerite and basalt	3,000
			Mt. Jope Basalt	Pillow lavas and pyroclastics	7,000
			Hardey Sandstone	Sandstone, arkose, conglomerate, basalt, quartzite and dolerite	4,000
ARCHAEAN	....	....	....	Talc-chlorite schist, volcanics, jaspilite and granite	

(1) Conglomerate may be equivalent to dark siltstone, quartzite and conglomerate of Mt. McGrath Beds.

THE PROTEROZOIC ROCKS.

Fortescue Group.

The Fortescue Group embraces the lower formations of the Proterozoic succession. These are most extensively exposed along the valley of the Fortescue River between Roy Hill in the east and the watershed between the Robe and Fortescue Rivers in the west. A large area of the Mt. Bruce Sheet is underlain by this group and it also appears in the extreme south-eastern section of the iron province, south of Mt. Newman.

The upper limit of the group is arbitrarily placed at the base of the Marra Mamba Iron Formation. The appearance of this thick and persistent iron formation marks the change from the initial volcanic activity and clastic sedimentation to the phase of chemically precipitated sediments of the Hamersley Group.

The type locality of the Fortescue Group is in the vicinity of Moonah Well (Lat. 22° 49′ S., Long. 117° 27′ E.) on the southern limb of the Rocklea Anticline.

The Hardey Sandstone is the basal formation of the Proterozoic succession and is about 4,000 feet thick. In the type area in the core of the Rocklea Anticline (see above) it dips radially off the Archaean nucleus with an average dip of about 60 degrees and is excellently exposed. The formation reappears in a similar fashion in the Milli Milli Anticline further to the east and in the core of the Wyloo Anticline near the western boundary of the province.

The Hardey Sandstone is a white to reddish brown and green quartz sandstone. It is commonly arkosic and in places rather calcareous. Basalt and volcanic agglomerate are interbedded with the sandstone, especially near the eastern side of the Rocklea Anticline near Rocklea Homestead. The Hardey Sandstone is conformably overlain by the pillow lavas of the Mt. Jope Basalt.

Mt. Jope Basalt.—This formation is of wide areal extent in the Hamersley Iron Province. It has been best studied in the central and southern areas of the Mt. Bruce Sheet, and is known to extend along the entire northern arc of the province from the Robe River to near Roy Hill, a distance of 300 miles. Basaltic lavas south of the Ophthalmia Range are also correlated with this formation.

In the type locality around Mt. Jope (Lat. 22° 57′ S., Long. 117° 29′ E.), three principal members have been distinguished and mapped. These include two thick pillow lava units separated by a zone of pyroclastics and sediments. The pillow lavas cover a wide area in the southern half of the Mt. Bruce Sheet and form prominent rugged hills. The best exposures occur around the Rocklea Dome.

The lower pillow lava member conformably overlies the Hardey Sandstone and is about 2,500 feet thick. The pillows are best exposed in the watercourses where the weathering products are being constantly removed. The lower pillow lava contains intercalations of blue-grey carbonate rocks and soft grey chlorite rocks with dark elongated pellets. These rocks have a peculiar fish scale weathering pattern and, on a larger scale, weather like flattened and sheared pillows.

The intervening pyroclastic unit which separates the two pillow lava flows includes finely banded grey ash beds with agglomerate and volcanic bombs. Minor amounts of chert, shale and jaspilite have been noted and there is some coarse-grained dolerite and pillow lava. The pyroclastic unit is about 2,000 feet thick. It has a marked topographic expression and can be readily identified from its photo pattern. The pyroclastic member has also been recognized in the Jeerinah Anticline, where it outcrops over an area of about 14 square miles.

The upper pillow lava member is the most widely distributed unit of the formation due to lower dips at greater distances from the centres of the domes. There are extensive exposures in the Jeerinah Anticline and the pillow structure can be seen at Jeerinah Rockhole (Lat. 22° 23′ S., Long. 117° 7′ E.), at Fish Pool on the Beasley River and at Bunjinah Spring (Lat. 22° 23′ S., Long. 117° 51′ E.). Pillows are also well-exposed on the south side of the Hardey River, 8 miles south-west of Rocklea Homestead. This unit contains vesicular basalt and volcanic breccia and these components are often seen in zones where pillows are not developed. Such a zone is at Stinking Pool on the Beasley River, about 17 miles north-north-west of Mt. Turner. The upper pillow lava member is about 2,500 feet thick.

The Jeerinah Formation includes the sediments and doleritic sills and flows in the upper section of the Fortescue Group. The formation comprises shale, chert, jaspilite, mudstone, quartzite and dolerite. The softer sedimentary members are rarely well-exposed; the harder dolerite and jaspilite outcrop more frequently.

The formation has been named from its wide exposure within the Jeerinah Anticline around Jeerinah Rockhole and this may be regarded as the type locality. A type section has been measured about 1 mile south of Mt. Turner (Lat. 22° 43′ S., Long. 117° 26′ E.) where the formation dips steeply to the north. The section is as follows:—

	Feet
Top—Coarse-grained dolerite	620
Chert, shale, mudstone	280
Coarse-grained dolerite	400
Shale and jaspilite	110
Coarse-grained dolerite	510
Chert and calcareous shale	320
Coarse-grained dolerite	250
Base—Chert, shale, mudstone and quartzite	510
Total	3,000

The Jeerinah Formation conformably overlies the Mt. Jope Basalt and is overlain by the Marra Mamba Iron Formation of the Hamersley Group.

In the Jeerinah Anticline the lowermost sedimentary member forms a prominent scarp about 400 feet high. A thick white quartzite bed has controlled the formation of this escarpment. Here the sediments dip to the east at about 10 degrees. In some parts of the province, basalt flows are interbedded with the shale and chert, and dolerite intrusions are poorly developed. In the Robe River area, white shale and chert are the principal rock types. A persistent white shale unit, between 50 and 100 feet thick, is the uppermost member of the formation in the Fortescue valley and can be followed continuously from the Robe River to Roy Hill, a distance of 300 miles. Near Roy Hill the shale is interbedded with dolomite and chert. This member is a useful marker bed for the upper limit of the Fortescue Group.

The Hamersley Group.

The sediments of the Hamersley Group are predominantly of chemical origin. Chert, jaspilite and dolomite are the principal rock type. Thin lutites are interbedded with jaspilite and dolomite, and coarse clastics have not been recorded. The lithology of the lower part of the group indicates a prolonged period of alternating phases of precipitation of iron, silica, lime and magnesia under still water conditions. The acid lavas in the upper section of the group were probably extruded under sub-aerial conditions. The uppermost sedimentary unit, the Boolgeeda Iron Formation, contains a higher proportion of clastic material than the two lower iron formations. The Hamersley Group is conformably overlain by the coarser sediments of the Wyloo Group.

Over three-quarters of the total area of the iron province is underlain by rocks of the Hamersley Group. It has been subdivided into eight formations whose total thickness amounts to about 8,000 feet.

Marra Mamba Iron Formation.—The wide distribution of this formation is clearly shown on the map of the iron province which accompanies this report. It extends, with almost continuous outcrop, along the entire northern front of the Hamersley Range for a distance of over 300 miles. In the central and southern sections of the province, where folding is more intense, the Marra Mamba Iron Formation faithfully outlines the principal structural elements of the region and serves as an invaluable marker bed.

The Marra Mamba Formation is 600 feet thick. The type locality is at Marra Mamba (Lat. 22° 20′ S., Long. 117° 15′ E.). The thickness has been measured in the northern limb of the Hardey Syncline, where the beds dip steeply to the south. It is conformably overlain by the Wittenoom Dolomite.

Chert and jaspilite are the principal lithological components. The chert bands are generally yellow to yellowish brown and have a distinctive "pinch and swell" structure, which is often sufficiently pronounced to separate the chert into individual lenses within the jaspilitic matrix. These chert lenses are rarely more than two inches thick but are up to 2 feet across. Many are elongated at right angles to the elliptical section. Magnetite concentrations are common on the surfaces of these chert lenses and these can be veined by thin seams of crocidolite.

The jaspilite is similar to that of the other iron formations. Thin bands of chert and iron minerals rapidly alternate and are sharply demarcated. Magnetite and hematite as martite are the principal iron minerals.

Numerous hematite deposits have been recorded in the Marra Mamba Iron Formation but these are smaller and of lower grade than those of the Brockman Iron Formation. Broken Hill Pty. Co. Ltd. are currently drilling and mapping hematite zones in this formation at Roy Hill and in the Chichester Range.

At Marra Mamba the formation contains seams of crocidolite. These were the first to be worked in the State and some 49 tons of fibre were extracted in 1941. Here the crocidolite occurs at the top of the iron formation, close to the contact with the overlying Wittenoom Dolomite. The deposits have been mined in four localities along the northern flank of the Jeerinah Anticline and are scattered over a length of 12 miles.

Small showings of crocidolite have been seen on the eastern end of the Mt. Brockman Syncline and on the northern side of the Mt. Turner Syncline. In both localities the asbestos appeared in the upper section of the iron formation.

The Marra Mamba Iron Formation is also characterized by the common appearance of skins of manganese dioxide. This is rare in other iron formations. Most of these deposits are too small to be of any economic significance but it is possible that some would merit development if large scale exploitation of the iron resources of the region was commenced.

At the eastern end of the Mt. Turner Syncline a manganese deposit has originated by replacement of jaspilite. The manganese body is 2 to 5 feet thick, dips at 40 degrees and is clear of overburden. It is at least three chains long and more than 50 feet high. The grade is possibly better than 40 per cent. manganese.

Wittenoom Dolomite.—The Marra Mamba Iron Formation is conformably overlain by 500 feet of dolomite, chert and dolomitic shale. The formation is named from its type locality in the hills south of Wittenoom township (Lat. 22° 15′ S., Long. 118° 20′ E.). Sections of the formation have been examined in many localities but the base is rarely exposed as it is usually covered with heavy detritus from the surrounding jaspilite hills. In most sections the lower part of the formation is composed of well-bedded grey to bluish grey crystalline dolomite. Chert and shaly intercalations are more abundant towards the upper part. At Mt. Sylvia and the Robe River, shales and dolomitic shales form the uppermost 200 feet of the formation. At Wittenoom Gorge, chert is more abundant than dolomite in most of the exposed sections.

The best exposures of the Wittenoom Dolomite are along the northern escarpment of the Hamersley Range. The dolomite forms most of the spurs and isolated hillocks at the edge of the plain of the Fortescue Valley. Most of this broad, alluvium-filled valley is believed to be underlain by dolomite. The Goodiadarrie Hills, north-east of Wittenoom are composed of the Wittenoom Dolomite.

The formation is thin in the Hardey Syncline near the southern boundary of the iron province. Thin and limited exposures of calcareous and cherty shale between the Brockman and Marra Mamba Iron Formations in this area probably represent the formation.

Minor folding is a common feature of the Wittenoom Dolomite. This is particularly well seen in the Robe River sections and at Weeli Wolli. The minor folds are tight and randomly orientated and are thought to be drag folds resulting from the relative incompetence of the dolomite during the broad warping and gentle folding of the more competent jaspilite beds between which the dolomite is confined.

Mt. Sylvia Formation.—This formation includes three thin, but remarkably persistent, beds of jaspilite with interbedded dolomitic shales. The three jaspilite members outcrop prominently along the escarpments of the Hamersley Range and can be followed continuously for many miles. These are excellent marker beds and serve to clearly define the base of the Brockman Iron Formation where most of the large hematite deposits of the region have been found.

The type locality and measured section of the formation are at Mt. Sylvia (Lat. 22° 18′ S., Long. 117° 37′ E.). This is a few miles south-west of Hamersley Homestead, close to the road and easily accessible. The formation is 110 feet thick at this locality and is seen to conformably overlie the Wittenoom Dolomite.

The uppermost jaspilite bed is 18 feet thick and defines the top of the Mt. Sylvia Formation. It is a finely banded, light green and brown to maroon jaspilite with many highly ferruginous bands. Despite the small thickness of this unit it has been seen to persist from the Buckland Hills on the Robe River to the eastern end of the Ophthalmia Range, a distance of over 300 miles, with little change either in thickness or lithology.

The two lower jaspilite members are thinner and contain a higher proportion of greenish white banded chert than the uppermost unit. The chert and jaspilite beds are separated by blocky calcareous shale and thinly bedded fissile shale with dolomitic intercalations. These sediments weather rapidly to give smoothly concave slopes from which the jaspilite beds stand out as prominent low cliffs.

The upper shale unit has been seen to range between 15 and 50 feet in thickness and the lowermost units between 8 and 15 feet.

Mt. McRae Shale.—This formation conformably overlies the Mt. Sylvia Formation and its type locality is also at Mt. Sylvia. The formation takes its name from its similar mode of occurrence on the nearby Mt. McRae, 3 miles to the north-west.

The Mt. McRae Shale is about 300 feet thick. Its upper and lower limits are sharply defined by the overlying Brockman Iron Formation and the uppermost jaspilite of the Mt. Sylvia Formation at the base. The formation includes shale, siltstone and dolomitic shale with thin beds of jaspilite and chert. At Wittenoom Gorge the formation contains a high proportion of chert and dolomite and closely resembles the lower Wittenoom Dolomite. In this area it is necessary to identify the Mt. Sylvia jaspilite beds before the Mt. McRae Shale can be recognised.

The shaley sediments have low resistance to erosion and in cliff sections weather to concave slopes with white outcrops. Exposures are rare and the formation is often masked with a veneer of jaspilite scree from the overlying Brockman Iron Formation.

Brockman Iron Formation.—This iron formation is the thickest and most widely exposed formation of the Hamersley Group. It conformably overlies the Mt. McRae Shale and is conformable with, or grades into the overlying Weeli Wolli Formation.

The type locality for the formation is at Mt. Brockman (Lat. 22° 28′ S., Long. 117° 18′ E.) but the thickness cannot be reliably measured in this area because of much minor folding and faulting in the limbs of the Mt. Brockman Syncline. The thickness has been measured in the steeply dipping northern limb of the Hardey Syncline where it is seen to be about 2,200 feet. In the northern area of the province, where folding is gentle, the upper part of the formation has usually been removed by erosion and measurement of total thickness cannot be made. An excellent section is exposed at Mt. Bruce where the uppermost 1,500 feet of the mountain is composed of flat-lying Brockman Iron Formation.

The high resistance to erosion of the jaspilite of this formation is the dominant topographic control of the region. Most of the prominent hills of the Hamersley and Ophthalmia Range, many of which approach 4,000 feet above sea level, are composed of Brockman Iron Formation. The elevated hogback ridges in the limbs of the major folds have controlled the regional drainage patterns at least since Mesozoic time.

The Brockman Iron Formation consists mainly of jaspilite and chert. The jaspilite is usually very finely banded with alternating laminae of iron ore minerals and quartz. The bedding ranges from fissile and flaggy to medium and is normally regular and well defined. In the Robe River headwater region the lowermost beds are medium-bedded and cherty with well marked red, green, black and white colour bands. The greater part of the formation, however, has bedding within the range of 2 to 6 inches and the individual beds are finely laminated to impart a monotonous dark blue-grey colour to the outcrop. The upper part of the formation contains more fissile varieties which weather to a reddish brown shaley outcrop. Bedding is normally regular and laterally persistent but pinching and lensing of beds has been observed. Chert "rolls" are also seen but are less common and on a smaller scale than those of the Marra Mamba Formation. Interbedded shales have been recorded on the southern side of the Mt. Brockman Syncline and thin interbedded tuffs and acid lavas occur near Yerra Bluff on the Robe River.

A dolerite sill has been intruded into the upper part of the formation in the limbs of the Mt. Brockman Syncline. The sill is about 50 feet thick and because of its lower resistance to erosion has weathered out to a steep-walled gully. This gully is a prominent and useful feature on aerial photographs and serves as a useful structural and stratigraphic indicator. On the south side of the syncline the dolerite is overlain by 400 feet of jaspilite and underlain by 250 feet of ferruginous shale.

Thin section examination reveals that the banding of the jaspilite is due to alternating zones of magnetite, hematite, martite or limonite with a very fine-grained quartz mosaic. Carbonate minerals are commonly present in the quartz-rich bands. The boundaries between the laminae may be sharp or diffuse and there is some degree of replacement of the iron minerals by silica. Riebeckite occurs in bands, veins, or cavity fillings and as bundles of fine acicular and curved crystals. The overall iron content of the Brockman Iron Formation is estimated to be between 20 and 25 per cent., and the silica content within the range of 40 to 60 per cent.

The Brockman Iron Formation is the locus for most of the large hematite deposits in the region. The ore appears to have formed as a result of selective leaching of the silica from the jaspilite by meteoric and ground waters. The ore only forms close to the old land surface, and particularly in synclinal troughs where residuals of the Brockman Iron Formation have been preserved by infolding.

The Brockman Iron Formation also carries the important deposits of crocidolite near Wittenoom. The crocidolite seams occur near the base of the formation close to the contact with the underlying Mt. McRae Shale. Here the shale formation is mainly dolomitic in composition. A similar close relation between the asbestos and dolomite has been noted in the Marra Mamba Formation near its contact with the Wittenoom Dolomite.

Weeli Wolli Formation.—In the central and eastern half of the iron province the Brockman Iron Formation is overlain by a thick succession of interbedded dolerite and jaspilite. This formation is extensively developed in the Ophthalmia Range and particularly so to the north of Weeli Wolli Spring where it occupies the troughs of two long and gentle synclinal folds. This area is taken as the type locality for the formation. A type section has been measured in the northern limb of the Hardey Syncline at Lat. 22° 53′ S., Long. 117° 6′ E. This is as follows:—

	Feet
Top—Dolerite	350
Jaspilite	60
Dolerite	250
Jaspilite	30
Dolerite	260
Jaspilite	50
Base—Dolerite	600
Total	1,600

A similar succession has been noted in the Ophthalmia Range along the valley of the Fortescue River where many beds of jaspilite, some only a few feet in width, occur in the dolerite between the thicker jaspilite members.

It is not yet established whether the dolerite of this formation is extrusive or intrusive. If it is intrusive, there has been a remarkable degree of confinement to one horizon in the stratigraphic column, viz., the junction of the Brockman Iron Formation and the Woongarra Dacite. In some areas the dolerite is vesicular but if the rock is extrusive it is difficult to account for the wide lateral extent of individual thin jaspilite beds.

Woongarra Dacite.—The acid lavas are conspicuous and widespread throughout the iron province and excellently exposed in many localities. The dacite was first recognised in the Mt. Brockman Syncline where it forms low bouldery hills on either side of the valley. In the southern limb the lava is 2,000 feet thick and in the northern limb about 1,600 feet. At the type locality, Woongarra Pool on the Beasley River (Lat. 22° 53′ S., Long. 117° 6′ E.), the dacite is about 1,900 feet thick, and dips south at 60 degrees where it overlies the Weeli Wolli Formation. West of Palra Spring, in the north-western corner of the Mt. Bruce Sheet, the Weeli Wolli Formation is missing, and the Woongarra Dacite directly overlies the Brockman Iron Formation. The dacite is thinner in the Ophthalmia Range; generally less than 1,000 feet.

Textural variations in the dacite suggest that separate flows are represented. Some varieties are eucrystalline and equigranular but the most common type is a grey to black porphyritic rock with abundant phenocrysts of quartz and white felspar. Dark aphanitic lava with flow banding is common. Perlitic cracks, indicative of devitrification of originally glassy material, have been recognised in thin sections. Autobrecciation of the acid lava is commonly observed.

Another variant, classified in the field as a "green quartzite," has been recorded in many localities. This contains rounded quartz grains like a sedimentary rock. There is some obvious banding and cavities are infilled with calcite and iron carbonate. Thin section examination has established that the rock is actually a silicified lava and that the green colour is due to an abundance of chlorite. Despite the distinctive appearance of this rock it is neither continuous in outcrop nor constant in stratigraphical position, and, accordingly is of little value as a marker.

Boolgeeda Iron Formation.—The youngest formation of the Hamersley Group is exposed only in the cores of synclines in the central and southern parts of the iron province. It has been recognised in the Mt. Brockman, Mt. Turner and Hardey Synclines on the Mt. Bruce Sheet in the Turee Creek Syncline further to the south and in the Duck Creek area. Extensive exposures are found in the eastern section of the Ophthalmia Range.

The type locality of the Boolgeeda Iron Formation is on the south side of Boolgeeda Creek, about 18 miles west-south-west of Mt. Brockman (Lat. 22° 36′ S., Long. 117° 4′ E.). Here it dips to the north at 45 degrees, conformably overlies the Woongarra Dacite with a sharp and well-exposed contact, and is about 700 feet thick.

The formation is composed of purplish red, flaggy siltstone and ferruginous shale with some jaspilite. Pale creamy shale and siltstone occur near the base of the formation in the Ophthalmia Range. Boulders of ferruginous shale containing riebeckite have been found in Boolgeeda Creek and these are believed to have been derived from this formation.

Jaspilite is more common towards the eastern end of the province, where many large hematite deposits are developed within the formation. No hematite deposits have been recorded in the Boolgeeda Iron Formation in the Mt. Bruce, Wyloo and Yarraloola Sheets. The formation is capped with limonite deposits up to 20 feet thick along the limbs of the Mt. Brockman Syncline. Some limonite also caps the iron formation where it is steeply dipping in the northern limb of the Hardey Syncline.

Wyloo Group.

The rocks of the Wyloo Group are the youngest within the Hamersley Iron Province. They conformably overly the Hamersley Group in the Mt. Brockman Syncline, the Turee Creek Syncline and the Hardey Syncline, and are well exposed in the Hardey River valley and in the Duck Creek area.

This part of the Proterozoic succession was only briefly examined during the 1962 field season and detailed subdivision of the group is not yet possible. However, several formations have been recognised and the general characteristics of the group have been studied.

The total measured thickness of the Wyloo Group is of the order of 11,000 feet. Coarse clastic sediments are thick and abundant in contrast to the underlying Hamersley Group, and rapid thinning and lensing of formations along the strike is common. Basic volcanic rocks are interbedded with the sediments and the whole sequence is strongly folded and much disturbed by faulting. The group has been followed for over 200 miles around the western and southern periphery of the Hamersley Range and, although the general assemblage of formations remains much the same, the lithology of the succession undergoes wide variations as members thicken and thin and sometimes disappear entirely. Facies changes and lensing of the beds raise difficulties in correlation of sections in different localities.

The group has been provisionally subdivided as follows:—

Top—Greywacke;
Duck Creek Dolomite;
Conglomerate;
Dark Shale;
Cheela Springs Basalt;
Mt. McGrath Beds;
Beasley River Quartzite;
Base—Turee Creek Formation.

Formal definition and naming of the formations is deferred pending further field work during the 1963 field season.

The Turee Creek Formation, which consists mainly of greywacke and shale, conformably overlies the Boolgeeda Iron Formation and was first recognised in the Mt. Brockman Syncline. It is well exposed in the Hardey Syncline where it is protected from erosion by a capping of the resistant Beasley River Quartzite. The greywacke is greenish, thinly bedded and schistose and in places grades into a conglomerate. Near Meteorite Bore it carries quartzite boulders up to two feet in diameter and is interbedded with dolomite, siltstone and basalt. The thickness of the greywacke is of the order of 1,000 feet.

The Beasley River Quartzite conformably overlies the greywacke of the Turee Creek Formation. In some places where folding has been strong, tectonic dislocation has occurred resulting from the greatly differing competencies of the resistant quartzite and the underlying greywacke, and locally the two formations appear to be in angular unconformity.

It is a white, medium to coarse-grained quartzite with occasional current bedding and ripple marks. Conglomeratic zones have been noted. It ranges between 300 and 550 feet in thickness and because of its highly resistant character, weathers into bold ridges.

The Mt. McGrath Beds are incompletely known but have been seen to include conglomerate, sandstone, greywacke and shale. The unit is characterised by very rapid changes in thickness and lithology along the strike. In the western areas it underlies the Cheela Springs Basalt but further east, at a point two miles south of Meteorite Bore, some 1,300 feet of coarse pebbly sandstone overlies basalt. These beds are thought to be equivalents of the Mt. McGrath Beds. In both areas the succession is directly overlain by the Duck Creek Dolomite.

An important feature of the Mt. McGrath Beds is the presence of highly ferruginized conglomerates. Locally, within these beds, the chert and jaspilite pebbles have been completely replaced by hematite and magnetite. A high-grade iron ore body, about 9,000 feet long and 20 feet thick, occurs in this formation about two miles south of Medalla Bore in the Duck Creek valley. Replacement of the conglomerate has been complete throughout most of the body, and the deposit is estimated to contain about 10 million tons of high grade ore.

The Cheela Springs Basalt overlies the Beasley River Quartzite near Meteorite Bore and it is estimated to be about 5,000 feet thick. Similar basalt overlies the quartzite in the Duck Creek valley. The basalt is epidotized and amygdaloidal with quartz, chlorite and pyrite in the amygdules. There are extensive exposures of the basalt along the southern flank of the Hamersley Range between Wyloo Homestead and the Beasley River.

The Duck Creek Dolomite is one of the most persistent units of the Wyloo Group and can be traced from the Beasley River to the lower Robe River, a distance of 200 miles. The dolomite is about 1,000 feet thick. It is a tough, light grey to buff, crystalline dolomitic limestone with medium to thick bedding. The lower part of the formation includes grey and buff coloured, thinly bedded limestone with interbedded shale. The rock is often silicified and interbedded cherts are common. Chert breccia often forms a capping on the dolomite. Skins of manganese minerals have formed on the dolomite in many localities but none of these appear to be of any economic value.

Stylolites have been recorded in the dolomite at Duck Creek Gorge, and "collenia" have been collected south of Mt. June, further west in the Duck Creek valley and also near Cheela Springs.

The Duck Creek Dolomite is overlain by greywacke and younger basalt flows and agglomerates of unknown thickness.

STRUCTURAL GEOLOGY.

In terms of structure the Hamersley Iron Province may be broadly divided into three main zones. These zones are aligned parallel to the long axis of the province and reflect an increasing intensity of folding and faulting on passing from north to south.

The northern zone includes the greater part of the Hamersley Range. Here the rocks have a gentle regional dip of generally less than 5 degrees to the south. This regional attitude is punctuated by occasional block faulting and narrow zones of strong flexuring; some of which serve as loci for ore. In the north-western sector, near Silver Grass Peak, and in the central and eastern sectors near Wittenoom, a gentle basin and swell structure is apparent. Most of the northern zone is underlain by the thick and resistant Brockman Iron Formation and, accordingly, the most extensive areas of high plateau country are found within this northern zone of the province. Younger members of the Hamersley Group are preserved in some of the deeper basin structures.

The central zone of the province is much more strongly folded and the topographic forms faithfully reflect the major structural units. Two superimposed fold trends are apparent and these have combined to produce a regular pattern of large domes and basins en echelon. The Mt. Brockman Syncline, the Jeerinah Anticline, the Mt. Turner Syncline, the Rocklea Anticline, the Milli Milli Anticline and the Turee Creek Syncline are the major structural units of the central zone. The limbs of the major structures dip at about 30 degrees, but minor folding and drag on the numerous fault planes cause local steepening. The minor folds within the limbs of the large synclines are the most favourable loci for hematite ore as is strikingly demonstrated in the case of the Mt. Brockman Syncline.

The southern structural zone is the narrowest, but extends with variable width along the entire southern and south-western boundary of the iron province. Here the folding is particularly strong with near vertical dips and accompanied by strong faulting with large displacements. The south-western corner of the province is the most violently disturbed portion of the region. In the Ophthalmia Range, at the eastern extremity of the province, folding is almost isoclinal in places. The east-west trending folds have been transected by a system of north-east-trending faults, one of which appears to have controlled the course of the upper Fortescue River. Between Duck Creek and the Robe River, the western boundary of the Hamersley Group is largely controlled by a north to north-west-trending fault pattern of great complexity.

The Brockman Iron Formation has a persistent regional joint pattern with the dominant system trending about 30 degrees west of north and with a secondary system at right angles. In the western section of the province, the major joint system and trend of the fault planes are clearly closely related. Minor movements on the north-west joint system are common but not always easy to detect.

THE IRON ORE DEPOSITS.

Although exploration is far from complete it is now apparent that the Hamersley Iron Province is one of the largest in the world. From mid-1961 to the end of 1962, intensive exploration has disclosed the existence of iron ore resources amounting to about 8,000 million tons of material of grade exceeding 50 per cent. iron. Of this total, inferred reserves of high-grade hematite-goethite ore of at least 60 per cent. grade amount to about 3,000 million tons. Lower grade pisolitic limonite-goethite ores, which contain between 50 and 60 per cent. iron, constitute the balance.

THE HEMATITE-GOETHITE ORES.

General Characteristics.

The hematite-goethite ores are of the Lake Superior type and occur within the jaspilite of the Brockman, Marra Mamba and Boolgeeda Iron Formations of the Hamersley Group. Over 100 ore zones have so far been located within the province and further exploration appears certain to reveal many more. In these ore zones all gradations in size and quality of ore have been observed. In some there is a sporadic development of small zones of porous, platy ore with abundant chert and jaspilite intercalations. Others are large bodies, extending continuously for several miles, composed of high-grade massive hematite in which remnants of unaltered jaspilite are rare or absent over large areas.

Considerable textural variations are to be observed within any one ore zone. In the most common occurrence bands of massive hematite up to several feet in width are intermingled with strongly banded and porous, platy material containing a high content of goethitic cement. The porous ore, locally termed "biscuit ore," forms the greater part of many ore zones and has an iron content within the range of 56 to 62 per cent. The more massive ore ranges between 63 and 68 per cent. iron. The overall grade of any particular ore zone is determined by the relative content of the two types.

The ore bodies appear to have originated as a result of selective leaching of silica and other impurities from the jaspilite. There has been some degree of concurrent mobilization and reprecipitation of the iron in the form of hydrated oxides. The unaltered banded iron formation contains between 20 and 30 per cent. iron and usually at least 50 per cent. silica. The process of enrichment has reduced the silica content of the ore to less than 4 per cent. It is believed that this enrichment has been achieved through the agency of ground and meteoric waters.

Examination of many ore bodies has revealed a dependence on certain structural and geomorphological conditions. Firstly, ore formation occurs only in vertical proximity to the old land surface and is rarely found at depths greater than 200 feet below this surface. Secondly, the ore is usually restricted to the basal sections of the Brockman Iron Formation, where the jaspilite has been infolded into structural traps, flanked and underlain by the relatively impermeable Mt. McRae Shale.

The formation of a large ore body appears to involve the wholesale transformation of the iron formation roughly in concordance with the profile of the ancient surface. When viewed in vertical section the ore bodies appear as crusts and cappings on the unaltered jaspilite where a favourable combination of structural controls has permitted the leaching of silica by supergene waters.

The Marra Mamba Iron Formation is similarly underlain by a white shale and ore enrichment occurs in structural troughs as in the case of the Brockman Iron Formation. The lowermost member of the Boolgeeda Iron Formation is of similar lithology and ore is abundant in this formation, in the strongly folded sections of the Ophthalmia Range.

Ore bodies are most abundant and extensive along the troughs of minor synclinal folds on the limbs of the major domes and basins in the central and southern sections of the iron province. These conditions are best exemplified in the limbs of the Mt. Brockman and Mt. Turner Synclines and in many places in the Ophthalmia Range. Zones in the jaspilite which have been closely faulted are also favourable loci for hematite enrichment.

The age of the hematite ore bodies is unknown. It is clear that they were formed prior to the rejuvenation of the rivers which has produced the deeply dissected terrain of the present day. Their dependence upon proximity to the remnants of the old land surface could indicate that enrichment occurred concurrently with the development of this surface.

Distribution of the Hematite Ores.

The largest hematite ore bodies are located within the Brockman Iron Formation in the central and south-eastern sections of the iron province. There the rocks are more strongly folded into major domes and basins and favourable loci for hematite enrichment are abundantly presented in the limbs of these major structures. The Mt. Brockman and Mt. Turner Synclines have been carefully explored by geologists of Conzinc Riotinto Australia Ltd. and many large and high-grade ore bodies have been located. Drilling and assessment of these zones is now in progress.

Of the areas so far examined, the Ophthalmia Range appears to be the richest in ore. There the rocks are strongly folded on east-west axes and the Brockman Iron Formation forms long ridges as erosion residuals in the cores of synclines. Many large and high-grade deposits have been found in this region which, as yet, is but partially explored. The north-western limb of the Turee Creek Syncline appears to be another promising area for ore as is the country around and to the west of Weeli Wolli Spring.

Along the northern front of the Hamersley Range the jaspilite has a gentle regional dip to the south and there are no persistent major folds as in the central and southern areas of the province. Nevertheless narrow zones of strong flexuring are common and these commonly serve as sites of hematite enrichment. The most significant of these ore-bearing structures occur at Mt. Pyrton, Mt. Lockyer, Mt. Farquhar and in the hills north of Hamersley Station homestead. Some of these deposits have been drilled and assessed by Conzinc Riotinto Australia Ltd. These flexure belt ore bodies are individually smaller than those in the limbs of the Mt. Brockman Syncline, but the grade of ore is generally similar. These smaller deposits clearly illustrate the structural importance of synclinal troughs as a prerequisite for iron enrichment.

Numerous hematite ore zones have been found in the Marra Mamba and Boolgeeda Iron Formations. The richest area in the Marra Mamba Iron Formation appears to be at Roy Hill, and in the Chichester Range to the west of Roy Hill. In general these superficial deposits are thinner than those of the Brockman Iron Formation and deteriorate in grade at shallow depths below the surface. Chert bands are common and persistent.

Some large and high-grade ore zones have been found in the Boolgeeda Iron Formation in the Ophthalmia Range. None of these has as yet been tested in depth and it is possible that they may suffer the same deterioration at shallow depths as those of the Marra Mamba Iron Formation. Both formations are underlain by impermeable shaley beds and iron enrichment seems to have been controlled by the same structural and geomorphological conditions as apply to the Brockman Iron Formation.

Mineralogical and Chemical Composition.

Hematite, in the form of martite octahedra, and goethite are the principal mineral constituents of the ore. The proportion of the two varies widely in any one ore zone. The ore is usually banded in appearance and cavities, parallel to the banding, are a common feature. The cavities are often lined with coarse specular hematite and sometimes with goethite. In the "biscuits ore" the cavities are commonly infilled with black vitreous goethite or yellow ochreous material. Clusters and strings of fine quartz crystals are occasionally noted in thin section. Most of the ore is non-magnetic but specimens which are highly magnetic are not uncommon, and small magnetite octahedra have been recorded in thin section examination. In the massive recrystallised ore the grain size of the hematite is larger and the proportion of goethite much reduced. The banding in the ore is still detectable even in massive material of the highest grade and is presumably inherited from the protore jaspilite. Rhombohedral pseudomorphs, presumably derived by complete replacement of carbonate mineral in the protore, have been occasionally noted.

A vast amount of chemical data is now available concerning the hematite ores. The range in iron content is usually within the limits of 56 to 68 per cent., with the bulk of the material grading 60 to 64 per cent. The silica content is usually less than 4 per cent., alumina averages about 1.5 per cent., sulphur ranges between 0.03 and 0.06 per cent., titanium is less than 0.1 per cent. and the combined water content is generally less than 1 per cent. The phosphorus content averages about 0.12 per cent. with an extreme range between 0.05 and 0.17 per cent. This is a rather higher figure than that of ores for Yampi Sound and the Middleback Ranges. In all, the hematite of the Hamersley Range compares very favourably in composition and texture with other major deposits in the world.

THE PISOLITIC IRON ORES.

General Characteristics.

The pisolitic iron ores are widely distributed throughout the Hamersley Iron Province, but are most abundant in the ancient drainage channels of the Robe River, Duck Creek and the Beasley River. The ore forms the cappings of mesas and elongated ridges which are aligned along the courses of the original drainage channels, and is readily recognisable both on the ground and on aerial photographs. These ores represent an unusual variety of sedimentary iron deposit and the mode of origin is not completely understood. Very large reserves of this type of ore are available. In the Robe River valley alone the deposits cover a total area of about 30 square miles with the ore ranging in thickness from a few feet to nearly 200 feet.

The ore is usually pisolitic in texture and the iron content of the highest grade material is within the limits of 52 to 60 per cent. Silica and alumina are the main impurities, but collectively amount to less than 10 per cent. The content of combined water is of the order of 10 per cent., sulphur and phophorus are low and the ore is remarkably free of other metallic impurities.

Limonite, goethite and hematite are the principal mineral constituents of the pisolitic ore. The material is resistant to erosion, as is evidenced by its preservation as mesa cappings, but is friable and easily crushed and could be mined relatively cheaply from steep natural faces.

Distribution of the Pisolitic Ores.

The limonitic ore is found in all drainage systems radiating from the Hamersley Range which rise on the Brockman and Marra Mamba Iron Formations. There can be little doubt that these highly ferruginous formations are the ultimate source of the iron in the secondary pisolitic accumulations. The ore characteristically appears as elongated deposits along the low-gradient river valleys immediately below the steep hills and ranges composed of the Brockman Iron Formation.

The most important pisolitic deposits are to be found in the western section of the iron province in the drainage systems of the Robe River and Duck Creek. There appears to be a rough proportionality between the amount of ore within each drainage system and the area of Brockman Iron Formation drained by that system. The Robe River system, which has changed little since the ores were deposited, drains almost the entire northwestern sector of the Hamersley Range and contains by far the largest deposits of limonite ore in the province. The deposits can be followed almost continuously for 100 miles from Warramboo Station on the North-West Coastal Highway to the upper reaches of the Robe River near Silver Grass Peak. The largest individual deposits are in the downstream section between Deepdale and Warramboo and these are now being exhaustively examined and assessed by Broken Hill Pty. Co. Ltd. Total indicated reserves are measurable in thousands of millions of tons of ore in excess of 50 per cent. iron content.

The limonite deposits in the middle and upper reaches of the Robe River are held under Temporary Reserves by Basic Materials Pty. Ltd. In the middle reach of the river the mesas are generally smaller and narrower than those further downstream, but there is little difference in the grade of the ore and several hundreds of millions of tons have been indicated by face sampling and measurement of the mesaform deposits.

In the upper section of the Robe River, within the Hamersley Range, there are extensive terrace deposits of ore along the walls of the narrow gorges. These deposits have been deeply dissected following rejuvenation of the Robe and its numerous headwater tributaries. The gorge deposits tend to be more variable in texture and mineralogical composition than those downstream. In some sections the ore is of higher grade due to admixture with hematite-goethite conglomerate and assays of better than 60 per cent. iron are commonly recorded. Reserves of ore in the gorges are rather more difficult to assess due to the highly irregular base of the deposits on the valley walls. In some places the ore is up to 120 feet thick, but abrupt variations are common both in the direction of the river and across the valley. To all appearances the gorge deposits represent remnants of thick valley fill, which has been deeply incised and much of it scoured downstream by river action. The gorge deposits have been mapped and partially sampled. Reserves must be well in excess of 100 million tons. The value of this iron ore is rather offset by the difficulties of access within this rugged area.

There are numerous limonite deposits along the valley of Duck Creek and its tributary, Boolgeeda Creek. The ore-capped mesas are similar to those in the Robe River, but the ore layers are generally thinner and the overall grade is lower. Many of the mesas are deeply eroded and only thin residual cappings of ore remain. Estimated reserves of ore of grade exceeding 50 per cent. iron amount to about 800 million tons. These deposits have been mapped and sampled by Conzinc Riotinto Australia Ltd. and the Geological Survey. Duck Creek and Boolgeeda Creek are the main drainage units of the centre and northern limb of the important Mt. Brockman Syncline.

The Beasley River is the main southerly drainage unit from the southern limb of the Mt. Brockman Syncline. Extensive limonite deposits have formed along its valley for a distance of 15 miles. The ore is generally between 30 and 50 feet thick and the upper pisolitic layer assays between 53 and 57 per cent. iron. Reserves of the order of 250 million tons have been inferred.

Other large deposits of limonite have been found along the southern branch of the Fortescue River, where it traverses the Hamersley Range west of Wittenoom and at Dale's Gorge, which is situated in the plateau country to the south-east of Wittenoom. In the Dale's Gorge area the ancient land surface is preserved over a wider area than anywhere else in the province and it seems likely that further deposits may be located in the broad, alluvium-filled valleys beneath the more recent detrital veneer. Other pisolitic deposits, some quite extensive, occur along Yandicoogina Creek and Weeli Wolli Creek in the eastern section of the Hamersley Range. The remoteness of this area from the coast renders such ore of little immediate value in view of the abundant, nearby deposits of higher grade hematite ore.

Mineralogical and Chemical Composition.

The ore is characteristically pisolitic in texture with most of the pisoliths between 1 and 3 mm. in diameter. Examination, even in hand specimens, discloses great variation in the nature of the pisoliths. Many are composed of red, ochreous iron oxide, some of vitreous black and dark brown goethite and others of hematite with metallic lustre. Thin section examination shows that many are complex in composition with concentric layers of limonite and hematite. Some pisoliths provide evidence of fracturing followed by recementation and further growth. Fragments of fossil wood, randomly orientated and generally less than 1 cm. in length, are abundant in some horizons.

The pisolitic ore is usually porous. Vuggy cavities partially infilled with black vitreous goethite are common. Some sections of ore are less obviously pisolitic and appear to be composed of brown vitreous limonite. This type of ore is often sharply demarcated from the pisolitic ore. In the Robe River sections the vitreous ore weathers to well-defined benches interbedded with pisolitic ore and it has been possible to correlate some of these separate beds over short distances.

Intercalations of fluviatile sediments are rare in the ore. Clay lenses have been recorded from drill holes together with zones of lower grade clayey limonite.

In the middle section of the Robe River the pisolitic ore overlies with a knife edge contact an old surface of lateritized basalt. In other zones the ore is separated from the basalt by a zone of low grade, porous ore with large cavities and an abundance of yellow ochreous clay. In the lower Robe River the ore is underlain by clay, sandstone and fluviatile grits.

Cavities within the ore are occasionally lined with opaline silica and veins of travertine have been detected in drill core.

Angular fragments of hematite are abundant in the material in the gorges of the upper Robe River. Most of these fragments are less than 1 cm. across and they are set in a pisolitic groundmass, similar to the common ore type seen downstream. Fluctuations in the grade of ore are presumably influenced by the relative proportion of goethite, limonite and hematite. Ore of lower grade is usually recognisable by a high content of yellow ochreous limonite in large cavities and pipes, while ore of high grade has a sub-metallic lustre and numerous pisoliths of red ochre.

Many hundreds of chemical assays of the limonitic ores are available from Company and Geological Survey records. The ore in the Robe River may be regarded as fairly representative of the entire region and the results of over 100 face sample assays are summarised in the following table:—

	Lower Robe River		Middle Robe River	
	Average	Range	Average	Range
	%		%	
Fe	56·0	50·2–60·5	57·0	53·8–59·5
SiO_2	5·0	2·3–9·2	5·0	4·2–6·0
Al_2O_3	2·9	1·3–6·6	3·0	2·2–4·1
P	0·06	0·025–0·11	0·06	0·05–0·08
S	0·11	0·02–0·15	0·07	0·05–0·11
Ignition Loss	10·8	7·6–12·7	10·0	9·5–11·0
TiO_2	0·19	0·07–0·40	....	....
Mn	0·10	0·05–0·20	....	....

Genesis of the Pisolitic Ores.

As mentioned earlier the most significant occurrences of this type of ore are confined to long established drainage channels which rise on the Brockman and Marra Mamba Iron Formations. The upper drainage basin of the Robe River is almost entirely underlain by the Brockman Iron Formation over an area of nearly 2,000 square miles in the north-western sector of the Hamersley Range. Duck Creek, Boolgeeda Creek and the Beasley River drain from the same formation in the limbs of the Mt. Brockman Syncline, and at Dale's Gorge the limonite has accumulated within an internal drainage basin on the high plateau which is mainly underlain by the Brockman Iron Formation.

It is suggested that the pisolitic ores represent the end product of a protracted cycle of weathering and desilicification of transported jaspilite detritus. This detritus accumulated in most of the valleys within and around the Hamersley Range during the long period of erosion which culminated in a mature subdued landscape of broad valleys and domed, gently sloping hills. Remnants of this old surface are abundantly preserved throughout the Hamersley Range. The flat-topped mesas in the present river channels are regarded as remnants of this profile in the lowland areas.

Following the establishment of this mature surface climatic conditions were apparently favourable for the process of iron enrichment within the jaspilite. Silica was dissolved and retained sufficiently long in solution to be removed entirely. Iron was dissolved to a lesser extent and quickly reprecipitated. Where structural conditions were favourable, zones of hematite enrichment were developed on the slopes of the jaspilite hills to depths of up to 200 feet below the surface.

At the same time, in the river channels, similar processes of desilicification and iron enrichment are believed to have occurred within the thick detrital deposits which were mainly composed of the same jaspilite as that of the surrounding hills. In the river channels, where there was free and continuous movement of water through this unconsolidated detritus, desilicification apparently proceeded rapidly and almost completely. In the Robe River channel field evidence indicates that the old channel was almost entirely infilled with detritus which has now been transformed to pisolitic ore, in places over a width of four miles.

The first stage in the transformation of jaspilite detritus led to the formation of hematite-goethite conglomerate or "canga." Remnants of this conglomerate are found in the terraces which flank the ancient drainage channels. In the central zones of the channels, where water was more abundant the hematite conglomerate was progressively transformed to pisolitic limonite-goethite. Careful examination of the material in the gorges of the upper Robe River and along the northern flank of the Buckland Hills provides examples of all stages of progressive desilicification and transformation of hematite-goethite conglomerate into pisolitic ore.

In summation, this theory proposes a common mode of origin for both the hematite-goethite ores and the lower grade pisolitic limonite ores. Both are products of supergene enrichment of jaspilite by selective removal of silica. In the case of the limonitic ores hydration of the iron oxides has been more extensive due to their concentration at lower levels in well watered drainage channels. Hydration has been accompanied by the growth of pisoliths, and remnants of hematite are rare.

Following the rejuvenation of the rivers, probably in late Tertiary times, both the gorge and riverine deposits were deeply dissected and are preserved as terraces or mesa cappings.

The distribution of the limonitic ores in the Robe River has apparently been influenced by the resistant bar of Brockman Iron Formation at the northern end of the Buckland Hills. Large and thick deposits occur immediately upstream from this bar which appears to have dammed the transported material. Downstream, below the bar, the river followed a meandering course with a low gradient of the order of 10 feet per mile. It cut directly across the general strike of the sediments of the Hardey Group and older sediments further to the west. These conditions must have been favourable for the accumulation of the large deposits between Yerra Bluff and Warramboo. At Warramboo drilling has shown that the deposits continue below the more recent alluvium and are split into channels. This area may have been delta at the time of deposition.

It has been postulated that the limonite was deposited as bog ore. This would necessitate the transport of vast quantities of iron in solution and its subsequent precipitation in swampy reaches of the rivers. The most serious objection to this concept is the fact that environmental conditions appear to have been more in favour of the solution and transport of silica rather than iron. As the hematite ore bodies and the "canga" terraces have originated as a result of selective leaching of silica and consequent enrichment of iron in the parent jaspilite, it seems logical to believe that the pisolitic ores originated under a similar chemical regime.

Furthermore the grade of the ores is much higher than any recorded bog iron deposits in the world, and there is an absence of the common impurities such as manganese, lime, magnesia, sulphur, and heavy metals which normally contaminate bog iron deposits. Most of the deposits are curvilinear in surface plan and can be reasonably assumed to mirror the pattern of the old drainage system. It is clear that they have been deposited in well-defined river channels rather than in swampy areas of broad and ill-defined drainage such as are favourable to bog iron accumulation.

CONCLUSIONS.

A great deal of work remains to be done before a reliable estimation of the iron ore reserves of the Hamersley Iron Province can be made. It is unlikely that further major deposits of the pisolitic ore will be discovered except in areas far from the coast. However, it appears certain that further exploration will disclose more extensive deposits of hematite, particularly in the western section of the Ophthalmia Range and in the Turee Creek Syncline. These areas are far from the coast, but seem to offer better prospects for the occurrence of the highest grade of hematite ores containing more than 65 per cent. iron.

Photogeological examination of the eastern and southern section of the province has revealed ideal structural conditions for ore formation in many localities. These will be examined during the 1963 field season.

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THE IRON ORE DEPOSITS OF THE WELD RANGE, MURCHISON GOLDFIELD.

by W. R. Jones.

INTRODUCTION.

General.

The Weld Range, centred approximately at latitude 26° 50′ S., longitude 117° 40′ E., is a prominent line of hills 35 miles long by 2 miles wide. It rises from 200 feet to 800 feet above the surrounding plain. It is most widely known because of Wilgie Mia, the aboriginal red ochre mine, which was worked for centuries before the advent of the whites. Consequently the iron ore of the Range was known by whites at an early date but the distance from seaboard has discouraged its detailed examination. The Range is 40 road miles from Cue which is 264 miles by a 3 foot 6 inch gauge railway to the port of Geraldton, capable of handling ships of safe loaded draught of 27 feet and length of 525 feet.

As part of its plan to stimulate the search for iron ore the Western Australian Government, late in 1959, proposed to diamond drill the six known iron ore lenses of the Weld Range as listed by Johnson (1950). Drilling commenced in January, 1961, and was completed in September, 1962. The Range was mapped on a scale of 50 chains to the inch in March and April, 1962, by W. R. Jones and I. Gemuts.

Seven new lenses of probably economic size were found. In May and June lenses W1 to W6 were mapped on contour plans at 100 feet to 1 inch prepared from aerial photographs by the Photogrammetry Section of the Department of Lands and Surveys. Lenses W7 to W13 were measured by pacing and tape.

Plans accompanying this report are a geological map at 1 mile to 1 inch (Plate XXVI) and five plans, with sections, of each of lenses W1 to W6 at 200 feet to an inch (Plates XXVII to XXXI).

Previous Work.

Weld Range has been visited by many geologists but little detailed work has been done. Aspects of the geology have been mentioned by Gibson (1904), Woodward (1914), Johnson (1950), Miles (1953) and Ellis (1955) who describes the investigation of slight anomalous radioactivity found at Wilgie Mia in 1952. The original drilling programme of the present investigation was designed by R. R. Connolly.

GEOLOGY.

General.

The Weld Range is a series of steeply dipping jaspilite beds interlayered with dolerite, some of which may be extrusive. Less important are porphyry, sandstone, breccia and granite. Apart from superficial deposits the rocks are probably of Archaean age.

Jaspilite.

The jaspilite beds are typical banded iron formations ranging in width from 1 foot to 400 feet. Most of them contain between 20 and 60 per cent. magnetite interbedded with chert in distinct alternating bands of 1 inch maximum width. The grain size is in the order of 0.01 mm.-0.03 mm.

Some jaspilite has a prominent lensing structure. All lenses are chert and in the hand specimen magnetite has the appearance of flowing around each lens. Two groups of jaspilite (Madoonga beds and


LOCATION MAP
INDIAN OCEAN
BROOME
PORT HEDLAND
ROEBOURNE
ONSLOW
HAMERSLEY IRON PROVINCE
WESTERN AUSTRALIA
HAMERSLEY RANGE
OPHTHALMIA RANGE
FORTESCUE RIVER
MT. PYRTON
MT. BROCKMAN
MT. TURNER
MT. BRUCE
MT. LOCKYER
MT. NEWMAN
Wittenoom
Hamersley
Marillana
Roy Hill
Rocklea
Wyloo
Coodiadarrie Hills
DALES GORGE
INDEX OF 1:250,000 MAP SHEETS
YARRALOOLA
PYRAMID
MARBLE BAR
WYLOO
Mt BRUCE
ROY HILL
EDMUND
TUREE CREEK
NEWMAN
AREA COVERED BY MAP
LEGEND
CAINOZOIC
Valley Fill, Scree, Alluvium.
PROTEROZOIC
WYLOO GROUP
Quartzite, Conglomerate, Greywacke, Dolomite.
HAMERSLEY GROUP
Boolgeeda Iron Formation. Woongarra Dacite Weeli Wolli Formation.
Brockman Iron Formation.
Mt. McRae Shale, Mt. Sylvia Formation, Wittenoom Dolomite.
Marra Mamba Iron Formation.
FORTESCUE GROUP
Basalt and Sediments.
ARCHAEAN
Granite, Gneiss, Greenstone.
Iron Deposits – Pisolitic
– Hematite
REFERENCE
Geological boundary.
Fault.
Synclinal axis.
Anticlinal axis.
Watercourse.
Road
GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
GEOLOGICAL MAP
OF THE
HAMERSLEY IRON PROVINCE
WESTERN AUSTRALIA
SHOWING DISTRIBUTION OF IRON DEPOSITS
SCALE: 15 MILES TO AN INCH
Geology by W.N. Macleod, L.E. de la Hunty, W.R. Jones and R. Halligan.
1962
7492

Lulworth beds) near the northern side of the range have characteristic structures and although similar they are easily distinguishable and remarkably consistent along the strike (Figs. 11 and 12). Occasional zones of slumping and minor contemporaneous brecciation are the only additional variations in the uniform appearance of the jaspilite.

The search for iron ore was concentrated in jaspilite sufficiently wide to carry ore in large quantities. The iron ore-bodies are anomalous concentrations of magnetite, hematite and goethite confined, so far as is known, to the Madoonga and Wilgie Mia beds. Of these the Wilgie Mia bed is by far the more important.

Dolerite.

The dolerite is fine to medium-grained and rarely porphyritic. It makes up the major part of the range as a number of intrusions, with possibly some flows. It is normal dolerite except near the margins of the range. Thin sections cut from bore core of DDH No. 10 have been examined by Dr. Trendall, (Petrologist of the Geological Survey) who reports: "These rocks together suggest a steady metasomatic breakdown of original dolerite, consisting of quartz, sericite and limonite. The whole process would be expected to involve relative enrichment in silica and potash and relative impoverishment in soda and lime." This metasomatism is undoubtedly associated with the intrusion of porphyry and granite.

Porphyry.

Fine to medium-grained quartz-plagioclase porphyry, typical of the goldfields, is widespread but outcrops infrequently. The maximum exposed development is near the western end of the range, on its northern fringes. The largest outcrop within the range proper is a plug-like mass near the northern end. The formation of the porphyry was associated with the end stages of the granite intrusion which was also responsible for the quartz veins in the faults and the metasomatism of the dolerite.

Granite.

A coarse-grained gneissic biotite-granite forms prominent outcrops flanking the range closely at its northern end.

Breccia.

There is a distinct band of breccia of doubtful origin within the Madoonga jaspilite. It is best exposed in the vicinity of the yellow ochre mine.

Sandstone.

There are a few small outcrops of coarse-grained, clayey sandstone southwest of Little Wilgie Mia. This sandstone is in the stratigraphic position of the Wilgie Mia jaspilite which is not seen for several miles to the southwest.

STRUCTURAL GEOLOGY.

Folds.

Johnson (1950) has published a structural sketch map of a wide area near Weld Range. This map shows that the Range is probably on the southern limb of a northeasterly plunging anticlinal segment of a large granite intrusive. The range may be an almost complete syncline but this is not clear. On any interpretation parts of the southern beds are overturned.

Minor folds are not numerous but there is a widespread monoclinal flexure plunging 15°-25° northeasterly. There are occasional drag folds associated with movement along the faults. Chevron folds with axial planes usually parallel with the joint-fault system are common, particularly near the faults.

Faults.

The Weld Range is segmented by a well-developed fault system, the pattern of which is clearly shown on the accompanying geological map. Strong jointing parallels the fault system. The strike of the faults is resolved into three main directions each of which has two directions of dip. The observed range of dips is 25°-90° but numerous strong joints dipping at less than 25° suggest that the range is wider. At the Weld Hercules gold mine the dip of the fault containing the gold-quartz vein changes from 70° to 35° in about half a mile.

The large faults which displace the Range northeast of lens W1 and elsewhere are the resultants of groups of small faults en echelon (Fig. 13).

The numerous faults have strongly affected the iron ore bodies, considerably reducing the potential of some and adding the complication of mullock horses in others. Separation by as much as 100 feet of parallel fault planes has produced strike blanks in jaspilite and ore. Plate XXVII shows at least one such separation in Lens W2. The rock in these blanks is highly decomposed but it is probably dolerite.

DIAMOND DRILLING.

The drilling was done by private contractors using equipment hired from the Mines Department. Drilling conditions were bad and the core recovery was poor. Table 1 summarises the results:—

TABLE 1.
SUMMARY OF DIAMOND DRILLING RESULTS 1961-62.

Hole No.	Lens No.	Angle of Depression	Depth of Hole	Iron Formation	Estimated True width	Core Recovery in Iron Formation	Acid-soluble Iron	Sludge samples	Acid-soluble Iron
		Degrees	feet	feet	feet	%	%	feet	%
1	W. 1	50	812	143–168 244–322	18 60	9 65	57·5 57·5	....	....
2	W. 1	50	647	Nil	....	....	....	....	....
3	W. 6	45	808	440–522 522–637 715–760	70 90 40	91 100 100	52·3 approx. 40 53·5	....	....
4	W. 3	45	802	399–429	26	88	68	....	....
5	W. 3	45	605	196–241	35	52	44	....	....
6	W. 3	45	429	199–312	90	30	64	....	....
7	W. 6	40	383	206–383	130 Hole abandoned	9	60	....	....
8	W. 3	40	411	248–390	110	6	66	....	....
9	W. 4	50	650	Nil	....	....	....	....	....
10	W. 5	40	472	469–472	.... Hole abandoned	....	....	....	....

TABLE 1—*continued.*

Summary of diamond drilling results 1961-62—*continued.*

Hole No.	Lens No.	Angle of Depression	Depth of Hole	Iron Formation	Estimated True Width	Core Recovery in Iron Formation	Acid-soluble Iron	Sludge Samples	Acid-soluble Iron
		Degrees	feet	feet	feet	%	%	feet	%
11	W. 1	30	362	182–330	135	50	56	182–330	51 (*a*)
12	W. 1	50	334	228–297	40	15	59	231–303	56·2
13	W. 2	40	313	174–313	110	11	59	177–270	52
14	W. 5	40	417	262–378	85	29	64	265–375	56·5 (*b*)

Total Footage Drilled: 7,247.

(*a*) Includes two assays of less than 40 per cent. The sludge was probably contaminated in casing operations.

(*b*) Includes three assays of less than 40 per cent. There was no casing operation comparable to that of "a" and the sludge probably in part came from the mullock band shown on the plan of Lens W. 5.

IRON OREBODIES.

General.

The iron ore is boldly exposed in hills which rise to about 200 feet above the surrounding plain. All lenses are almost vertical and only Lens W2 has any overburden. The removal of wallrock waste is a minor problem to the depths listed in Table 2.

The hematite bodies are largely of specularite with bands of red and yellow ochre and of earthy and botryoidal goethite. They would produce a large proportion of fines in any mining operations. The magnetite ore is more massive.

Details of the orebodies are summarised in Table 2. Plates XVII to XXXI show the shapes, mostly arbitrary, of the blocks used to estimate the tonnages of ore in Lenses W1 to W6. Poor recovery of core and incomplete surface sampling preclude stating an exact ore grade but the estimates given are restricted to those blocks with a reasonable chance of containing 60 per cent. iron. A factor of 8 cubic feet of ore to a long ton has been used in the calculations.

TABLE 2.

SUMMARY OF THE DETAILS OF THE IRON OREBODIES.

Lens No.	Length	Width	Depth	Long Tons	Main Minerals	Remarks
	feet	feet	feet	millions		
W. 1	1,800	96	400/2	4·3	Hematite, Goethite	Includes the old native ochre mine the desired preservation of which would reduce the estimate to about 4 million tons.
W. 2	1,200 less 60	60 60	260/2 20	1·2	Goethite, Hematite Mullock	Has a maximum of 80 feet of overburden at its N.E. end. Fault block.
W. 3	1,000 less 80	72 72	400/2 250	1·6	Hematite .... Mullock	A block of 500,000 tons at the western end is not included as numerous mullock seams would probably lower the mined grade.
W. 4	600 less 30	80 80	260/2 200	0·7	Hematite .... Mullock	Plunge of the eastern end is not known. Block shape may be uneconomic. Possible fault blank.
W. 5	700 +1,600 +560	48 56 50	210/2 230 240/2	3·4	Magnetite, Hematite and a little Goethite	Continuously mineable. Divided in places by 10 feet of mullock. Width is conservative.
W. 6	Two of 400 +880	60 60	300/2 300	2·9	Magnetite, *Goethite some Hematite	Probably continuously mineable. Estimate conservative.
W. 7	500 700	65 50	200 200	0·8 0·8	Magnetite and a little Goethite	There are other small blocks. Lens may total 4,000 feet by 100 feet of > 45% Fe, i.e., 10,000,000 tons to 200 feet.
W. 8	a 950 b 600	80 36	200 100	1·9 0·3	Magnetite and a little Goethite	a and b are separated by 75 feet of low grade jaspilite. Lens may total 4,600 feet by 100 feet of > 45% Fe, i.e., 12,000,000 tons to 200 feet.
W. 9	900	80	200	1·8	Magnetite	Has several smaller bodies from 200 feet by 20 feet to 300 feet by 80 feet. Lens may total 3,500 feet by 100 feet of > 45% Fe, i.e., 9,000,000 tons to 200 feet.
W. 10	3,500 700	72 56+	200 100	6·3 1·0	Magnetite Goethite	Lateritic crust. Low poor outcrop.
W. 11	2,300	60	200	3·4	Magnetite and some Hematite	Lateritised at its eastern end. Full width of iron formation is not exposed.
W. 12	1,000	32	100	0·4	Magnetite	Low comparatively poor outcrop.
W. 13	2,000	32	100	0·8	Magnetite	Least well examined.

* A complex association of minerals in core from D.D.H. No. 3 is recorded by the Government Chemical Laboratories in the Annual Report of the Mines Department for 1961, p. 158. Minnesotaite and an iron manganese phosphate were among the minerals identified. They are of mineralogical interest only.

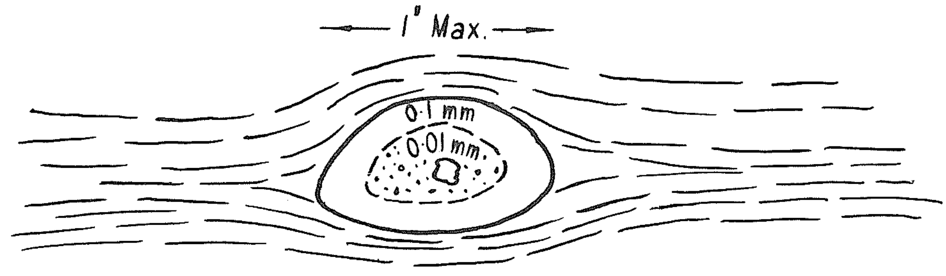


Fig. 11 Quartz eyes of the Madoonga jaspilite

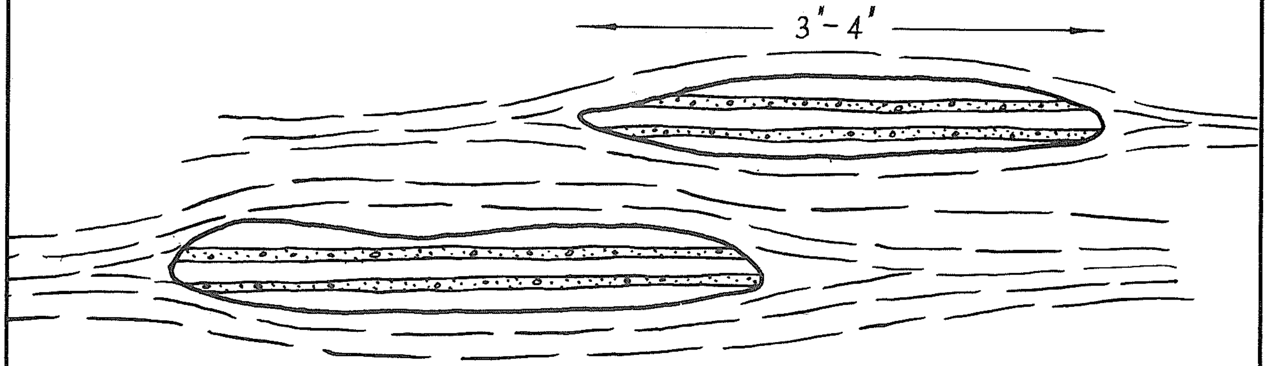


Fig. 12 Chert discs of the Lulworth jaspilite

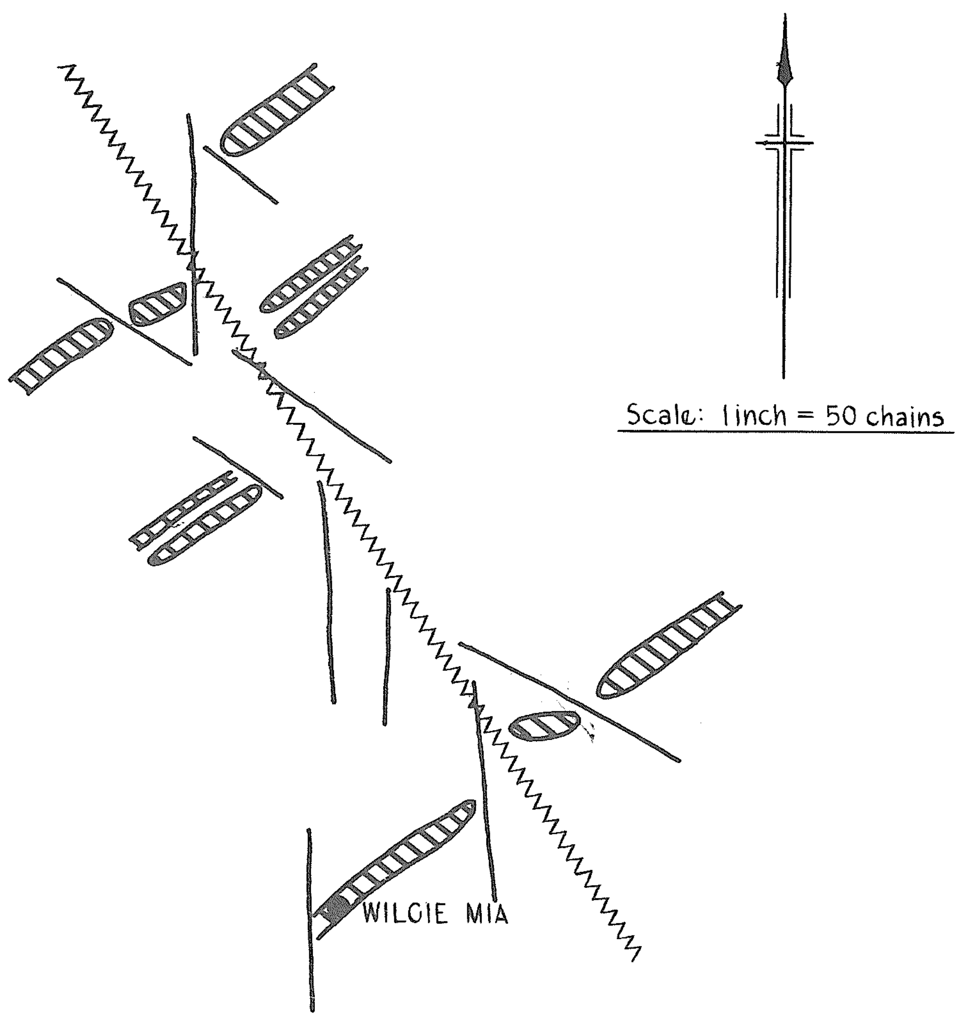
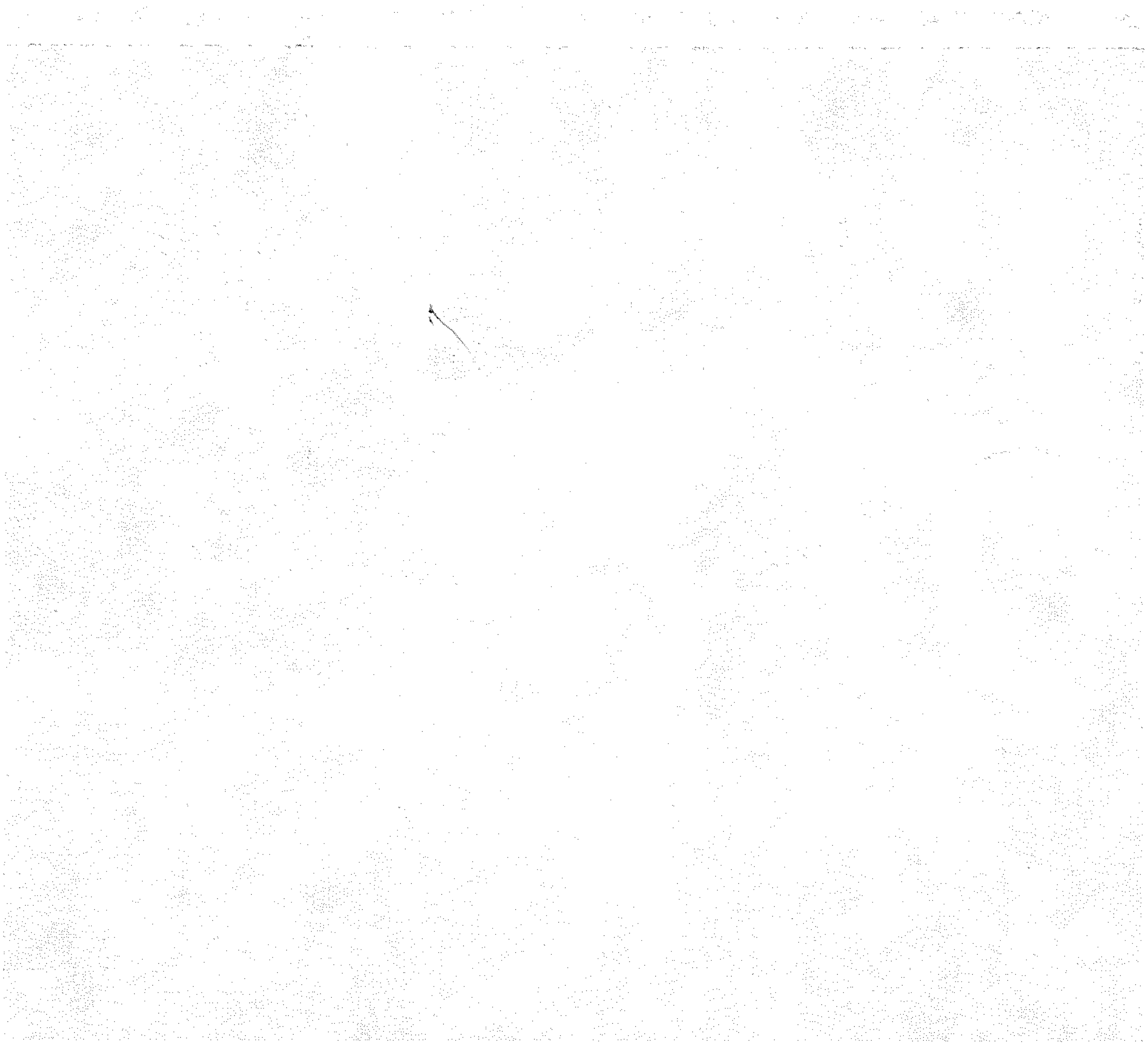


Fig. 13 Complex faulting near Wilgie Mia. The resultant break is normal to the strike of the Range



No estimates are given for ore in talus or in the 10 to 30-foot jaspilite associated with the Wilgie Mia bed. This jaspilite has a number of hematite-goethite bodies particularly near lenses W5 to W11, but they are probably not of economic width.

Impurities.

All samples which assayed better than 56 per cent. iron had a low impurity content. Ores of a lower iron percentage are high in silica but other deleterious elements are within the generally accepted limits and remain so, probably to a depth of 400 feet below the outcrops. Sulphur as pyrite might be a problem at depth. Core from 522 feet-637 feet in D.D.H. No. 3 had fine pyrite. This core assayed 40 per cent. iron and 1.4 per cent. sulphur.

Ore from lenses W1 and W2 has a consistently high water content which would probably prevent attaining a 60 per cent. grade for direct shipping. Table 3 lists the analyses of a number of composite samples.

TABLE 3.

ANALYSES OF A NUMBER OF COMPOSITE SAMPLES.

Lens	Sample Locality	ANALYSIS										
		Fe Total	Fe Acid Soluble	SiO_2	S	P	Ti	Mn	MgO	CaO	Al_2O_3	Ignition Loss
W. 1	DDH No. 1— 143–168 ft.	57·5	57·2	3·34	0·07	0·14	0·14	0·06	Tr.	0·16	2·14	11·2
	244–320 ft.	57·5	57·3	4·33	0·02	0·09	0·19	0·04	Tr.	0·07	2·61	10·0
	DDH No. 11— 182–330 ft.	58·4	58·4	3·16	0·02	0·13	0·05	1·0	Tr.	Nil	2·9	9·22
	Johnson (1950)— Sample M115	....	63·69	1·78	0·08	0·27	TiO_2 0·02	....	....	....	....	5·17
	Sample M116	....	62·7	2·35	0·06	0·18	0·02	....	....	....	....	5·98
W. 2	DDH No. 13— 173–313 ft.	58·9	58·9	4·22	Tr.	0·06	0·02	0·42	0·3	0·11	2·35	9·48
	Johnson (1950)— Sample M120	....	57·5	4·58	0·02	0·09	TiO_2 0·02	....	....	....	....	10·35
W. 3	DDH No. 6— 198–299 ft.	64·1	63·9	3·63	Tr.	0·02	0·03	0·02	Tr.	Tr.	2·9	1·64
	DDH No. 4— 399–429 ft.	68·3	68·1	1·94	Nil	0·01	0·02	0·01	Nil	Nil	Nil	0·43
W. 4	Johnson (1950)— Centre of Orebody M123	....	60·7	6·07	0·14	0·2	TiO_2 0·1	....	....	....	....	....
W. 5	DDH No. 14— 262–378 ft.	64·1	64·1	4·8	0·01	0·05	0·05	0·19	0·19	0·07	1·69	1·35
	Johnson (1950)— Sample M140	....	66·4	1·89	Tr.	0·08	TiO_2 0·03	....	....	....	....	1·17
W. 6	DDH No. 3— 440–522 ft.	51·6	51·6	23·0	0·46	0·07	Tr.	0·12	1·23	0·17	1·6	0·66
	715–760 ft.	54·1	53·2	12·9	0·24	0·08	0·02	0·56	1·54	0·16	0·6	6·66
	Johnson (1950)— Sample M143	....	64·38	2·11	0·02	0·12	Tr.	....	....	....	....	4·32
W. 9	Chip across 105 ft. width	61·1	61·1	4·31	0·04	0·1	0·02	0·04	Tr.	Tr.	1·8	6·15

Origin.

The orebodies have a complex geological history and the relative importance of each process involved in their formation can only be surmised. They may be—

(1) mainly as they were originally deposited;

(2) altered supergene enrichments of the jaspilite;

(3) predominantly of metamorphic origin.

There is abundant evidence throughout the Weld Range to show that the iron has been mobilised in part. This probably took place at the same time as the quartz injection and silica bleaching along some of the faults. The effects are quite localised and the largest altered mass observed is west of the yellow ochre mine where the jaspilite is altered to specular hematite quartzite for about 400 feet along the bedding from a cross fault.

It is not known to what extent mobilisation has contributed to the establishment of an economic grade. It has clearly modified the shape and limits of some orebodies, in places sufficiently to complicate a mining operation. An example is in lens W8 where blocks a and b (Table 2) are separated by a 75 foot wide zone of bleached jaspilite.

Later modification by intense weathering has produced the hematite-goethite bodies of lenses W1 to W4 in a part of the range cut by numerous large faults.

CONCLUSION.

Total indicated and inferred reserves of iron ore in the 13 orebodies of the Weld Range are 30 million tons of about 60 per cent. grade.

Lenses W5, W10 and W11, which are considered to be the best three orebodies, together contain about 13 million tons. Lens W1, the best known of the orebodies, has a high proportion of goethite and run-of-mine ore probably would not maintain a 60 per cent. grade.

A further 25-30 million tons of iron formation adjacent to lenses W7, W8, W9 and W12 might contain 45 per cent. iron. The Madoonga jaspilite is comparatively rich in iron and careful sampling might outline several tens of millions of tons of material suitable for beneficiation.

Most of the 30 million tons of ore listed in Table 2 could be mined cheaply with a low initial capital outlay. High transport costs over 40 miles of road and 264 miles of lightly ballasted railway of 3 ft. 6 in. gauge reduce its prospects for development in the near future.

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SOME PROTEROZOIC VOLCANIC ROCKS FROM THE NORTH WEST DIVISION.

by A. F. Trendall.

ABSTRACT.

The presence of perlitic, eutaxitic and quartz-felspar intergrowth textures (including spherulitic and micrographic) is noted in some acid volcanic rocks of the Western Australian Precambrian. The association of high-temperature albite and probable quartz paramorphs after tridymite suggest that many of the textural features described were formed during devitrification shortly after emplacement. Slow devitrification at normal temperatures is probably an unusual phenomenon.

INTRODUCTION.

In this paper selected textures and minerals of some acid intrusive, extrusive and pyroclastic rocks of the Nullagine successions of the Hamersley Range area (22-23° S.; 117-119° E.) and the Dampier Archipelago (centre 20° 30′ S.; 116° 50′ E.) are briefly described, and their possible significance discussed; systematic descriptions of the rocks are not given in this preliminary account.

DISTRIBUTION, RELATIONSHIPS, CLASSIFICATION AND APPEARANCE.

For information used in the following summary I am grateful to Drs. R. C. Horwitz and W. N. MacLeod and to Messrs. R. Halligan, L. E. de la Hunty, M. Kriewaldt and R. Ryan. The Hamersley rocks are mainly from the Woongarra Dacite, which includes tuffs as well as lavas. It is a thick and laterally extensive formation whose base is some 20,000 feet above the base of the Nullagine succession in which it occurs. Some come also from thinner bands of similar volcanic rocks which occur impersistently at other levels in the same succession and also from a few small plugs. In the Dampier Archipelago the rocks concerned crop out on several islands at and near the base of the succession; field evidence shows that most are intrusive.

For present convenience of reference these rocks may be grouped as follows:—

(1) Hamersley Area:
- (a) Homogeneous dacite.
- (b) Lava-breccia (stratiform and intrusive).
- (c) "Green quartzite" lava (MacLeod and others, 1963).
- (d) Tuff.

(2) Dampier Archipelago:
- (a) Granophyres.
- (b) Aphanitic and porphyritic rocks.

The field appearance is frequently misleading. Many of the quartz-rich aphanitic rocks are as dark as basalts, and tuffs are not distinguishable from lavas. A blotchiness in colour often gives a false impression of granularity, especially in the granophyres, and "green quartzite" is an apt, but erroneous name for the lower part of the Woongarra Dacite.

TEXTURES.

Quartz-Felspar Textures.

The "green quartzite" (R95, R96—numbers refer to rocks and thin sections in the registered collection of the Geological Survey of Western Australia) and the matrix of the porphyritic dacites (R207) are largely composed of an equidimensional quartz-felspar mosaic, of average grain diameter 0.02-0.1 mm., in which the boundaries are so grotesquely intercrenulated that it is impossible in a section of standard thickness to define the limits of any one grain. Irregular quartz-felspar boundaries of this type pass gradationally through fine brush-like (R 220) or myrmekite-like (R 94, R 222) intergrowths which produce irregular extinction effects into micrographic textures best displayed by the granophyres (R 152).

Spherulites formed of similar irregularly radiate linear quartz-felspar intergrowths are common in the aphanitic rocks of both the Hamersley and Dampier areas. They vary in excellence of development from a crudely radiate pattern imposed over a well crystallised mosaic (R 226) to feathery aggregates with sharp edges completely lacking granularity (R 153), and they vary in size from 0.3 mm. (R 223) to 3 mm. (R 153). They may be conspicuous or indistinguishable in hand specimen. Another type of spherulite often occurs in association with perlitic breccias. Each grain of what at first appears to be a fine quartz mosaic is a radiate (chalcedonic?) aggregate extinguishing with a black cross (R 104). Both these and the larger spherulites are radially fast. They may be closely packed in the rock (R 206) or widely spaced.

A common textural feature of the "green quartzite" and of the Dampier granophyres is the presence of interlocking laths or needles of quartz which are clearly defined under ordinary light by their complete freedom from turbidity. Under crossed nicols these laths extinguish in several parts, each part together with the quartz of the immediately adjacent matrix. They vary in length (maxima in individual thin sections from 0.1 mm. (R 89) to 2 mm. (R 152)) and have elongations as great as 100 : 1. They have no obvious preferred orientation, except that several needles often occur in acutely radiate and loosely aggregated bundles; such bundles are common in the Dampier granophyres, where they tend to form the central part of optically consistent areas of micrographic intergrowth (R 154).

Perlitic Texture.

Textbook examples of perlitic cracking occur frequently in the constituent fragments of lava-breccias in the Hamersley area (R 88, R 106, R 107, R 108, R 109). The cracks themselves are marked either simply by the grain boundaries of the plagioclase which is the main devitrification product of the original glass, by dark lines running through plagioclase crystals, or by thin chlorite bands. This plagioclase is arranged concentrically, together with some quartz and chlorite, around an irregular core of cryptocrystalline and effectively isotropic green chlorite. It is described more fully below.

Eutaxitic Texture.

Tuffs in which closely packed shards have been deformed into a crudely parallel arrangement have been collected from two localities in the Hamersley area; one is within the Woongarra Dacite proper (R 214) and another from a similar stratiform volcanic band lower in the succession (R 216, R 217). The shards are devitrified to quartz and plagioclose aggregates and average 0.5 mm. in greatest diameter.

MINERALS.

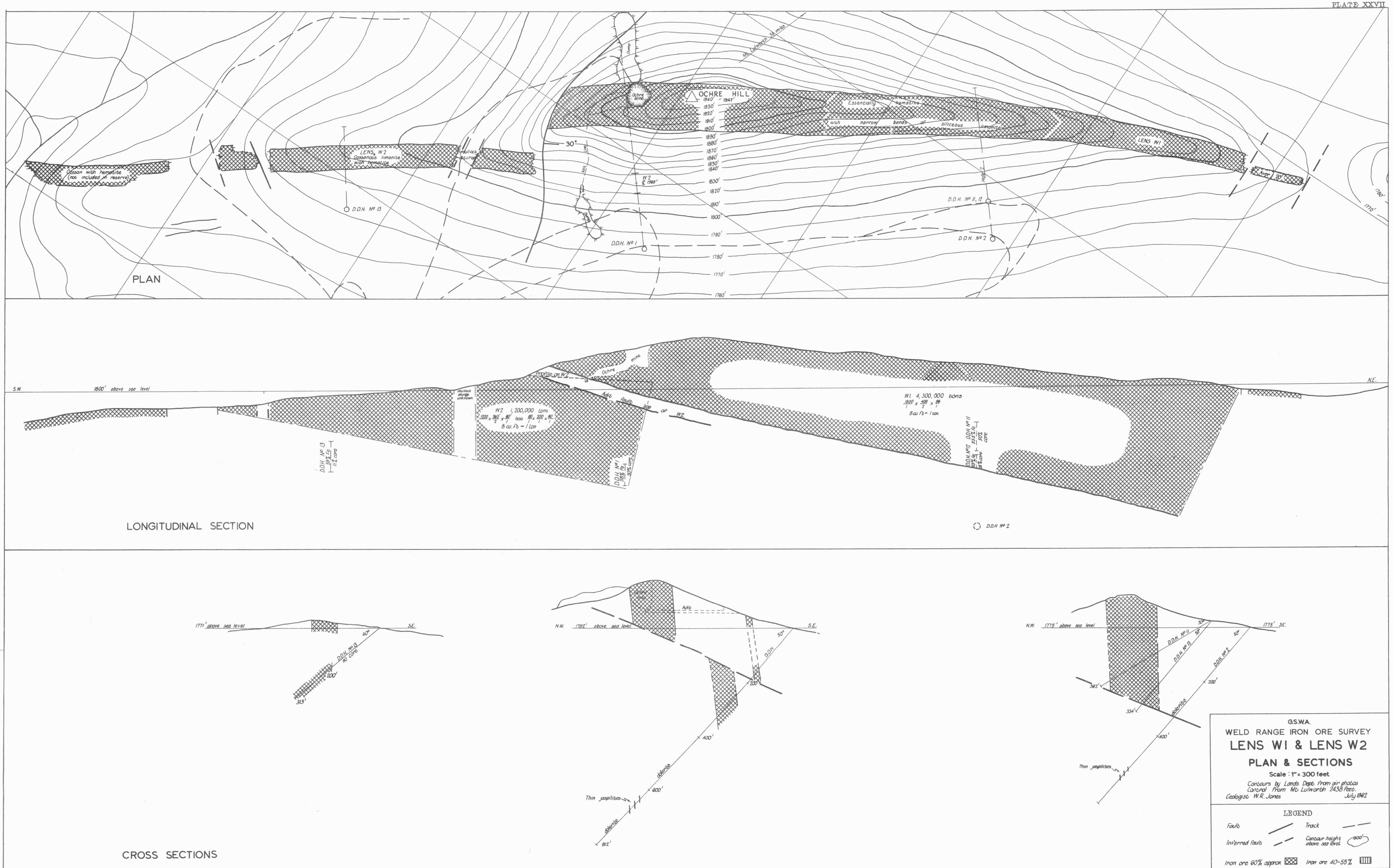
Plagioclase.

Plagioclase was noted above as a devitrification product of rocks with perlitic texture. A similar plagioclase is also the felspar of the quartz-felspar intergrowth textures described in both the Hamersley and Dampier areas. Its usual characteristics are as follows:—

1. (1) It never forms large or euhedral crystals.
2. (2) The extinction is often irregular (radiate or feathery).
3. (3) It is always cloudy with inclusions about 0.2 mm. across.
4. (4) The only twinning is of an unusual type, described below.
5. (5) One or two cleavages are defined by thin inclusion-free planes rather than by cracks. The strongest is (001).
6. (6) It is usually elongate parallel to (100).

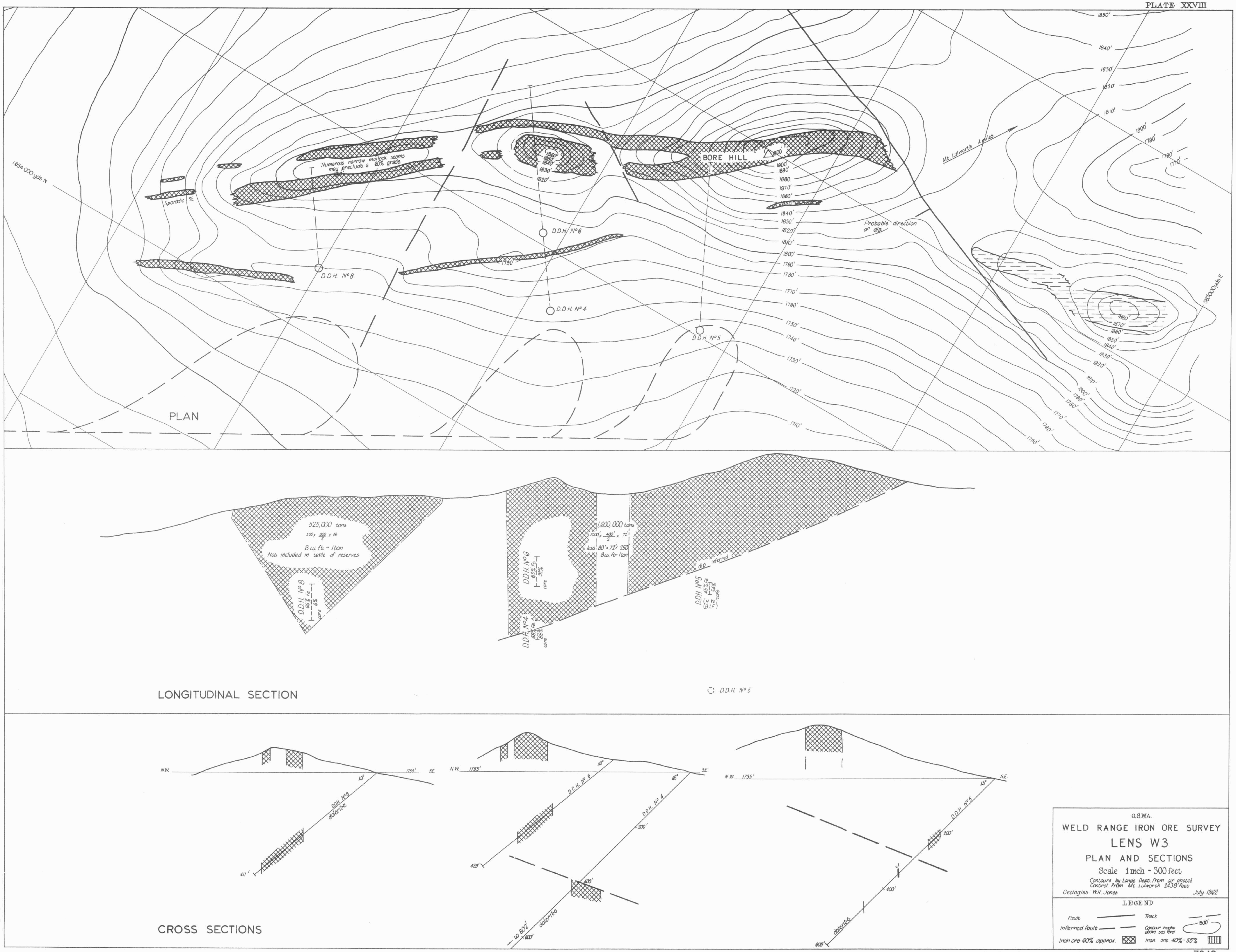
This plagioclase was tentatively identified as zeolite or orthoclase when first encountered. The twinning mentioned above, of which only a few examples have been seen, gives a lozenge-shaped


PLATE XXVI
Squatters Well
Mindoolah Well
soil covered flats
YELLOW OCHRE MINE
Four Mile Well
Madoonga Homestead
Stock Well
House Well
Ram Well
Range Well
W E L D
R A N G E
MT LULWORTH
W13
W6
THE GAP
Thin Jaspilites
HERCULES GOLD MINE
LITTLE WILGIE MIA
WILGIE MIA
W1
W2
W3
W4
W5
W7
W8
W9
W10
W11
W12
Mill
soil covered flats
to Cue
Uncertain
LEGEND
LATERITE: Includes canga.
CONGLOMERATE: Pebble sandstone, breccia.
IRON ORE: Hematite, magnetite & limonite
DOLERITE: Fine-to medium-grained rarely porphyritic, may include some flows.
JASPILITE: Wilgie Mia beds, Strongly banded chert & magnetite.
JASPILITE: Madoonga beds. Strongly banded chert & magnetite with characteristic chert eyes ½"-1" diam.
JASPILITE: Lulworth beds. Strongly banded chert & magnetite. with distinctive chert lenses 1"-5" long.
PORPHYRY Aphanitic to medium-grained quartz-plagioclase porphyry.
GRANITE: Medium-to coarse-grained gneissic. Strongly jointed.
Fault
Inferred fault
Quartz vein
Strike & dip
Track
Ochre workings
LOCATION MAP
Weld Range
Cue
Geraldton
Perth
G.S.W.A.
WELD RANGE
GEOLOGICAL MAP
Scale 1" = 1 mile
Geological mapping W.R. Jones & I. Gemuts
1962
7242

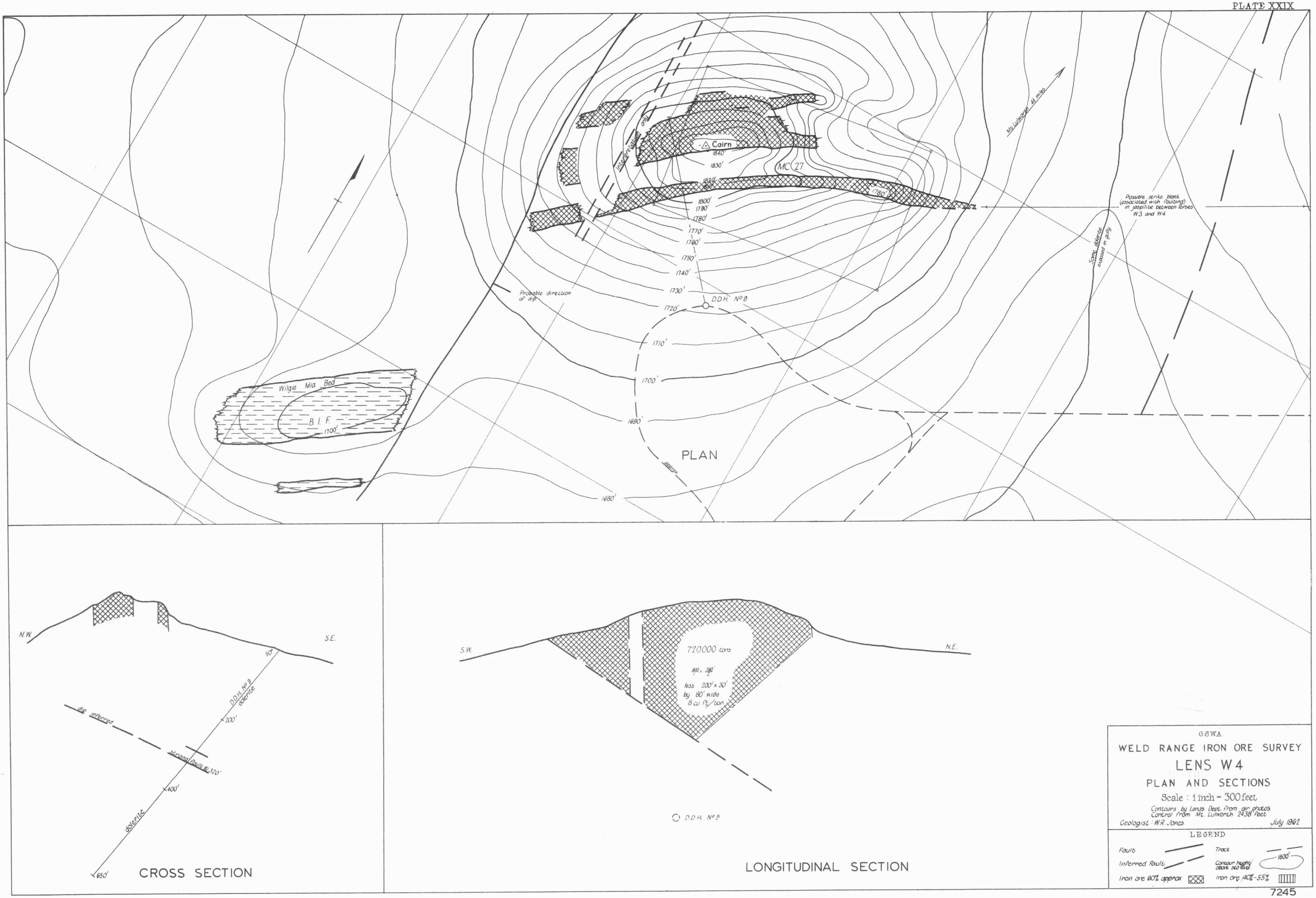

PLAN
OCHRE HILL
Ochre Mine
LENS W1
LENS W2
Gossanous limonite with hematite
Gossan with hematite (not included in reserve)
Essentially hematite with narrow bands of siliceous limonite
D.D.H. No 13
D.D.H. No 1
D.D.H. No 2
D.D.H. No 11, 12
LONGITUDINAL SECTION
S.W.
1800' above sea level
N.E.
W2 1,200,000 tons
W1 4,300,000 tons
8 cu. ft. = 1 ton
CROSS SECTIONS
1771' above sea level
1792' above sea level
1775' above sea level
N.W.
S.E.
Thin jaspilites
dolerite
G.S.W.A.
WELD RANGE IRON ORE SURVEY
LENS W1 & LENS W2
PLAN & SECTIONS
Scale : 1" = 300 feet
Contours by Lands Dept. from air photos
Control from Mt. Lulworth 2438 feet.
Geologist W.R. Jones
July 1962
LEGEND
Fault
Track
Inferred fault
Contour height above sea level.
Iron ore 60% approx
Iron ore 40-55%

7244

PLATE XXVIII



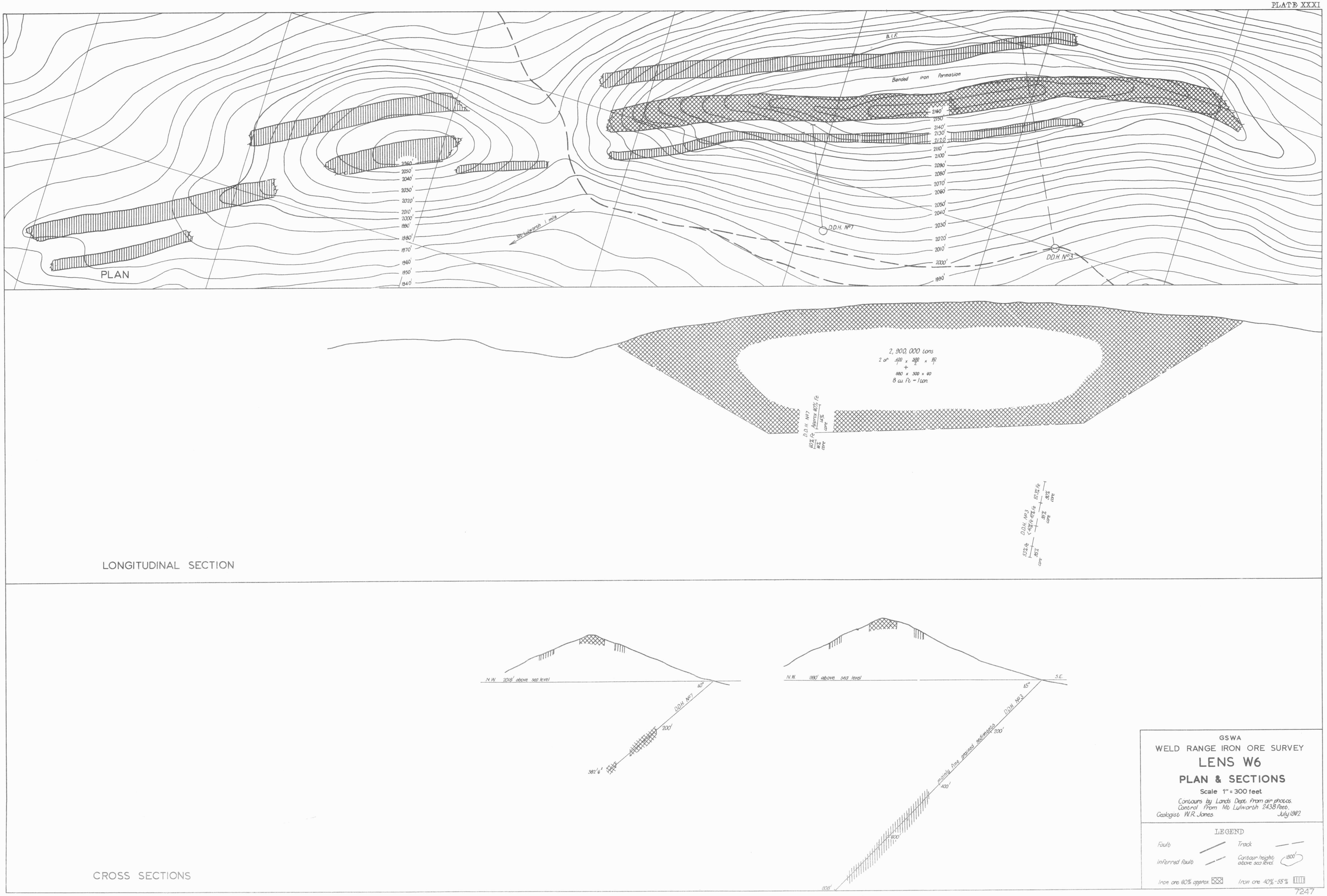
7243


Cairn
1840'
1830'
MC 27
1820'
1810'
1800'
1790'
1780'
1770'
1760'
1750'
1740'
1730'
1720'
D.D.H. No 9
1710'
1700'
1690'
1680'
1780'
Mt. Lulworth 4½ miles
Possible strike blank (associated with faulting) in jaspilite between lenses W3 and W4
Some dolerite exposed in gully
Probable direction of dip
Wilgie Mia Bed
B.I.F.
1700'
PLAN
N.W.
S.E.
D.D.H. No 9 dolerite
dip inferred
strong fault @ 320'
200'
400'
650'
dolerite
CROSS SECTION
S.W.
N.E.
720000 tons
less 200' x 30' by 80' wide
8 cu. ft./ton
D.D.H. No 9
LONGITUDINAL SECTION
G.S.W.A.
WELD RANGE IRON ORE SURVEY
LENS W4
PLAN AND SECTIONS
Scale : 1 inch = 300 feet
Contours by Lands Dept. from air photo's
Control from Mt. Lulworth 2438 feet
Geologist : W.R. Jones
July 1962
LEGEND
Fault
Track
Inferred Fault
Contour height above sea level
1800'
Iron ore 60% approx
Iron ore 40%-55%

7245

PLAN
W5
1928'
Band of mullock (approx)
Essentially magnetite
Essentially Magnetite
D.D.H. No 14
D.D.H. No 10
Low limonite outcrop extends out onto flat. May total 500' × 40' but not included in tonnage estimate.
589000 YDS E
LONGITUDINAL SECTION
S.W. 1900' above sea level
3,400,000 tons
8 cu. ft − ton
D.D.H. No 14 64% Fe 29% core
D.D.H. No 10
CROSS SECTIONS
N.W. 1875' above sea level
S.E.
40°
D.D.H. No 10
dolerite
472' Abandoned July 1962.
N.W. 1868' above sea level
dolerite D.D.H. No 14
200'
417'
G.S.W.A.
WELD RANGE IRON ORE SURVEY
LENS W5
PLAN & SECTIONS
Scale: 1" = 300 feet
Contours by Lands Dept. from air photos
Control from Mt Lulworth 2438 feet
Geologist W.R. Jones
July 1962
LEGEND
Fault
Track
Inferred fault
Contour height above sea level
Iron ore 60% approx
Iron ore 40%–55%

7246


PLAN
B.I.F.
Banded iron formation
D.D.H. No 7
D.D.H. No 3
Mt Lulworth 1 mile
LONGITUDINAL SECTION
2,900,000 tons
2 of 400/1 x 300/2 x 60/1
+
880 x 300 x 60
8 cu. ft = 1 ton
CROSS SECTIONS
N.W. 2018' above sea level
N.W. 1990' above sea level
S.E.
mainly fine grained sediments
GSWA
WELD RANGE IRON ORE SURVEY
LENS W6
PLAN & SECTIONS
Scale 1" = 300 feet
Contours by Lands Dept. from air photos.
Control from Mt Lulworth 2438 feet.
Geologist W.R. Jones. July 1962
LEGEND
Fault
Track
Inferred fault
Contour height above sea level.
Iron ore 60% approx.
Iron ore 40%-55%
7247

cross-section with opposite quadrants extinguishing together. It appears to be similar to that described by Klein (1939) and Rogers (1911) from microcline and orthoclase respectively.

The irregular extinction and small size of the crystals make optical measurements inaccurate. Twenty-six grains from 14 rocks from both Hamersley and Dampier areas were measured with the following results:—

	mean	maximum	minimum
2V	−67°	−83°	−54°
$\alpha \wedge \perp (001)$	82°	86°	76°
$\beta \wedge \perp (001)$	11°	23°	6°
$\gamma \wedge \perp (001)$	84°	90°	72°

Allowing for a high experimental error these optics could fit either orthoclase or high-temperature albite-oligoclase. However, there is independent evidence that this felspar is a plagioclase. In some rocks (R 154, R 159), the usually cloudy felspar is patchy with clear areas free of inclusions, in some of which there is lamellar albite twinning. These areas are of low-temperature albite. In some devitrified perlites (R 108) finely twinned low-temperature albite occupies the same textural position in relationship to the perlitic cracking that the cloudy felspar does in other parts of the same thin section. There is every appearance of inversion in place, and the mean values given above fit well with a high-temperature albite.

Quartz After Tridymite.

Wager and others (1953, Pl. XIII C) have described and figured a granophyre from Skye which is almost indistinguishable from some of the Dampier granophyres (R 152) which bear high-temperature albite. On the basis of comparison of the chilled edge of the Skye granophyre, in which tridymite was identified by shape and orientation of the replacing quartz (Ray, 1947), the acicular quartz of the body of the granophyre was thought to be after tridymite. Parts of the Skye granophyre (Wager, and others, 1953, fig. 2B) bear quartz "laths" with the same patchy extinction as has been described from both granophyre and "green quartzite" above. There is a high probability that many of the quartz "laths" in the rocks discussed represent tridymite, and it is hoped to carry out further work on this point.

DISCUSSION.

For clarity the principal propositions which are developed, and where possible justified, in the succeeding discussion are set out first:—

(1) Some of these rocks are devitrified glasses.

(2) The devitrification textures are closely associated with the development of high-temperature albite.

(3) High-temperature albite, closely similar in many ways, is also associated in both granophyres and lavas with quartz after tridymite.

(4) The Dampier granophyres may represent devitrified rocks.

(5) Most devitrification of glassy rocks takes place at high temperature within a comparatively short period after emplacement.

Although devitrification was proposed as a cause of some textures in igneous rock over a century ago (Ludwig, 1861) relict perlitic cracking in crystalline rocks, first suggested by Allport (1877), remains the only unequivocal criterion for post-solidification crystallisation. Later workers familiar with the textural complexities of volcanic rocks associated with lavas thus shown to be devitrified (Bascom, 1896; Bonney and Parkinson, 1903) accepted other features; while Iddings (1899, p. 420) argued against a devitrification origin for spherulites formed later than perlitic cracks, Harker (1909, p. 275) accepted some spherulites as resultant from devitrification. Subsequent work has not produced general agreement, or a clear distinction between immediate post-consolidation devitrification, subsequent slow devitrification at ordinary near-surface temperatures, and devitrification consequent upon later (metamorphic) stress and heat. Although glass is increasingly rare in older rocks (Marshall, 1961) it is uncertain whether this is mainly a result of the slowness of the devitrification or whether the likelihood of any rock escaping subjection to high temperatures and pressures also decreases with age.

The high-temperature albite associated with the perlitic rocks of the Hamersley lava-breccias shows that these rocks probably devitrified at a temperature below the transformation range of the material, but before complete cooling. Certainty is precluded partly by current doubts of the temperature significance of plagioclase optics and partly by the possibility of later metamorphism. On the second point the general metamorphic level of the Hamersley Nullagine rocks makes it unlikely that a temperature rise of the necessary severity ever took place after cooling. The actual temperature required for the formation of the albite is not known. Although Sandran (1959) succeeding in synthesising low-temperature albite at 900° C., it is not known at how low a temperature high-temperature albite can crystallise. If it is accepted, on the similarity of the felspars of the perlitic fragments and the "green quartzite," in which the felspar is associated with tridymite needles, that the two rocks have had similar cooling histories, then the devitrification probably occurred above 870° C., although Larsen (1929) has cast doubt on the validity of tridymite as a temperature indicator. The extreme elongation, and consequent fragility, of the tridymite crystals makes it certain that no relative internal movement of the rock took place after their crystallisation. Accurate information on the transformation ranges of natural lavas is non-existent, but what viscosity and temperature data exist suggest that 900° C. would be an unexpectedly high temperature to be below the transformation range.

Granophyre, and its micrographic texture, were suggested to result from devitrification by Bonney (1885; 1903) and Judd (1889) for different reasons, and Reynolds (1959) has more recently made the same suggestion on other grounds again. The common association in the Tertiary volcanic centres of Scotland (e.g., Bailey and others, 1924, pp. 334-336) between granophyres and felsites, which are there accepted as devitrified rocks, supports this view. In the Dampier Archipelago granophyres, the intercrystallisation of tridymite and high-temperature albite in textures similar to those of the Hamersley lavas, strongly suggests a similar thermal history for these rocks, with cooling below the transformation range before crystallisation. As in the Hamersley area, immediately after emplacement is the only time in the history of the Dampier rocks that the granophyres are likely to have attained the high temperatures believed to be necessary for rapid and complete devitrification to tridymite and albite. Devitrification is envisaged as an integral part of the cooling histories of these rocks.

The textural similarity is so striking between many of these Nullagine rocks, Bascom's (1896) Precambrian "aporhyolites" of South Mountain and the Tertiary volcanic rocks of Scotland and the Yellowstone Park (Iddings, 1899) that it is difficult to accept devitrification as a gradual process acting over immense periods of time, an early concept still implicit in recent text-books (e.g. Jung, 1959, p. 232; Turner and Verhoogen, 1960, p. 64). Walker (1962) has described a Tertiary welded tuff from Iceland, most of which is felsitic and devitrified. Careful study of modern acid volcanoes should reveal devitrification textures.

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Geological Survey Section Index

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