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COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS.

RECORDS.

1960/110

REGIONAL GEOLOGY OF THE NORTH-EAST CANNING BASIN, WESTERN AUSTRALIA.

by

J.N. Casey and A.T. Wells.

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Plate 1: GEOLOGICAL MAP OF THE NORTH-EASTERN PART OF THE CANNING BASIN. (At back of report).

Scale: 10 miles = 1 inch

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Table 1: Mean Average Temperatures (^{o}F), Halls Creek and Balgo Mission.

" 2: Meteorological Observations - Balgo Mission

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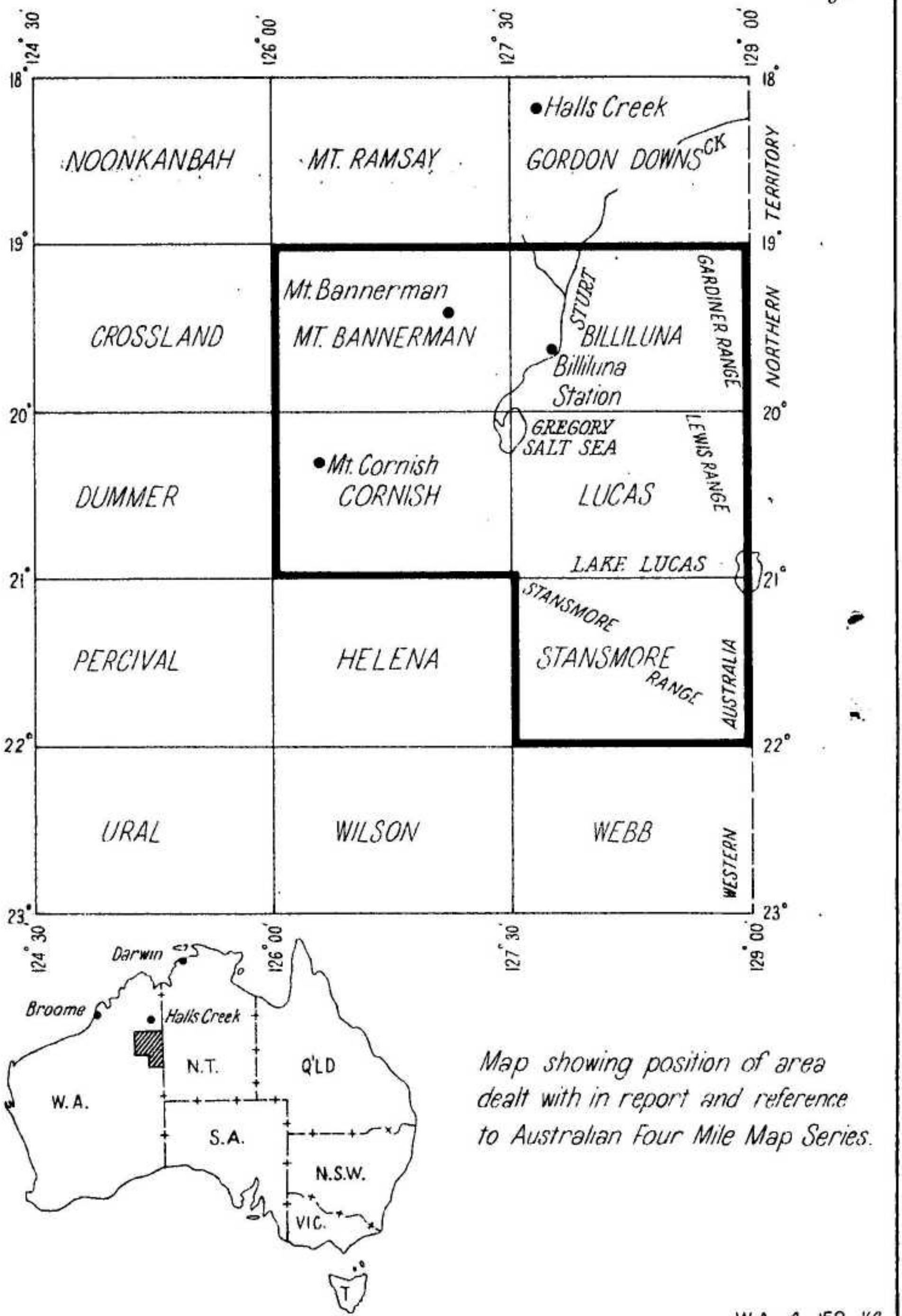
Fig. 1



Map showing position of area dealt with in report and reference to Australian Four Mile Map Series.

W.A. 4-158 V.C.

SUMMARY

The Palaeozoic and Mesozoic stratigraphic units and major structures recognized in the Fitzroy Basin by earlier workers (Guppy et al., 1958) continue into the north-eastern Canning Basin. Ordovician(?), Devonian, Permian, Mesozoic and Tertiary deposits rest with an angular unconformity on the Upper and Lower Proterozoic rocks with only slight unconformaties apparent within the units.

These younger Precambrian rocks are confined to the northern and eastern marginal areas, where the Halls Creek and King Leopold Mobile Zones meet. A small, partly obscured, off-shoot of these rocks occurs to the south in the Gardiner and Lewis Ranges.

The maximum measured thickness of the Palaeozoic and Mesozoic sediments is about 2,000 feet. The sediments do not appear to have a well established regional dip, but they are interrupted by a network of north-east-trending faults and other arcuate structural features. Gravity traverses across the Stansmore Fault have been interpreted (Garrett, 1956) as showing a displacement of 7,800 feet downthrown to the west of the fault

The Palaeozoic and Mesozoic sediments have been deposited on a stable shelf or in an intracratonic basin with accompanying eustatic fluctuation in sea level; both fossiliferous marine sediments and deltaic, barred basin or partly lacustrine sediments with plant leaves and stems are present. They include arenites, lutites and rudites. Arenaceous rocks predominate and contain a good deal of clayey material as well as feldspar grains. The probable Ordovician sediments contain marine organisms and are probably shelf deposits. The Grant Formation consists of sediments related to glaciation, and are the oldest Permian rocks found in the area. Plant bearing beds occur in the Permian and Triassic rocks; the Cretaceous rocks are probably marine.

No mineral or other deposits are being exploited in the area. Investigation of this edge of the Canning Basin has shown what units may be expected under the Mesozoic rocks and Recent sand in the central portion of the Canning Basin. This is important in assessing the oil potential of the basin, but further geophysical data and exploratory drilling are necessary for a complete appraisal. At present it appears that oil may be present in commercial quantities

particularly in hinge-line areas.

INTRODUCTION

GENERAL

Geological mapping in the Fitzroy Basin between 1948 and 1952 by geologists of the Bureau of Mineral Resources (Guppy, Lindner, Rattigan, ' Casey, 1958) indicated a large thickness of post-Precambrian marine sediments and large structures. As the sediments appeared to continue to the south-east into the north-eastern Canning Basin, the Mt. Bannerman, Billiluna, Cornish, Stansmore and Lucas four-mile military map sheets were mapped in 1955. The South-Western part of the Canning Basin was mapped in 1954 (Traves et al., 1956), and further land traverses were made in the southern and eastern part of the basin in 1956 by B. Stinear and A.T. Wells; the central part of the basin was covered by helicopter in 1957 (Veevers, 1957).

The geological party was in the field for about four months between May and August 1955, and worked in conjunction with surveyors from the State Lands and Surveys Department, Perth. A network of 28 astrofixes was obtained over the five sheets, (about 35,000sq. miles) and an effort was made to take nine astrofixes per sheet, positioned along the margins, through the centre of sheet, and on the photo tie-runs. From these, semi-controlled mosaics of Stansmore and Cornish and distorted grids of Mt. Bannerman, Billiluna, and Lucas were prepared by the National Mapping Division.

In 1956 a survey party from the National Mapping Division carried out levelling and observed astrofixes from Halls Creek to Balgo Mission and Well 48 near Godfrey's Tank. These heights were used to correct barometric observations made by the Bureau in 1955. West Australian Petroleum Company geologists also combined with Bureau of Mineral Resources geologists in 1955 on several traverses. They obtained gravity readings every five miles over several long traverses. Gravity observations were also taken as part of a reconnaisance geological and geophysical survey of the Canning Basin by helicopter (Veevers, 1957). These results were combined with those determined in 1956 by Mr. Van Son of the Bureau of Mineral Resources to produce a gravity contour map of the north-eastern Canning Basin.

All numbers (e.g. M27) marked on the geological map refer to specimen localities; a letter prefix identifies the sheet, M - Mt. Bannerman, B - Billiluna, C - Cornish, L - Lucas, S - Stansmore). All specimens are housed in the Bureau of Mineral Resources Museum, Canberra.

Although it has been several years since the field investigation was made, the material in this report has been used for the bulletin on the Canning Basin, the explanatory notes to accompany the various four mile sheets, and in the Stratigraphy of Western Australia (McWhae et al., 1958).

LOCATION

The region is covered by five four-mile military map sheets and lies between longitudes 126° and 129° east and latitudes 19° and 22° south (fig.1). It is reached from Perth either by the inland or coast road to Port Hedland, then via Broome and Fitzroy Crossing to Halls Creek. The total distance from Perth to Halls Creek is about 2,000 miles. Derby and Wyndham are the nearest sea ports. MacRobertson - Miller Airlines operate a fortnightly passenger-freight service from Halls Creek to surrounding stations, including Billiluna and Balgo Mission, which lie within the area examined. Conellan Airways, based in Alice Springs, operates a fortnightly service to Sturt Creek Station.

Access to the area examined was by a road which runs south from Halls Creek to Billiluna Station and Balgo Mission, and then by a rough track to Well 48 and Godfrey's Tank.

A few scattered tribes of nomadic aborigines live in the southern part of the area, and in 1956 tracks of aborigines were seen by a Bureau geological party near Red Cliff Pound on the Stansmore Sheet. "Smokes" from spinifex burned by nomadic aborigines were seen throughout the southern and north-eastern Canning Basin. Signs of recent native habitation were also seen around rock holes and wells.

The party was equipped with Traegar Type 43A6 and 51MA transceivers and contact could be made with Wyndham and Derby Royal Flying Doctor Radio Stations.

CLIMATE

Halls Creek and Balgo Mission are the only two weather stations in or near the area. Mean maximum and minimum shade temperature for these two stations are shown in Table 1.

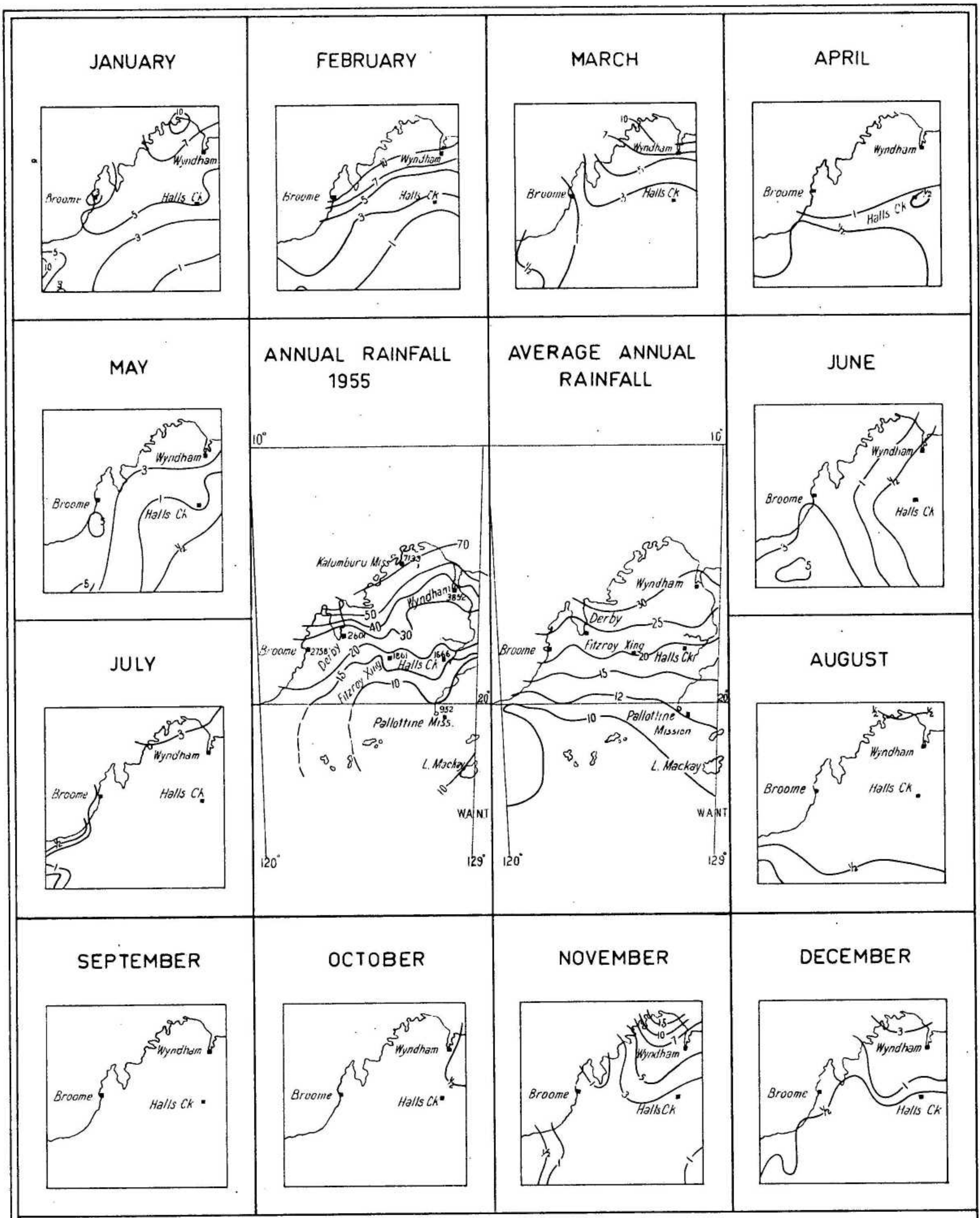
TABLE 1.

Mean average temperatures (^{o}F), Halls Creek area and Balgo Mission.

	Halls Creek 42 year average.		Balgo Mission 5 year average	
	Mean. Max.	Mean. Min.	Mean. Max.	Mean. Min.
Jan.	97.9	75.1	102.0	78.0
Feb.	97.1	74.2	101.5	76.5
March	95.1	71.1	101.7	75.6
April	81.9	63.5	93.7	71.0
May	85.5	56.0	84.9	60.9
June	80.6	50.8	79.9	56.0
July	80.1	48.0	78.6	53.5
Aug.	85.9	52.0	82.9	56.1
Sept.	92.7	59.1	92.4	64.0
Oct.	98.2	69.2	99.0	72.0
Nov.	100.3	74.1	102.0	75.8
Dec.	99.4	75.3	103.8	78.2
Year.	92.1	64.0	93.5	68.2

TABLE 2. METEOROLOGICAL OBSERVATIONS - BALGO MISSION

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann. Rainfall
1950													
Max t°								90.2	96.6	103.0	106.5	114.7	
Min t°F								50.9	55.6	58.0	61.7	59.9	
Rainfall	5	169	156	NR (no record)	296	9	NR	0	8	304	151	290	1388
1951													
Max t°	108	108.6	108.2	102	94.3	88.0	92.0	92.0	99.0	104	112	110	
Min t°F	72	72	69.7	62	50	45	38	46.4	55	59	62.5	71	
Rainfall	104	324	31	120	0	160	0	0	14	0	11	70	834
1952													
Max t°	110	110	107	104	96	82	89	92	101	106	109	113	
Min t°F	71	70	61	56	46	43	43	42.8	55	66	70	69	
Rainfall	156	129	61	137	9	0	0	15	0	2	68	52	629
1953													
Max t°	105	106	107	102	95	90	86	91	98	109	112	111	
Min t°F	65	67	74	60	50	46	44	40	53	66	62	69	
Rainfall	351	200	20	6	0	0	13	44	0	0	144	673	1451
1954													
Max t°	108	110	108	100	93	85	73	95	99	104	108	110	
Min t°F	72	66	69	61	52	43	49	44	52	64	70	64	
Rainfall	213	0	4	251	0	19	0	37	0	67	64	NR	749
1955													
Max t°	112	107	105	102	93	90							
Min t°F	71	73	68	55	50	49							
Rainfall	192	67	139	70	47	39							



MONTHLY DISTRIBUTION OF RAINFALL FOR 1955

Fig. 2 COMPARATIVE RAINFALL MAPS OF THE NORTHERN PART OF WESTERN AUSTRALIA

Isohyets in inches ———— 25 ————

Numbers at stations show rainfall in points 2758

(After Commonwealth Bureau of Meteorology. Melbourne 1955)

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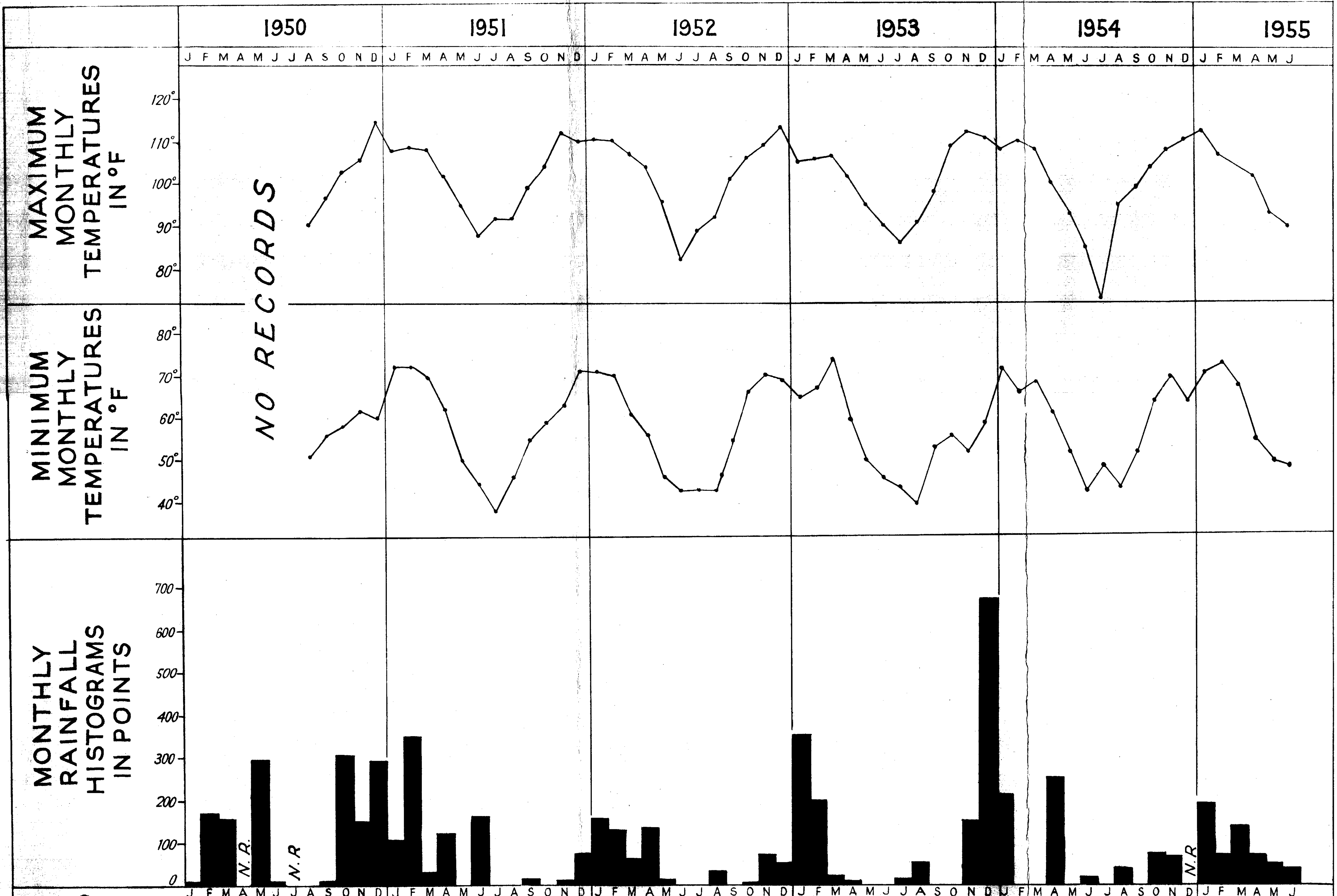


FIG. 3

METEOROLOGICAL OBSERVATIONS
PALLOTINE MISSION
(BALGO)

N.R. - No Record

Bureau of Mineral Resources, Geology & Geophysics · Sept 1957.

WAG 34-1

The regional distribution of rainfall is shown in figure 2. The annual rainfall decreases southwards from 60" at Wyndham to less than 10" at Balgo Mission. Most rain falls during the summer months when the area is under the influence of the north-west monsoons; some small falls occur during the winter, when the influence of Southern Australian weather extends this far north.

Fig. 3 is compiled from meteorological information at Balgo Mission listed in Table 2. It shows the months with highest maximum and minimum temperatures, and the highest rainfall. The annual rainfall figures at Balgo Mission, over the five year period, varied from 6¼" to 15". Note that the rainfall for May, July and November 1955, recorded in Fig. 3, was above average.

The daily maximum temperatures during the winter months varied from 75° to 90°F, with low relative humidity and with occasional night frosts; the summer temperatures are often over 100°F and the relative humidity is high.

FLORA AND FAUNA.

The north-east Canning Basin lies in the Eremian Floral Province as defined by Gardner (1941-42) and shown on his Vegetation Formations Map of Western Australia.

The Eremian Province has a very impoverished flora and is characterized by having less than 7" of rain in the four consecutive wettest months.

Two vegetation formations of the Eremian Province, the Triodia Steppe and the Desert Formation, are included in the area surveyed.

The Triodia Steppe Formation generally comprises areas of sandy soil having summer rain. The red sand supplies its edaphic requirement, except in the north, where the formation occurs on stony soil, which is expected, as the area is transitional between the stony dissected areas of the Kimberley Plateau and the sand plain country to the south. (The Steppe is typically devoid of trees and shrubs but has scattered eucalypts).

Triodia is the most prominent genus and grows as large tussock-like discontiguous masses. The drier the conditions the more pre-dominant Triodia becomes.

The Desert Formation - which is characterised by extreme aridity, absence of permanent surface water, the high annual mean temperature, extreme diurnal variation, paucity of vegetation, prevailing red sand, and seif dunes - includes the greater proportion of the area. The dunes are either devoidof vegetation or populated by sparse Triodia or a few harsh xerophytic shrubs; the interdune troughs contain sparse dwarf trees as well. Hakea lorea, Casuarina decaisneana (desert sheoak), Eucalyptus gamophylla, and E. setosa, are some of the few trees that occur in depressions or at the foot of escarpments. Various species of Melaleuca grow mainly on areas underlain by travertine and cover comparatively large areas. The following plant specimens from the Stansmore Range were determined by Gardner (W.A. Government Botanist). - Acacia, Aristida arenaria Gaud., Eriachne mucronata R.Br., Goodenia, Eragrostis setifolia Nees, Cyanostegia Bunnyana F. Muell., Newcastlia cladotricha F. Muell. The only genus indigenous to the true desert is Newcastlia.

A short lived flora flourishes after rain but disappears after completing a short life cycle. Some plants in the Desert Vegetation Formation are derived from a stock indigenous to the south-west, but which now grow on barren, dry, sandy soil. Other plants in this Formation have a northern origin, but have now developed a covering of epidermal hairs which protect them from this severe climate.

Gardner (1941-42) considers that an Eremian flora is encroaching on neighbouring floras as the area becomes dissected, and the desert extends.

Animal life was not as rare as one may have expected. They were seen mostly near water holes in Sturt Creek, or near rock holes and soaks in the desert. Many rabbit warrens were noticed in the Lake Lucas area and in areas of travertine. In the sand plain and sand dune areas, lizards, spinifex rats, kangaroos, dingoes, emus, wild camels and a few snakes were seen. Many birds exist near Sturt Creek, and include brolgas ("Native Companion"), cockatoos, pigeons. Swarms of birds were seen at Lake Lucas by the Bureau party in 1956, and included crested pigeons, finches, galahs, bustards (Epidotis), and budgerigars.

Cattle is the main stock raised by the few stations in the area; some horses and very few sheep and goats are also raised. By comparrison, more sheep than cattle are raised in the West Kimberley region (Fig.4).

Cattle from Billiluna Station, which is south of the tick quarantine line, are driven south along the Canning Stock Route to Carnegie Station, near Lake Carnegie, and then to the railhead at Wiluna.

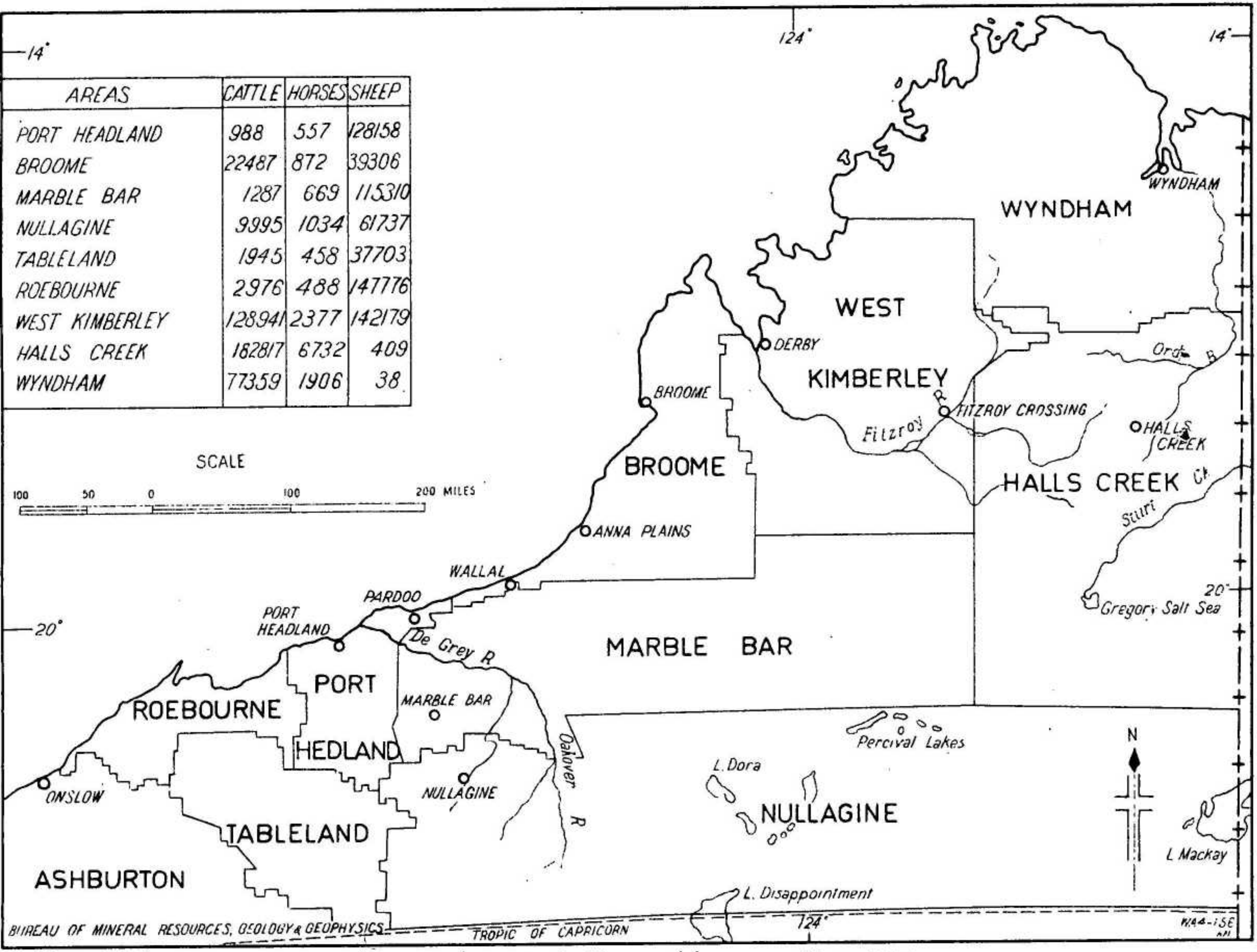
Casey and Nelligan (1956) discuss the land classification and relative distribution of the various units in the area. They consider that although isolated good patches of grazing land occur in the desert, access is too difficult for economic use to be made of it. The most suitable land, not already used for grazing, is in the Bishop and Stansmore Range areas.

FIELD METHODS

The size, position and lack of habitations in the area, the limited routes of access, and the scattered outcrops prevented any detailed geological mapping. The routes of traverses were limited by the topography, that is, by the trend and abundance of the sand dunes. Not all outcrops could be examined in the time available. Because of the traverse spacing, a great deal of reliance had to be placed on air-photo interpretation of rock, vegetation and soil patterns.

Uncontrolled four mile and one mile photo-mosaics, prepared by Division of National Mapping, were used in the field. Geological information was transfered from the air photographs (scale 1 : 50,000) directly on to the 4-mile mosaic by means of reduction squares and comparison grids, and the results traced on to a transparent medium, using a distorted grid where applicable. Barometric heights were recorded during most traverses. Readings were controlled by a diurnal curve compiled from readings taken every hour at a base camp; the difference between the diurnal variation at the base camp and at the points where heights were observed was assumed to be negligible.

The conditions encountered in the north-east Canning Basin and a resume of operational problems is given by Casey and Wells (1956). One Morris 4 x 4, 30 cwt. truck and three modified Landrovers were used. The modification carried out on these vehicles is also described in the above paper.



AREAS	CATTLE	HORSES	SHEEP
PORT HEADLAND	988	557	128158
BROOME	22487	872	39306
MARBLE BAR	1287	669	115310
NULLAGINE	9995	1034	61737
TABLELAND	1945	458	37703
ROEBOURNE	2976	488	147776
WEST KIMBERLEY	128941	2377	142179
HALLS CREEK	182817	6732	409
WYNDHAM	77359	1906	38

Fig 4 Local government boundaries and stock figures Mar. 1954.

Figure 5: Sand dunes west of Godfreys Tank; average height 50 feet.

Figure 6: Sand plain after spinifex has been burned by aborigines; low sand dunes in background.

PREVIOUS INVESTIGATIONS

Probably the first investigation of the area was by A.C. Gregory, who in 1856 followed Sturt Creek southwards and discovered the salt lake into which the creek drains. The salt lake was thereafter called Gregorys Salt Sea but, is now referred to as Gregory Salt Lake.

In 1873, Colonel P.E. Warburton (1875) travelled from Alice Springs to the Oakover River, but failed to find the salt lake discovered previously by Gregory; his route passed about 30 miles south of it.

In 1896, D.W. Carnegie (1898) set out from the Western Australian goldfields and travelled north to Halls Creek. The course of his return journey was to the east of his previous route and very close to the Western Australian - Northern Territory border, to as far south as Mt. Carnegie, and the Rawlinson Range. He named the Stansmore Range, where he erected a cairn, and he saw a mirage of a large salt lake, east of his route, at about lat. 22°40' which was later named Lake Mackay after D.F. Mackay (1934). He crossed the Gibson Desert and returned to the goldfields.

Between 1898 and 1900, A.A. Davidson (1905) led a prospecting expedition for the Central Australian Exploration Syndicate Limited, and travelled from Tennant Creek to the Gardiner and "Detached" (probably Lewis) Ranges.

A practicable stock route between Wiluna and Halls Creek was discovered by surveyor A.W. Canning, between 1906 and 1907. In 1908, H.W.B. Talbot (1910) accompanied Canning when the stock route was opened, and he published an account of the geology and water supplies. E. Kidson (1914) recorded magnetic observations along the stock route. M. Terry (1937) mentions an expedition by Weston in 1916, who travelled from Tanami to the Sydney Margaret Range. No other published record of this trip is available.

L.J. Jones (1922), travelled along the stock route in 1922 and made a geological investigation of Block 21H - (lat. 20° - 22°S, long. 123° 30' - 129°E) for the Locke Oil Development Syndicate and Kimberley Petroleum. Jones describes two well-defined structures, one a dome a mile and three quarters east of No.48 Well, Canning Stock Route, and the other a terrace or monoclinal fold, two miles west of

No.50 Well Canning Stock Route. Jones recommended preliminary boring at these sites. He found Permian marine fossils north-east of No.27 Well.

In 1925 M. Terry (1927) travelled from Halls Creek to Godfrey's Tank as part of an exploration and prospecting trip. It is interesting to note that Godfrey's Tank was dry when visited by this party. In his 1928 expedition (Terry, 1932) during the course of an investigation (exploration and prospecting) in the Tanami-Granites district, Terry prospected the area near the Gardiner Range at Larraganni Bluff. Part of Terry's 1932 Expedition (Terry, 1937) covered part of the Lake Mackay - Sydney Margaret Range area and many topographical features in this vicinity were named by him. Terry (1957) summarizes some of the exploration work in the Canning Basin.

W.G. Woolnough (1933) describes a flight from Louisa Downs to Gregory Salt Sea, in a report on aerial survey operations in Australia.

D.F. Mackay (1934) covered a great deal of the Canning Basin during an aerial survey expedition. Aerial photographs were taken and a topographical map compiled from strip maps made during flights. Outbases for the flights were at Roy Hill Station, Fitzroy Crossing, and Docker Base in the western Petermann Ranges. One of the flights from Fitzroy Crossing crossed the Lewis Range, then turned due west to Gregory Salt Lake and returned to Fitzroy Crossing.

C. St. J. Bremner (1940) made a preliminary aerial reconnaissance of the desert area for Caltex (Aust.), mainly to assess transportation difficulties and see the distribution of outcrops.

P.S. Kraus (1941) made a geological reconnaissance of the Fitzroy Basin (the north-west portion of Caltex Concession 7-H) but covered only one or two areas pertinant to this report. W.H. Maddox (1941) carried out geological reconnaissance in the north-eastern part of the Fitzroy Basin, including a traverse to Godfrey's Tank, and others east and south-east of Billiluna and Sturt Creek Stations. The geological work was carried out for Caltex (Aust.) Oil Development Pty. Ltd. Maddox observed beds plunging at 2-3^{o} to S.20^{o}W at Godfrey's Tank.

F. Reeves (1949) carried out extensive aerial and ground geological reconnaissance in the Fitzroy and

Canning Basins for the Vacuum Oil Company. Much of his report in the north-eastern area is based on work by P.S. Kraus, W.H. Maddox, W.A. Findlay and H.J. Evans. An account of the geology south and south-west of Balgo Mission is given by H.J. Evans (1948) in an unpublished report to Frome Broken Hill Pty. Ltd.

In 1948, during their investigation of the Mt. Ramsay four-mile sheet, Matheson and Guppy (1949) made a traverse to the Wolf Creek Meteorite Crater and described it in Guppy and Matheson (1951).

Traves (1955) carried out a regional survey of the adjacent Ord-Victoria region to the north.

TOPOGRAPHY

The area can be divided into three main divisions: Sturt Plateau, Semi-Desert and Transitional.

Sturt Plateau:

This geomorphological unit was defined by Paterson (1954) in the Ord-Victoria Region, and it includes only a small area in the north-east Canning Basin. The Plateau is nearly flat and has a poorly developed, senile, inland-drainage system, and is thought to be an old Tertiary land surface (Traves, 1956).

Remnants of the partly dissected plateau occur on the northern part of Mt. Bannerman sheet, and as flat plains merging into the Semi-Desert on the northern part of the Billiluna sheet.

Transitional:

The marginal plains, with isolated ranges, appear transitional between the Semi-Desert and Sturt Plateau. Besides remnants of the Halls Creek Ridges (Paterson, 1954), remnants of the Kimberley Plateau are included here. Isolated ranges occur in the north and east of the area; the more prominent ranges have an altitude of 1500 feet. Mt. Brophy, the highest point in the Gardiner Range is 1790 feet above sea level. All the marginal ranges are composed of the more resistant Precambrian rocks. The sand plain has a general elevation of 1100 feet in the marginal area, and slopes gently west to 700 feet north of Mt. Rosamund.

Semi-Desert:

It is composed of flat sand plains (fig.6) with east-west trending seif dunes (fig.5) penetrated by isolated hills or dissected breakaways which give rise to a mesa and butte topography. The dunes average 50 feet high, but some are over 100 feet; they are often over 50 miles long. The slopes are fixed by sparce vegetation and their tops are nearly bare, except for spinifex clumps and isolated large gum trees. The Semi-Desert is underlain by easily-eroded Phanerozoic sediments, compared with the most resistant rocks of the Precambrian marginal ranges.

Drainage System:

The streams in the area can be divided into two classes:

(1) Streams draining directly into salt lakes - they are of varying lengths, and probably once formed major drainage lines, as for example Sturt Creek; many contain pools of salt water. Where the headwaters of the stream is in the rugged Precambrian, run off is heavy; but other streams (e.g. those draining into Lake Lucas) the run off is unsufficient to form large continuous channels.

(2) Streams draining into the sand plain - they have short stream courses, alluvial fans, and some form, narrow alluvial piedmont deposits. Many streams have a similar distributary pattern to their tributary pattern where they terminate on alluvial flats after draining from small hills. These streams were probably never very large.

The drainage system is internal, and is dominated by Sturt Creek which flows south-west to terminate in Gregory Salt Lake, 900 feet above sea level. It is probably a consequent stream. It rises 20 miles north-east of Mt. Wittenoom. The gradient of Sturt Creek, between Wolf Creek junction and Stretch Lagoon (distance of 35 miles) is 4 feet per mile; between Stretch Lagoon and Gregory Salt Lake (distance of 30 miles) it is 2 feet per mile; between Astrofix N4 and the Wolf Creek junction, it is slightly more than 1 foot per mile. This explains the wide flood plain, with white, light-textured alluvial sand and clay in the upper reaches of Sturt Creek, near Gordon Downs and Sturt Creek homesteads.

Discontinuous patches of travertine, alluvium and claypans probably represent an old course of Sturt Creek which ran east and south of the Denison Range, south-east to Stretch Lagoon. Slatey and Lewis Creeks, which now drain into the sand plain from the Gardiner Range, were probably tributaries of the old Sturt Creek.

Wolf Creek is the main tributary of Sturt Creek, and the floodwater from this creek is red due to detritus from the nearbye red sand plains, whereas the floodwaters from Sturt Creek are generally milky due to detritus from the dissected Sturt Plateau.

Aitchison Creek drains a granite area in the Lewis Range, flows south and ends in an alluvial fan.

Development of Topography:

The development of the topography has been controlled by the climate and the age, type and structure of the rocks.

The initial surface in this area was probably a peneplain caused largely by latertisation process which acted on the marginal emergent surface. The peneplain underwent desert weathering to form breakaway scarps, and on further reduction, became a plain of arid erosion. The initial peneplain was broken by prominent structural elements in the Palaeozoic sediments and transected by ridges of basement rocks around the margin; these ridges maybe part of an exhumed Permian landscape.

Erosion of mountains, ridges, hills, breakaways formed pediments around them, and the pediments were later modified by deflation, whereas the mesa and butte topography is a result of differential weathering aided by water; the pediments were redistributed to form sand plains and dunes.

The dunes grew in breadth and height during periods of bidirectionel winds, and grew in length when prevailing winds blew.

The area is at present at a stage of late maturity.

The persistant internal drainage is responsible for local and temporary base levels which control the reduction of the upland areas. The highlands were dissected in youth and were accompanied by aggradation of the basins which produced a continued rise of local base levels.

Wolf Creek Meteorite Crater:

A prominent topographic feature on the west of the Billiluna sheet is the Wolf Creek Meteorite Crater

Figure 7: Wolf Creek Meteorite Crater, looking north-west; Wolf Creek crosses photo in middle distance (Australian News and Information Bureau Photo)

Figure 8: Lake Lucas with Lucas Beds in foreground and jointing and bedding visible on lake bed.

(fig.7).

It was first observed from the air by F. Reeves in 1947(Reeves & Chalmers 1949, Holmes 1948), and described by Guppy and Matheson (1951).

It is 65 miles south of Halls Creek lat.19°10'S, long.127°46'E.; the floor of the crater is 160 feet below the rim, and 70 feet below the level of the sand plain. The outer slope of the rim is 10° - 15° and the inner 30° - 40°; the rim outline is nearly symmetrical. The flat floor of the crater is 1400 feet in diameter, and total width is 2800 feet.

The crater is the fourth largest in the world, surpassed only by the Meteor Crater in Arizona, the Chubb Crater in Quebec, and a crater in Siberia.

Pieces of metallic material were found on the south side of the crater by Guppy and Matheson, and they yielded 1.9% NiO on analysis. The material was magnetic and consisted mainly of hydrated iron oxide, small amounts of iron oxide - impregnated silicates, and a little chalcedony. One specimen gave 0.06% metallic iron retained on a 90 - mesh screen.

Cassidy (1954) collected several oxidised specimens weighing over 300 lbs. from the crater but no wholly metallic meteoritic material was recorded. A summary of the investigation of these larger specimens by Lapaz (1954) is as follows: The smaller pieces are "shale-balls", analagous to those found previously at the Barringer and Odessa Meteroite Craters, U.S.A. A few nickel-iron granules and sinuous veins of nickel-iron, 1" or more long and up to ⅛" across were found in some sections. The specimens show evidence that they are incompletely oxidised remains of well-oriented iron meteorites. Pressure fissures radiate from "noses" of masses and extend 4-5" into the interior of the masses; the fissures are filled with congealed melt. Zaratite is visible in the outermost 2-3" of sections, and in smaller zones in the interior. The density of the matrix is in the basal part of the conoids. Evidence points to an original sideritic nature of the mass.

The age of the meteroite impact is not definitely known. It has affected Upper Proterozoic silicified sandstones, and laterite has been broken and tilted; the young topographic form suggests a Quaternary or even Recent event;

TABLE III

STRATIGRAPHY OF THE NORTH-EAST CANNING BASIN

AGE		FORMATION	THICKNESS	LITHOLOGY AND PALAEONTOLOGY	CORRELATION	
					SOUTH-WEST CANNING BASIN (Traves, Casey & Wells 1956)	NORTH-WEST FITZROY BASIN (Guppy et al, 1958)
QUATERNARY	RECENT		20' + 0-120' + 10' +	Alluvium and black soil Aeolian sand salt Tufa Travertine	Similar Recent deposits occur in this portion of the basin.	Sand, caliche, alluvium etc.
TERTIARY		WOLF GRAVEL	20' +	Alluvial gravel and sand		WARRIMBAH CONGLOMERATE
		LAWFORD BEDS	100' ±	Lacustrine limestone and marl overlain by hard vuggy chalcedony	OAKOVER BEDS	-
		Laterite and pisolitic ironstone	30' ±	Laterite profile and isolated outcrops of pisolitic ironstone.	Pisolitic ironstone	Pisolitic ironstone
MESOZOIC	CRETACEOUS	GODFREYS BEDS	300' +	Micaceous shale and sandstone with pelecypods and the worm Rhizocorallium	ANKETELL SANDSTONE	MEDA FORMATION AND MOWLA SANDSTONE
	TRIASSIC	CULVIDA SANDSTONE	200' +	Crossbedded, red-brown sandstone with interbedded fine, white shale containing Cladophlebis and Thinnfeldia	Part of CALLAWA FORMATION	ERSKINE SANDSTONE
		BLINA SHALE	100' ±	Grey micaceous shale and siltstone with Isaura.	-	BLINA SHALE
		UNCONFORMITY				
PALAEOZOIC	PERMIAN	HARDMAN MEMBER	100' +	Poorly sorted, medium-grained sandstone with brachiopods, gastropods and Aulosteges	-	Mt. Hardman beds LIVERINGA FORMATION
		CONDREN SANDSTONE MEMBER	(150' measured)	Freshwater sandstone and shale with Glossopteris and Gangamopteris		Plant bearing beds LIVERINGA FORMATION
		BALGO MEMBER & LIGHTJACK MEMBER	200' ±	Micaceous shale, sandstone, greywacke and conglomerate of concretions. Contains pelecypods with some brachiopods.		Basal marine beds LIVERINGA FORMATION.
		NOONKANBAH FORMATION	200' ± (30' measured)	Sandstone and shale with abundant marine fossils. Some calcareous shale and coquinite.	DORA SHALE	NOONKANBAH FORMATION
		GRANT FORMATION	200' +	Poorly sorted, coarse sandstone with occasional rounded quartz pebbles. Contains fossil wood.	PATERSON FORMATION & BRAESIDE TILLITE.	GRANT FORMATION
	UPPER DEVONIAN OR LOWER CARBONIFEROUS		200' +	Medium to coarse grained sandstone. Current bedded with subrounded pebbles. Contains fossil wood Lepidophloem australe.	-	-
	DEVONIAN	?LIMESTONE	10' exposed	Blue-grey limestone with much secondary calcite.		BUGLE GAP LIMESTONE
		?CONGLOMERATE	50' ±	Oligomictic conglomerate		SPARKE CONGLOMERATE

AGE		FORMATION	THICKNESS	LITHOLOGY AND PALAEONTOLOGY	CORRELATION: SOUTH-WEST CANNING BASIN (Traves, Casey & Wells 1955)	CORRELATION: NORTH-WEST FITZROY BASIN (Guppy et al, 1957)
PALAEOZOIC	ORDOVICIAN		250' exposed	Interbedded medium-grained conglomerate and sandstone with trilobite remains.		PRICE'S CREEK GROUP?
PALAEOZOIC	UNDIFFERENTIATED	LUCAS BEDS	100' exposed	Fontainbleu sandstone with interbedded laminated claystone. Sandstone is well sorted with occasional clay pellets. Calcareous matrix.	POSSIBLY EQUIVALENT IN AGE TO EXTENSIONS OF LOWER PALAEOZOIC ROCKS FROM THE NORTHERN TERRITORY.	
				UNCONFORMITY		
PROTEROZOIC	UPPER?	PHILLIPSON BEDS	200' +	Soft, current-bedded sandstone, poorly sorted and with dips up to 10 degrees.	Upper Proterozoic sequence of south-western Canning Basin	Kimberley Plateau succession.
PROTEROZOIC	UPPER?	GARDINER BEDS	500' +	Hard, silicified, current-bedded and ripple marked sandstone, strongly jointed and folded with dips up to 15°. Micaceous shale and fine sandstone are also present. Conglomerate occurs at the base with quartz, quartz greywacke slate, and quartz tourmaline hornfels pebbles.		
PROTEROZOIC	UPPER?	KEARNEY BEDS	2000' +	Silicified flaggy sandstone, folded with dips up to 70°.		
				UNCONFORMITY		
PROTEROZOIC	LOWER?	LEWIS GRANITE		Muscovite granodiorite with pegmatite and quartz veins.	Lower Proterozoic Granite	Granite of LAMBOO COMPLEX
PROTEROZOIC	LOWER?	HALL'S CREEK METAMORPHICS		Quartzite, quartz-greywacke, slate laminated claystone and fine, clay sandstone. Folded, beds often vertical, intimately injected by granite and cut by numerous quartz veins.	Lower Proterozoic Metamorphics	HALL'S CREEK METAMORPHICS

it is not apparently in native legends, so probably was pre-Recent. The aboriginal Djaru tribe call the crater Kandimalal.

STRATIGRAPHY

GENERAL

The stratigraphy covers a small portion of the post-Precambrian sediments of the Canning Basin, and some of the basement rocks which act as the floor and border of the basin, and which were probably the main source of ferrigenous sediments of the Canning Basin. The Canning Basin is defined as the sedimentary basin between the Kimberley and Pilbara areas of Precambrian rocks and extending westward on to the present continental shelf; it contains Palaeozoic and younger sediments. The area of the Canning Basin therefore includes both the geographical area, called the "Great Sandy Desert" of Warburton (1875) and the Fitzroy River Valley. The term "Desert Basin" was used for the poorly defined artesian basin between the Kimberley and Pilbara Blocks in a map accompanying a "Report of the Interstate Conference on Artesian Water, Sydney, 1912" (Sydney, Government Printer, 1913). The term Canning Basin was first used by Gentilli and Fairbridge (1951) to include the Palaeozoic and Mesozoic sedimentary basin.

The marine and plant bearing Permian sediments are the most widespread of all rocks of the N.E. Canning Basin. The Ordovician and Devonian rocks are confined to small marginal areas to the north and do not reappear beneath the younger sediments of the basin to the south. The only limestones observed were limestone of probable Devonian age, and the marly sediments of the Tertiary Lawford Beds, both on the Mt. Bannerman sheet.

The Permian and Mesozoic sediments are almost entirely arenaceous and have only minor calcareous beds associated with coquinities. Fossils are generally rare but some thin beds contain abundant marine fossils or plants in some localities.

In most cases existing stratigraphic names have been used except where revision in accordance with the Australian Code of Stratigraphic Nomenclature was necessary. New stratigraphic names have been approved by the Western Australian Committee on Stratigraphic Nomenclature.

PRECAMBRIAN

Precambrian rocks crop out at the margin of the Canning Basin in the north and east of the area. The division of these rocks here into Upper and Lower Proterozoic follows on from work carried out in the Kimberley (Guppy et al. 1958) and Ord-Victoria areas (Traves 1955). The older metamorphics and granite are regarded as Lower Proterozoic, and most of the sediments which overlie them with pronounced angular unconformity, are referred to the Upper Proterozoic.

Gill (1955) has shown from work in the Canadian Shield that simultaneous shield-wide deformation does not necessarily take place; in fact, many different orogenies may occur at different times in different parts of the shield area. Hence well-sorted, shelf type sediments formed by erosion from the first mountain system may rest unconformably on folded geosynclinal sediments, but they may be of the same age or older than geosynclinal sediments in other folded belts in the shield. It is wrong therefore to use "Upper Proterozoic" in reference to shelf-type sediments and "Lower Proterozoic" in reference to folded geosynclinal sediments and volcanics without some positive evidence of age.

In the north-east Canning Basin it has been found convenient to subdivide the Precambrian into Lower Proterozoic Halls Creek Metamorphics (Traves, 1955), Lewis Granite and indifferentiated granites which are overlain with a pronounced angular unconformity by the Upper Proterozoic quartz sandstones named the Phillipson Beds, Gardiner Beds, and Kearney Beds, each of which possess a unique structural style of its own; although the lithology does not vary greatly between these three units, it is distinct enough to allow identification of widely separated outcrops. The subdivision of the Upper Proterozoic rocks into these three groups has been based on similarities of lithology, structure and photo pattern. Hence the steeply dipping quartzites and silicified quartz-sandstones of the Cummins Range, Kearney Range, and Sturt Creek area are called the Kearney Beds, but there is not evidence at present to suggest whether for example they are the same or of a different age to the gently folded silicified quartz sandstones of the Denison Range, Mt. Weeks and the Gardiner Range, which are grouped as the Gardiner Beds.

The Precambrian rocks in this area were previously investigated by Davidson (1905) between 1898 and 1900; he visited the Gardiner and Lewis Ranges and reported traces of gold from quartz reefs in the Halls Creek Metamorphics which underlie the Upper Proterozoic rocks in these areas. Talbot (1910) investigated the Precambrian rocks in the Gardiner Range and at Tent Hill, and described the unconformity at Larranganni Bluff. He reported that several of the quartz reefs in the metamorphics showed traces of gold on analysis.

Maddox (1941) regarded the rocks at Palm Spring, 15 miles east of Sturt Creek Homestead, and granitic rocks in the Cummins Range as Proterozoic. Reeves (1949) described Archaen (Mosquito Creek Series ?) rocks in the Cummins Range, and granitic rocks and Upper Proterozoic quartz sandstones ('Nullagine Series') 15 miles east of Balgo Mission. He also described Upper Proterozoic quartzites overlapping older rocks north of Mt. Bannerman and in the Lewis, Erica and Stansmore Ranges. The rocks in the Stansmore Range have since been shown to be Permian in age.

Lower Proterozoic.

Halls Creek Metamorphics:

This name was first used by Traves (1955) for a belt of metamorphic rocks in the Halls Creek area, where they are intruded by granites of the Lamboo Complex (Archaean or Lower Proterozoic), and which are unconformably overlain by rocks thought to be Upper Proterozoic.

Rocks which occupy a similar stratigraphic position to the Halls Creek Metamorphics occur in areas bordering the north-east Canning Basin. They are intruded by the Lewis Granite, and other granites, and are unconformably overlain by probable Upper Proterozoic sediments.

The metamorphics do not show as high a degree of metamorphism in this area, as they do in the Halls Creek area. Phyllites and amphibolites are absent, and basic lavas have not been recorded; quartzite (granitised in places), sandstone, slate, shale and micaceous sandstone with quartz veins are common to both areas.

Traves (1957) describes quartzite and greywacke between Ruby Creek and Rock Hole (near northern edge of the Billiluna Sheet), and these outcrops are continuous with similar rocks mapped as Halls Creek Metamorphics on the Billiluna and Mt. Bannerman Sheets.

The metamorphics also crop out north-west of Cummins Range, and at the base of the Gardiner Range; quartzite, sheared quartz-greywacke, slate, laminated claystone, siltstone and sandstone are the commonest rock types (Appendix B).

Slate and quartz greywacke, with dips from 50° to vertical crop out at Larranganni Bluff, at the south end of Gardiner Range (Figure 9). Quartz veins with haematite cut these sediments. Similar sediments crop out at B35 locality, where white kaolinised slate, chocolate brown slate, and quartz greywacke are cut by numerous quartz veins. A porous, 5 foot cap of weathered rock caps the metamorphics, and this may be a remnant of a widespread laterite profile.

Other metamorphic outcrops are seen underlying the Upper Proterozoic Gardiner Beds at Mt. Mansbridge in the Gardiner Range, and as scattered inliers to the west and south.

In the northern part of Mt. Bannerman sheet, Christmas Creek cuts through ridges of steeply dipping, kaolinised, grey to white laminated claystone, sheared pale grey quartz greywacke, and slate; quartz veins (¼" - 12" wide) cut these sediments. Upper Proterozoic dark coloured shale, similar to that outcropping at Mt. Frank to the north (Hardman 1884, Maddox 1941) overlies these metamorphics.

At locality M36, south of Christmas Creek, lit-par-lit injection has granitised the quartzite; ramifying vuggy quartz veins are common.

<u>Lewis Granite</u> (New Name):

The Lewis Granite is the batholithic granite which intrudes the Halls Creek Metamorphics and is unconformably overlain by the Phillipson Beds in the Lewis Range (lat. 20° 10'S., long. 128° 40'E). The age is tentatively regarded as Lower Proterozoic, and although it maybe contemporaneous with granitic rocks in the Lamboo Complex, it is normally a very fresh-looking granite, not gneissic, and it maybe younger than the mineral-bearing granites of Tanami and The Granites.

So far no obvious mineral deposits have been found associated with the Lewis Granite.

In the Lewis Range the granite varies from a fine-grained aplitic type to a coarse-grained granite. A coarser pegmatitic phase of the granite contains graphic intergrowths of quartz and feldspar, with plumose aggregates and muscovite "books" up to two inches across. In rare cases, the granite is crused and cut by slickensided fault planes, which have been subsequently filled by cryptocrystalline vuggy silica.

Figure 9: Angular unconformity between the Halls Creek Metamorphics and the Gardiner Beds (breakaway in background) at Larranganni Bluff.

Figure 10: Ripple marks in the Phillipson Beds, Phillipson Range.

The Lewis Granite also crops out at Tent Hill, 15 miles east of Balgo Hills Mission, and at Mt. Elphinstone, where it is a biotite granite with large feldspar phenocrysts. There are small outcrops of undifferentiated granite intruding quartzite at M36, and much of the quartzite shows signs of granitisation.

No extensive areas of granite are exposed; the largest outcrop is east of the Lewis Range. However, granite almost certainly underlies the sand plain south and west of the Gardiner Range, and between Mt. Elphinstone and the Kearney Range. In these sand plain areas, the sand derived from the granite is coarser than elsewhere, and does not form prominent dunes; it is comparatively easy for cross country travel.

Upper Proterozoic.

Kearney Beds: (New Name)

The Kearney Beds are defined as beds of steeply dipping, hard, silicified, flaggy, quartz sandstone, which crop out at the type locality in the Kearney Range (lat. 20°08'S., long. 128°05'E), 20 miles east of Balgo Mission.

They are unconformably overlain by Upper Devonian or Lower Carboniferous sandstone, and are probably unconformably above the Lewis Granite; the beds are tentatively regarded as Upper Proterozoic.

The beds are generally flaggy or massive, banded in places; they have a uniform grain size and rarely show depositional structures such as ripple marks, current bedding etc.

Contacts with either the Halls Creek Metamorphics, or with other probable Upper Proterozoic units has not been observed.

The predominant silicified quartz sandstone of the unit, crops out as low resistant ridges, cuestas and hogbacks in the Cummins Range, and extend eastwards to Wolf Creek, and south to the Kearney Range.

The fresh rock is white, but weathers to give ochreous stains.

Thin conglomerate bands occur.

The unit is usually intensely jointed.

In some areas, such as the low hills west of Wolf Creek at B43 and B44, the rocks are tightly folded. At B43, fine to coarse-grained, silicified, ferruginous sandstone dips 30° north, and is overlain by unaltered, fine-grained conglomerate and silicified medium-grained sandstone with current ripple marks, current bedding and weathered out clay-pellets. At B44, a fault cuts a medium-grained silicified sandstone, which dip at 30° east and are cut by ramifying quartz veins.

At B28, 15 miles east of Billiluna homestead, undifferentiated sandstone probably of Upper Devonian or Lower Carboniferous age, overlies steeply dipping, hard, silicified sandstone of the Kearney Beds, with an angular unconformity.

Upper Proterozoic rocks in the Cummins Range were visited by J. Veevers in 1957. A specimen M57, is a pink quartz sandstone which crops out near a fault zone and contains numerous thin quartz veins.

Gardiner Beds: (New Name).

The Gardiner Beds are defined as beds of hard, silicified, current bedded, ripple marked sandstone and interbedded shale, that crop out in, and are named from, the Gardiner Range (lat. 19°15'S., long. 128°45'E.). The beds of sandstone are strongly jointed and gently folded with dips usually up to 15°. Wherever the base of the Gardiner Beds is exposed, a polymictic conglomerate is developed. At Larranganni Bluff the Gardiner Beds dip 9° north and overlie the Halls Creek Metamorphics with an angular unconformity (see fig.9). In the Erica Range, a conformable contact is visible with overlying friable, current-bedded, sandstone which is thought to belong to the Phillipson Beds. The Gardiner Beds are probably Upper Proterozoic in age.

The type section at B34 (Larranganni Bluff), in descending order is -

60' Sandstone - hard, silicified, medium-grained, strongly jointed, current and wave ripple marked, with thin beds containing moulds of clay pellets. The current ripple marks have an index of 8 and the wave ripples an index of 4; the wave ripple marks are more abundant. Forms the resistant steep cap of the bluff.

100' Sandstone - flaggy, with minor interbedded micaceous shale; much clay pellet conglomerate.

120' Sandstone - light brown to yellow brown, rarely green, laminated, micaceous in beds two inches thick alternating with -

Shale - chocolate brown, micaceous in beds up to one foot thick. Massive and very fine grained when mica is absent.

40' Conglomerate - boulders up to 1 foot consisting of slate, quartz greywacke, and quartz from the underlying Metamorphics. Fragments irregular, subrounded to subangular, average diameter 1". Quartz greywacke fragments generally ellipsoidal and subrounded; quartz pebbles subangular and irregular. Quartz grains of matrix average 1.5 m.m. in diameter.

- UNCONFORMITY -

Lower Proterozoic

Halls Creek Metamorphics - quartz greywacke, slate, and subgreywacke intruded by quartz and quartz-hematite veins.

The unconformity surface is locally very irregular and can be seen where an isolated pinnacle of the conglomerate overlies the Halls Creek Metamorphics at B33. The unconformity was seen also at B36, 2 miles south-east of Mt. Stubbins. The basal conglomerate crops out at Fort Hill and contains fragments up to one foot across with a few pebbles of quartz-tourmaline hornfels. A silicified sandstone and conglomerate with numerous small quartz veins crop out at Pyramid Hill. The conglomerate contains pebbles up to 10 inches across, which are usually subangular, irregular in shape, sometimes faulted and composed chiefly of quartzite and silicified sandstone. The rock may be equivalent to the basal Upper Proterozoic conglomerate seen in other areas.

This basal conglomerate is similar in many respects to the conglomerate at the base of the "Nullagine Series" in the Marble Bar area which yields gold; however no gold or other minerals have as yet been found in the conglomerate at the base of the Gardiner Beds.

The 500 foot section exposed on the southern flanks of Mt. Brophy appears to be stratigraphically higher than the sediments at Larranganni Bluff. At B37, the section consists of purple and brown micaceous shale with some sandy beds, overlain by current bedded, wane ripple marked, silicified, well jointed, flaggy sandstone with clay pellet beds; the sediments dip 5° north. This section is in turn overlain by micaceous shale at B40 and B41 north of Mt. Brophy. A bed rich in magnetite and secondary hematite is contained in the shale at B41. The beds here dip 3° to the north-east.

Many outcrops of the Gardiner Beds were seen on the eastern margin of the Billiluna, Lucas and Stansmore 4-mile sheets.

The beds crop out in the Denison Range (Fig.11), Pyramid Hill, Palm Spring, Mt. Weekes, the Wolf Creek Meteorite Crater, Erica Range, Sydney Margaret Range and Red Cliff Pound. The sediments in nearly all these sections are quartz sandstone and shale with variations, mainly in bedding, fissility, sedimentary structures and degree of silicification. One exception, is the presence of dolomite at Red Cliff Pound; dolomite exposed at S82, dips 20° to the west and overlies silicified white shale, laminated sandstone, and very coarse sandstone ($\frac{1}{8}$" - $\frac{1}{2}$" grain size). The dolomite is laminated, pink or pale purple on a fresh surface, and weathers into circular boulders. It is overlain by hard, fine and medium grained, variegated, well bedded and well sorted sandstone. Some of the bedding planes in this sandstone show fine striations similar to groove casts. On the western edge of Red Cliff Pound, the dolomite crops out. It is fine grained, pink and laminated, and overlain with an angular unconformity, by fine white siltstone capped by siliceous siltstone containing Cretaceous radiolaria. Many dry or salty bores drilled in the Gardiner Beds on Sturt Creek Station have penetrated a brown shale section; there is probably a larger percentage of shale in the beds than is seen from the outcrop examination.

Smooth bedding planes, and ripple marked surfaces are a common feature of the Gardiner Beds. Fissility is well developed in the sandstone at the Wolf Creek Crater, in outcrops or the west bank of Sturt Creek opposite Sturt Creek Station, and in the Sydney Margaret Range; the rock can be split into thin large slabs. Well preserved wane ripple marks occur in the silicified, white sandstone at S90, and large slabs measuring 12 feet by 6 feet show continuous ripple marked bedding planes.(fig.13).

The Gardiner Beds usually show open asymmetrical folds with steeply dipping axial planes and gently dipping beds.

Figure 11: Upper Proterozoic Gardiner Beds, Denison Range.

Figure 12: Drag folding in incompetent Upper Proterozoic shale 10 miles east of Lake Wills.

Figure 13: Steeply dipping, Upper Proterozoic, ripple marked sandstone 16 miles E.S.E. of Warrie Peak, Stansmore Range.

Figure 13a: Large-scale current bedding in probable Devonian sandstone, Knobby Hills.

In the Denison Range, the plunge of the folds reverses several times along the straight axial trace. At Red Cliff Pound the beds have been folded into synclines and anticlines with dips that are steeper than elsewhere; eastern flank dips in this area are 5 - 35°, and western flank dips are nearly vertical, and the beds are silicified and cut by many quartz veins.

A comparison of the sediments on these two limbs, illustrates the sharp change that occurs, within a short distance, in the degree of silicification and intensity of tectonics that the Upper Proterozoic rocks have undergone.

The intensity of the folding in the Gardiner Beds seems to have increased from east to west.

At S59 on the synclinal axis, the beds are horizontal, silicified, fine and medium-grained sandstone, well sorted except in some interbeds of fine conglomerate which contain chert. The bedding is well defined and ripple marks are common in places.

At S52 and S53 ladder quartz veins and slickensiding is visible, and at S88, a breccia marks the position of a east-west fault along the scarp of the outcrop. At S55 the sandstone and conglomerate form strike ridges with troughs weathered out of the interbedded shale and claystone. This rhythmic alteration of arenites and lutites suggests cyclic sedimentation. Drag folds are present in the soft incompetent shale (figure 12).

The Gardiner Beds show uniform sedimentation over a wide area. Subsequent tectonism and selective silicification make correlation of the various outcrops difficult, but sediments which only differ in degree of alteration have been shown as the same age (e.g. Red Cliff Pound). Therefore in areas of isolated outcrops correlation is based on aerial distribution, sedimentary structures, prevailing dips and predominant lithology.

The total thickness of the Upper Proterozoic sequence in the Red Cliff Pound area, estimated from the exposures visible on the aerial photographs and the dips measured in the area is about 5,000 feet.

Since the Gardiner Beds overlie the Halls Creek Metamorphics with an angular unconformity, and the Phillipson Beds unconformably overlie the Lewis Granite, the two units may be co-eval. A doubtful contact of the Phillipson Beds overlying the Gardiner Beds has been mapped in the Erica Range. This is discussed more fully under the Phillipson Beds. However as their lithology and structure is different, they have been given separate names.

Phillipson Beds. (New Name):

The Phillipson Beds are defined as beds of friable, current bedded sandstone, with a basal polymictic conglomerate; the beds have a well developed joint pattern.

They crop out in the Phillipson Range (lat. 20°33'S., long. 128°32'E), and extend as lines of cuestas north to Tent Hill (west of the Gardiner Range); they overlie granite in the Lewis Range and at Mt. Hughes.

They unconformably overlie the Lewis Granite, and contacts occur with beds doubtfully referred to as the Gardiner Beds. No overlying unit has been seen in contact with the Phillipson Beds.

They are referred to as probably Upper Proterozoic in age.

At Tent Hill (B10) the beds are friable, current bedded sandstone, dipping 5° west, and unconformably overlie the Lewis Granite. The section here, in descending order is:-

20 feet Sandstone - hard, silicified, with some fragments of angular quartz and quartzite;

80 feet Sandstone - coarse, friable, with some rounded quartzite pebbles and thin beds of fine conglomerate;

120 feet Sandstone - red-brown to light brown, medium-grained, flaggy to laminated; beds average one inch thick. Friable, well sorted, with large-scale current-bedding; distinctive well developed joint pattern on aerial photographs.

10 feet Conglomerate - coarse, with pebbles of granite and quartzite.

- UNCONFORMITY -

Lewis Granite:

The eastern side of the Lewis Range is 230 feet high; at L25, granite composes 200 feet of this scarp, and is overlain by a coarse, ill-sorted, conglomerate containing angular quartz, muscovite and felspar. Above the basal conglomerate is a friable, current-bedded, medium-grained sandstone with some quartz pebbles and muscovite flakes. The granite surface dips 3° east.

The Phillipson Beds also crop out at Mt. Hughes (L13). The Lewis Granite is exposed on the eastern flank of the hill and the section is almost identical with that exposed in the Lewis Range. Above 20 feet of medium-grained sandstone, with a basal polymictic conglomerate, unconformably overlies the Lewis Granite. Small faults in the sandstone are marked by silica-coated slickensided surfaces and quartz crystals have grown in most joints and cavities. Several small granite boulders which are nearly covered by sand, occur, about 3 miles west of Mt. Hughes.

The thickest section of Phillipson Beds is exposed in the Phillipson Range between L14 and L16. At L14, a conglomerate with subangular to angular chert and jasper fragments, is interbedded with medium to coarse sandstone and is overlain to the south by a ripple-marked medium-grained silicified sandstone/(fig. 10) which dips at 15° to the south; this sandstone has ripple marks with a wave length of 1 foot and amplitude of 2", and is overlain by soft sandstone at L15, where the following section, in descending order, occurs:-

> 50' Sandstone - flaggy to laminated medium grained well bedded light brown, with abundant ripple marked surfaces.
>
> 20' Shale - chocolate brown, fine, micaceous, with inter-bedded friable light brown sandstone; occasional ripple marks are present.
>
> 20' Sandstone - hard-flinty, siliceous, massive. The dark purplish brown colour is probably secondary in origin.
>
> 20' Sandstone - ripple marked, dark reddish brown medium grained. Interference and wave ripple marks are extremely abundant and well preserved.
>
> 10' Sandstone - soft, friable, variegated, poorly sorted. The beds dip at 3-5° south.

At L16, a 200 foot thick sandstone unit presumably overlies the sequence at L15 conformably, and probably represents the youngest part of the Phillipson Beds in the Phillipson Ranges. This top unit is a white to light brown, medium-grained (maximum grain size 0.5 mm) sandstone, ripple marked only in parts, thickly cross-bedded with sets up to 5 feet thick, and containing some beds in which clay pellets appear to have been leached out. It has a pronounced joint pattern, and gullies have formed along these joints to produce a very rough surface. This sandstone is similar to the one at Tent Hill and the Lewis Range.

Unaltered sandstone, possibly equivalent to the Phillipson Beds, crops out in the Erica Range. Here it overlies silicified arenites which are possibly equivalent to the Gardiner Beds. The top beds consist of white, yellow or dark red-brown sandstone, wave ripple marked (with sharp crests), and with dips up to 10° to the west-south-west. The sandstone is well sorted, contains no pebbles, and is massive, with current beds in sets up to five feet thick. Bedding is not well marked when the outcrop is viewed from a distance, although very even bedding plane surfaces show when the rock is split. The weathered sandstone is dark red-brown, and in many places, deeply iron stained but otherwise, it is white or slightly mottled. The underlying sandstone (Gardiner Beds?) is silicified, purplish brown, laminated or flaggy, cross-bedded, ripple marked with beds up to two feet thick. It appears to be conformable with the overlying sandstone but does not show the well-developed cross-bedding and is silicified and more massive.

This two-fold division of the Upper Proterozoic in the Erica Range may not be justified as it has been shown elsewhere that soft unaltered sandstones pass laterally into silicified, hard sandstones. However, in this instance the sediments dip at about 10° and there appears to be a distinct lithological change.

Undifferentiated Palaeozoic.

Lucas Beds:

The Lucas Beds are defined as beds of friable, pale-purple, well-sorted, fontainebleau sandstone with some clay pellets and interbedded laminated claystone. They are named from Lake Lucas (lat. 21°00'S., long. 129°00'E.) where they crop out on the eastern shore, and in the floor of the lake (fig. 8).

The age of the Lucas Beds is not known but they are similar in both photo-pattern and lithology to the Permian Noonkanbah Formation.

The Lucas Beds are separated from the Upper Palaeozoic and Mesozoic sediments of the Canning Basin by

Upper Proterozoic basement rocks cropping out to the west of Lake Lucas.

Work by Bureau of Mineral Resources geologists in 1956 in the Lake Lucas area has shown contacts of the Lucas Beds with both probable younger, and older formations. At Yam Hill (L48) the following section is exposed:-

30' Sandstone - medium and fine grained, partially highly siliceous, massive and current ripple marked. Light brown, white and pale yellow with some thin laminae of fine white or yellow brown siltstone.

10' Sandstone - friable, porous, purple brown, medium grained. Contains some clay pellets and has a calcareous cement.

The sandstone at the base undoubtedly belongs to the Lucas Beds, and it is lithologically similar to the Permian sediments to the west; the overlying sandstone is also regarded as probable Permian. However, it must be kept in mind that the Lucas Beds could represent an extension of Lower Palaeozoic rocks already known in the western half of the Northern Territory.

The Lucas Beds exposed to the north-east of Yam Hill at L46 and L47 are grey-brown, medium-grained, partly silicified sandstone, with interbedded pink sandy dolomite. The outcrops are obscured by sand, alluvium or caliche. The low scarp at L46 is formed of leached sandstone with a thin cap of duricrust.

The outcrop area of the beds is rimmed by Upper Proterozoic sediments; about 3 miles north of L21, an outcrop of probably Upper Proterozoic sandstone is surrounded by Lucas Beds.

The beds underlie the floor of Lake Lucas (fig.8), and bedding trends, joints and small faults are very pronounced on air photos, but a thin cover of salt and sand prevented an examination of these rocks being made. The alternating dark and light thin bands visible on the photos are probably due to the rhythmically bedded sandstone and claystone. The Permian Noonkanbah Formation in the Fitzroy Valley often shows a similar photo pattern to this pattern in Lake Lucas.

At the large salt lake south-east of Lake Lucas, the beds dip at 3° east and a thickness of about 900 feet is estimated here; a 50 foot scarp occurs at the lake edge.

If these beds represent an uninterrupted sequence with those at Lake Lucas, then the total inferred thickness of the Lucas Beds is about 1900 feet.

At L17, at the northern end of the large salt lake, there is a section 23 feet thick which consists of:

5 feet Caliche - calcareous, sandy, nodular.
3 feet Sandstone - medium-grained, flaggy, calcareous, with rounded dark, purplish brown clay pellets;
4 feet Claystone - laminated, varigated, usually a dark chocolate brown;
1 foot Sandstone - fontainebleau;
3 feet Claystone - laminated;
2 feet Sandstone - fontainebleau;
5 feet Claystone - laminated;

Both the sandstone and claystone are current-bedded. Current ripple marks in the sandstone have an amplitude of 0.3 inches and wave length of 1".

The caliche, which invariably caps these sediments, is a hard, cavey or vuggy yellow deposit which contains fragments of the underlying rocks. It is highly calcareous, nodular and contains abundant sand grains. The caliche dips at about 2^{o} to the east and there may be a slight angular unconformity with the underlying Lucas Beds.

Near L18, a line of barite floaters occurs; they probably originally formed a thin bed or lens in the Lucas Beds. Barite nodules often occur at unconformaties.

The lithology, photopattern and structural expression of the Lucas Beds suggests similarities with the Permian Noonkanbah Formation. On the Helena Sheet at He9, rocks of similar lithology and photopattern crop out on Thornton Flat and have been tentatively mapped as the Noonkanbah Formation; in this area they are overlain to the north by the Balgo Member of the Liveringa Formation.

Ordovician:

Undifferentiated:

Outcrops of probable Ordovician age are confined to the north-east part of Mt. Bannerman and north-west part of Billiluna sheets.

Figure 14: Lucas Beds on eastern shore of Lake Lucas showing interbedded hard calcareous sandstone and soft claystone with a lighter coloured caliche capping.

Figure 15: Lucas Beds with caliche capping, Lake Lucas.

The only definite outcrop of this age is on the Halls Creek to Billiluna road, 31 miles north of Billiluna at B3. The rocks crop out on a low rise, and the beds dip to the south-south-east at 5 to 15°; thickness exposed is 250 feet.

The lithology is mainly medium-grained sandstone and conglomerate, apparently interbedded. The sandstone is more prominent near the base of the outcrop and is ill-sorted, with scattered pebbles and worm markings; the conglomerate has boulders up to 1 foot across.

The age of the rocks at B3 is based on a solitary trilobite pygidium; the form does not allow a specific age to assigned to it, but it is probably Ordovician (J. Gilbert-Tomlinson - pers. comm.).

One outcrop of questionable Ordovician age, west of here on the Mt. Bannerman sheet, was visited in 1957 by J. Veevers.

The rocks are preserved in a syncline, and unconformably overlie the Kearney Beds.

A specimen from M58 is a pale pink, medium-grained, felspathic sandstone.

The discovery of Ordovician rocks at the north-east margin of the Canning Basin may have economic significance, as the deeper water equivalents of these rocks are source beds for petroleum in the Fitzroy Basin, where oil traces were discovered at Prices Creek, north-west of B3.

A large gravity negative anomaly, north-west of Billiluna homestead, probably suggests that a considerable thickness of Upper Proterozoic clastic sediments underlie the outcropping Ordovician sandstones, or it is possible, but unlikely, that a section of sediments (such as Cambrian), hitherto not known from the north-east Canning, intervenes between the Proterozoic and Ordovician sandstones.

The Ordovician sandstones were deposited near shore, with a rapidly rising shore line which might be expected to give conglomerates in the sequence. The Ordovician dolomites and calcareous sandstone at Prices Creek were formed under shelf-type conditions.

Devonian

Limestone:

The only evidence of Devonian sedimentation is found on the northern half of the Mt. Bannerman Sheet, where a small outcrop of limestone, at M38, may represent the equivalent of the Bugle Gap Limestone (Guppy et al., 1958) of the Fitzroy Basin. There is no fossil evidence for the age of the rock but the Devonian limestone which crops out at Pinnacle Spring (north of Christmas Creek Station) trends in this direction. The rock is mottled, almost brecciated in appearance, light grey on a weathered surface, dark grey on a fresh surface. It contains calcite veins and nodules, and irregular masses of pure calcite which protrude from the weathered surface. The air-photo pattern shows distinct bedding of the outcrop but no dip or strike measurements could be made on the solitary outcrop visited. It appears to overlie Upper Proterozoic shale and Lower Proterozoic granite to the north and east.

Conglomerate, perhaps equivalent to the Upper Devonian Sparke Conglomerate, crops out to the south and may underlie the limestone. The Tertiary Lawford Beds overlie the limestone to the west but no contacts were seen. The calcareous material present in the Lawford Beds may be partly derived from this limestone.

The thickness of the limestone from this solitary exposure is not known.

Conglomerate:

A conglomerate overlying the Precambrian metamorphics in the Christmas Creek area is probably equivalent to the Sparke Conglomerate (Guppy et al., 1958) of the Fitzroy Basin. The conglomerate is also limited to the Christmas Creek area and occurs near the solitary outcrop of limestone above. This is significant when discussing the age of the conglomerate and correlating it with formations in the Fitzroy Basin.

The formation does not crop out as large masses of rock in situ, but rather as a debris of pebbles scattered over the surface of the ground. There is no fossil evidence of the age of the conglomerate, and it is unlikely that fossils will be found in such a sediment. Its geographical position, the smooth aerial photograph pattern, of rounded, dissected hills, and lithology suggest correlation with the Sparke Conglomerate. Its distribution suggests that it overlies the limestone.

The conglomerate contains pebbles and well-rounded cobbles from ½" to 6" in diameter.

They were eroded after being latertised, and derived cobbles form the basal beds of the Tertiary Lawford Beds.

The conglomerate in places resembles a river gravel; it occurs up to 50 feet above the present river level of Christmas Creek.

The Sparke Conglomerate abuts the Precambrian Lamboo Complex in the Sparke Range, about twenty miles north-east of Christmas Creek Station, where boulders up to twelve feet in diameter occur in the outcrop, but no boulders this size occur in the conglomerates in the Christmas Creek area.

The conglomerates are unsorted and consist of 90% quartzite boulders.

The total thickness is about 100 feet.

There is no evidence of glaciation and it is probably a torrential conglomerate.

UNDIFFERENTIATED - UPPER DEVONIAN OR LOWER CARBONIFEROUS.

Sediments, probably of Upper Devonian or Lower Carboniferous age, crop out on the Billiluna Sheet at Knobby Hills and Skeen Hill. A stem impression, probably of Leptophloem australe (McCoy) (see White, Appendix A), was found in a medium to coarse-grained sandstone at B4 in the Knobby Hills. This plant fossil is most typical of Upper Devonian to Lower Carboniferous horizons, extending probably higher into the Carboniferous.

At B4, about three quarters of a mile east of Sturt Creek, are some very coarse beds of sandstone with subrounded pebbles up to four inches in diameter. The rock is generally silicified on the surface but friable below. Dips up to 40° were measured at this outcrop, but may be those of the current bedding fore-sets (fig. 13a). Siliceous veins cut the rock in other localities.

At B28, ten miles east south east of Skeen Hill, these beds lie unconformably on steeply dipping Upper Proterozoic quartzite. No contacts with younger beds were found.

The basal clayey medium-grained sandstone at Skeen Hill (B29) about 7 miles north-east of Billiluna Homestead, contains abundant wood fragments and clay pellets, and some are micaceous. The overlying few feet of sediments are current-bedded, better sorted, medium-grained, massive sandstone with no mica. The beds dip at 20° to the west.

At B27 outcrops of non-silicified, strongly current-bedded, medium-grained sandstone occur as hills 70 feet high. Clay pellets are common, particularly on the current bedding planes, and some sections of the friable well-bedded sandstone contain large mica flakes. Pebbles are scattered throughout the rock. The sediments are identical with those at B29, except that the basal beds are conglomeratic and are associated with a red shale.

Reeves (1949) reports a specimen of *Lepidodendron* sp. 9 miles north 80° east of Balgo Mission. This specimen was re-examined by Brunnschweiler and Dickins (1954), who considered it to be an impression of a lycopodinaean plant of the genus *Leptophloem*, of Upper Devonian or early Carboniferous age. A medium-grained cross-bedded clayey sandstone with quartzite pebbles, at L41, deposited in a fault trough in Upper Proterozoic Kearney Beds may be of this age.

Reeves described conglomeratic sandstone 25 miles north of Billiluna Homestead, which may be from the Knobby Hills area near B4, as belonging to the Grant Formation overlain by the Poole Sandstone; the presence of *Leptophloem australe* suggests that the beds are older than this.

The beds were probably deposited in fresh water lakes at the margin of the basin.

PERMIAN

GENERAL:

Permian marine and freshwater sediments are widespread throughout the Canning (and Fitzroy) Basins and have the greatest aerial extent of any rocks in the area. They form good aquifers and many of the cattle stations depend on these sediments for their water supplies. Permian sediments almost certainly extend far into the centre of the Canning Basin and underlie Mesozoic rocks in the central part of the Basin. The degree of tectonism increases towards the northern margin of the basin, where many pronounced and important structures are found in Permian rocks. The complete sequence exposed in the Fitzroy Basin is not present here: the Poole Sandstone has not been identified in this area. Otherwise all other formations are correlateable. It was found preferable to subdivide the Liveringa Formation into three members on the basis of lithology and faunal and floral content. The members of the Liveringa Formation have not been differentiated on geological maps that cover the Fitzroy Basin.

Grant Formation:

The Grant Formation (Guppy et al., 1958) was first recognised in the area surveyed at the Falconer Hills about four miles north north west of Billiluna Station. Later, outcrops at Mt. Mueller and Mt. Bannerman were regarded as belonging to this formation. Outcrops of the Grant Formation are restricted to areas near Upper Proterozoic rocks at the margin of the Canning Basin. The massive resistant rocks and prominent jointing produce a characteristically rough terrain.

The Grant Formation is predominantly a medium-grained buff and red, fairly well sorted, sandstone, with some clay pellets, and some rounded or facetted pebbles. Scattered fragments of fossil wood or wood impressions are common; some clay occurs in the matrix but mica is practically absent. Cross bedding is visible in some beds. The sand grains show sparkling grain surfaces indicating they have grain regrowth and recrystallization.

Some beds, generally from one half to 4 inches thick, are coarse sandstone and contain quartz and quartzite pebbles up to four inches in diameter; the sandstone becomes finer grained in other outcrops, and the bedding is almost laminated.

Some small quartz veins cut the rock; the veins may be small silicified fault planes or intersecting joint planes; the vein edge is not sharp.

No complete section of the formation is exposed, but it is about 500 feet plus thick. In the Fitzroy Basin, over 8,000 feet of Grant Formation was penetrated in W.A.P.E.T.'S Grant Range No.1 well. It wedges out against older Palaeozoic rocks north of the Pinnacle fault, also in the Fitzroy Basin.

At Mt. Mueller (B24), 150 feet is exposed:

50 feet Sandstone - bedded, blocky, medium-grained, with clay pellets, ripple marks, current bedding and wood remains;

100 feet Sandstone - massive, friable, clayey, micaceous, with some pebbles; foresets of the current beds dip to south-south-west; has very characteristic honeycomb weathering (fig.24).

Shale is not conspicuous in any section; wood and plant remains are common in the clean, medium-grained sandstones; worm trails occur at B23.

At L39, the foreset in the current beds dip north; here clay pellets, mica and wood occurs in the coarsely cross-bedded sandstone.

Other outcrops occur at Shiddi Pool and near Mt. Bannerman, and ferruginous wood-bearing sandstone east of Mt. Bannerman also is part of this formation. A current-bedded, coarse-grained sandstone at Shiddi Pool shows contemporaneous deformation and contains lenses of conglomerate with angular pebbles, ½ - 2" in size.

North of Bulka Hills at M43, M44 and M45 (last two are on Mt. Ramsay Sheet) light brown conglomerate and sandstone, poorly sorted with sub-angular pebbles of sandstone, quartz-mica schist, quartz and quartzite (½"-8" diameter) probably are part of the Grant Formation. Wood remains occur in sandstone at M45, where the sandstone is faulted against the Noonkanbah Formation. The fault has caused silicification of the rock, and quartz grains show regrowth.

About 70 feet of section is exposed at M44, where it dips 1° to the west-north-west and consists of clayey sandstone, cross-bedded, pebbly, ill-sorted, white to light brown and pink, and finely laminated.

At Pyramid Hill, east of Sturt Creek Station, a conglomerate with faceted cobbles, up to 8" in diameter overlies Proterozoic quartzitic sandstone; this conglomerate maybe part of the Grant Formation.

The predominance of sand in the formation, the presence of scattered wood and plant fragments, and pebbles (in places facetted) of various types, the widespread current bedding, suggest the unit is a shallow water shoreline deposit.

It is stratigraphically and lithologically similar to the Grant Formation in the Fitzroy Basin, and is probably in part, fluvioglacial or aqueoglacial in origin; however, no varves or morainic deposits have been found in the north-east Canning area.

The source of the sediments cannot be deduced from field evidence, but its distribution suggests that it was primarily derived from marginal Precambrian rocks and from Devonian conglomerates.

At Mt. Bannerman, the Condren Sandstone Member overlies the Grant Formation.

No unit equivalent to the Poole Sandstone of the Fitzroy Basin has been recognised in the north-east Canning Basin, but an equivalent unit may be present in the deeper trough area of the basin.

Noonkanbah Formation:

The Noonkanbah Formation (Guppy et al., 1958) crops out on rubble-covered plains or black soil flats. The formation occurs near Balgo Mission, south of Christmas Creek Station, around Lakes Jones, Betty and Lonergan, in the Southesk Tableland, and in the Stansmore Range. The sediments are pre-dominantly fine sandstone, quartz-greywacke, and shale, with some coquinites. They are nearly all very soft and porous, and the consequent lack of outcrops prevented measurement of detailed sections.

The outcrops near Balgo Mission consist predominantly of calcareous and ferruginous shale with some medium-grained sandstone. Marine fossils from this formation were collected from spoils from a salt well near old Dooma Dora Mission at L.4. Here the sediment is an amber to brown, micaceous, medium-grained, soft, greywacke-siltstone with some black, micaceous shale; it contains bryozoa, echinoderm plates, gastropods, and ostracods. At L.38 and L.29 near Balgo Mission, coquinite beds rich in Chonetes crop out at the surface. At L.30 at Thomas Peak concretionary fine silty sandstone of the Noonkanbah Formation is overlain by the Balgo Member of the Liveringa Formation.

The Noonkanbah Formation also crops out on the clayey flats south of Mt. Mueller at B21 and B22. The sediment is fossiliferous, calcareous, fine, silty sandstone with red clay pellets and coquinite beds.

Scattered surficial sand deposits, black soil flats and rubble covered plains west of Shiddi Creek, on the Mt. Bannerman sheet, are probably underlain by sediments of the Noonkanbah Formation or the Lightjack Member of the Liveringa Formation. The plains have some small outcrops of shale. In some places at the margin of the plain the Noonkanbah Formation or Lightjack Member is overlain, probably unconformably by the Blina Shale.

Well bedded to laminated, micaceous shale and sandstone, with worm trails, crop out at M8; at M45, on the Mt. Ramsay Sheet, brown and white, fine micaceous sandstone and shale dip south-west until they are cut off by a north-south fault which brings the Grant Formation in contact with the Noonkanbah Formation. The Condren Sandstone member of the Liveringa Formation caps the isolated buttes of Noonkanbah in this area.

Throughout the Southesk Tableland and Roberts Range, poor outcrops of either the Balgo Member or the Noonkanbah Formation occur - the two units cannot be distinguished from each other in some areas. The Noonkanbah Formation crops out on flats partly obscured by sand, black soil, and clay, but trend-lines are commonly visible and produce a characteristic photo-pattern, which, together with the soil type and topography, has enabled the formation to be identified. Outcrops on the flats in Southesk Tableland consist of unsorted yellow micaceous clayey sandstone showing ripple marks and clay pellets. At C42 a calcareous clayey sandstone with some interbedded shale crops out. Some massive beds contain abundant concretions.

In the Fitzroy Basin the formation has a consistent thickness of 1200 to 1300 feet (Guppy et al., 1958); but in the north-east Canning Basin the outcrops are too poor to be able to construct a sedimentation picture, or to be able to correlate the sediments entirely with the section exposed in the Fitzroy. The thickest section seen is about 50 feet in the Dooma Dora old well.

The formation was probably laid down quietly on a gently subsiding shelf, without winnowing by currents, but with some stationery strand lines during which beds of coquinites accumulated.

The fauna suggests identity with the Noonkanbah Formation.

Few contacts with the underlying Grant Formation were seen, and it seems to grade upwards into the Balgo Formation.

Liveringa Formation:

The Liveringa Formation has been defined by Guppy et al., (1958) in the Fitzroy Basin. Recent work in the north-eastern Canning Basin has shown that three distict units occur within the formation and they have been classed as members. These members have also been recognised in the Fitzroy Basin but only two have been defined (viz. Lighjack and Hardman). The middle plant-bearing Condren Sandstone Member is well defined in the north-eastern Canning Basin but the overlying Hardman Member was only recognised at one locality. All three members appear to be conformable although the rock types are distinct and the contacts between the members are fairly sharp.

Balgo Member (New Name):

The Balgo Member is defined as the basal marine member of the Liveringa Formation which crops out in the north-east Canning Basin and is named from Balgo Mission (lat. 20°08'S., long. 127°48'E.). Highly ferruginized shale, fine and coarse-grained sandstone, and quartz greywacke predominate. The Balgo Member can be correlated with the Lightjack Member (Guppy et al., 1958) which has been defined and mapped in the Christmas Creek area. Owing to the lack of traceable boundaries, paucity of outcrops, and the great distance from Christmas Creek area, a new name has been used.

Outcrops of the member are widespread near Derbai Creek, the Stansmore Range, Southesk Tableland, Thomas Peak, Point Alphonse, and west of Mt. Bannerman; outcrops of undifferentiated Permian in the Southesk Tableland may also be the Balgo Member. Spoil from Well 47 on the Canning Stock Route is reported to contain fossils "like the Shell-sign" - probably Aviculopecten which is common in the Balgo unit.

Generally the outcrops are poor, and have been reduced to ironstone rubble; but in folded areas (such as the Stansmore Range fig. 16) good outcrops occur. It forms low ferruginous rises and crops out at the base of many breakaways which are capped by resistant beds.

It has some lithological similarity to the Noonkanbah Formation, but no calcareous or coquina beds are

Figure 16: Permian marine and plant-bearing sediments of the Liveringa Formation, Stansmore Range. Dip is to the east.

Figure 17: Plant-bearing Condren Sandstone member of the Liveringa Formation at Mt. Erskine.

evident.

At the type section S67, at the south end of the Stansmore Range, the member dips 10° south, and although the thickest measured section was 65 feet it is estimated from photo-interpretation that the member maybe up to 800 feet thick. The section at S67 is as follows:-

20 feet Sandstone - fine, red to pink and white, massive, poorly bedded, contains laminae of white fine siltstone. Abundant conical worm casts filled with white, fine, hard siltstone. Topmost beds dark brown ferruginized medium-grained sandstone.

25 feet Sandstone - fine and medium-grained, light brown, massive, poorly bedded, with very small amounts of mica. Mottled in parts, with reddish colour in finer sandstone. Few irregular white or red stained clay pellets; topmost light brown, medium grained sandstone is porous.

5 feet Sandstone - coarse, porous, dark brown, moderately well-sorted, poor bedding. Matrix is white, fine-grained, siliceous and may be secondary. Abundant small vertical worm burrows.

10 feet Sandstone - hard, fine to medium-grained, stained a reddish colour. Massive, poor bedding, moderately well-sorted and breaks into angular irregular pieces. Contains thin beds of very fine sandstone.

1 foot Sandstone - coarse-grained, light brown, with rounded pebbles up to 3" in diameter.

5 feet Sandstone - fine grained, micaceous, soft, laminated, silty pink to red and light brown. Ferruginized dark red to brown sandstone bed 6 inches thick near centre, with concretions and muscovite, and marine fossils pelecypods, gastropods, and rare brachiopods.

Other good sections of the Balgo Member are exposed in the Stansmore Range and marine fossils were found at many localities. At S9, about two miles north-west of Warri Peak, and at S1(near White Hills), the Balgo Member crops out and contains abundant marine fossils in interbedded fine micaceous quartz greywacke and medium to coarse-grained sandstone. Felspar grains occur in the greywacke at S1 and at Pt. Moody, a small conical hill in the N.W. of Stansmore

Sheet. Slump folds, concretions (which often contain fossils) ripple marks, clay pellets, and worm trails are abundant; the sediments generally are poorly sorted. Some beds are composed of dark red ferruginous clayey sandstone.

At S1, the blocky micaceous quartz greywacke with felspar grains dips 4^{o} west; the basal beds contain clay pellets, concretions and marine fossils.

At S6, the concretionary beds contain smooth quartzite pebbles, 6" in diameter, as well as marine fossils.

At Thomas Peak (L30) 40 feet of quartz-greywacke (with pelecypod fragments, clay pellets, ripple marks, worm trails) overlies 25 feet of sandstone which contains many manganese-stained concretions to form almost a "conglomerate" of concretions.

A siliceous duricrust caps many of the outcrops in the Stansmore Range.

Thin conglomerate bands occur in some sections; at B14, the top 5 feet of sandstone has lenses of sub-rounded quartz pebbles $\frac{1}{4}$" across, and the underlying 40 feet of sandstone has scattered $\frac{1}{4}$"-6" diameter pebbles of rounded quartz, quartzite, soft sandstone and rarely granite in its upper part. Some fossil wood was found in pink micaceous sandstone in this section.

At the base of breakaways near Derbai Creek, the Balgo Member is conformably overlain by the Condren Sandstone Member. At L9, the Condren Sandstone overlies interbedded coarse and fine-grained sandstone, conglomerate and variegated siltstones with marine fossils in a ferruginised, clay pelleted quartz-greywacke. At Pallotine Headland, gastropods occur in a micaceous, laminated, variegated siltstone at the base of the hill.

No contact with the Noonkanbah Formation was seen, but it is thought the contact will be conformable.

Lightjack Member:

The Lightjack Member (Guppy et al., 1958), was originally defined as the basal marine horizon of the Liveringa Formation in the Fitzroy Basin, deriving its name from Lightjack Hill (lat. 18^{o}59'S, long. 125^{o}50'E.). Several incomplete sections of the Lightjack Member were measured south of Christmas Creek Station.

At M56 near Astrofix N21, about 4 miles north of Christmas Creek, fragments of pelecypods were found in quartz greywacke of the Lightjack Member. The section here is :-

20 feet Condren Sandstone Member - flaggy, light brown well jointed sandstone with small amounts of mica.

50 feet Siltstone - shaly, light brown to amber.

20 feet Quartz greywacke - dark grey and brown, micaceous, and fine grained. Contains some beds of finely laminated, white to light brown sandstone.

A similar section occurs at M55, where fossils were found in a bed of micaceous, fine grained, clayey quartz greywacke 6 inches thick. The rock is dark green-brown to grey brown on the fresh surface, weathering dark brown. Similar fossiliferous sediments were found at M49, where a concretionary sandstone crops out; the fossils occur in the concretions. Fossils were also found in spoils from a well south of Tonka Spring.

The thickness of the Lightjack Member is estimated as approximately 150 $\pm$ 50 feet. The thickest section measured was about 70 feet.

Condren Sandstone Member (New Name):

The Condren Sandstone Member is defined as the middle fossil plant and wood bearing member of the Liveringa Formation and crops out at Condren Pinnacles (lat. 20°06'S, long. 127°38'E. - fig.19), on the Lucas 4-mile sheet about 12 miles west-north-west of Balgo Mission. This is the type locality (L44).

The Condren Sandstone Member is widespread throughout the area; the best exposures occur in the Balgo Mission, Christmas Creek and Stansmore Range regions, where large areas of dissected sediments give rise to breakaways and mesa and butte topography. Continuous outcrops occur between Gunnawarrawarra Rockhole, Pallotine Headland, Namalook Rockhole, and Narelli Rockhole. The Condren Sandstone Member probably covers the greatest area of the three members of the Liveringa Formation. The Member is usually found capping breakaways or forming isolated pinnacles. The sandstone is nearly always massive, light coloured and porous and has a pronounced joint pattern which produces a rough surface, easily recognised on the aerial photographs. Generally the sediment is a white, well-sorted, micaceous, sandstone, with interbedded (in places rhythmically bedded) claystone. The sandstone contains a characteristic flora.

The 60 foot type section at Condren Pinnacles (L44), from which the member derives its name is:-

15 feet Sandstone and Claystone - white to green and red, clayey, rhythmically bedded;

10 feet Sandstone - white, clayey, weathered pitted surface;

15 feet Sandstone - medium-grained, white, friable, micaceous, contains some interbedded claystone. Plant fossils abundant.

20 feet Sandstone - fine to medium-grained, well-bedded blocky, buff coloured, micaceous with abundant wood fragments.

- Conformably over -
Balgo Member - ferruginised concretionary sandstone and siltstone which crops out on the plain.

Only two outcrops were seen where younger beds overlie the Condren Sandstone; one was at Bababaru Rockhole where Estheria - bearing siltstone of the Triassic Blina Shale apparently conformably overlies the Condren Sandstone which dips 7° south-east and here consists of massive, current-bedded, medium-grained sandstone with conglomerate bands and plant remains; the second outcrop was at Mt. Bannerman (M5) where a 130 foot section, which dips 2° to the north-north-west, is capped by 20 feet of horizontal conglomerate (with 3" diameter pebbles) with a siltstone breccia at the base where it rests on white micaceous siltstone of the Condren Sandstone; abundant plant roots, seeds and leaves occur near the top of this 130 foot section, and current bedding dips in the basal 30 feet are to the west. The age of the 20 feet of conglomerate is not known.

At Point Alphonse (L35), 22 miles south-west of Balgo Mission the following 145 foot section is exposed -

55 feet Sandstone - fine grained, bedded to thick-bedded, micaceous, with clay pellets. Some interbedded claystone, ripple-marked and current-bedded.

Figure 18: Conical hills of Permian Condren Sandstone caused by erosion along joints, Forebank Hills.

Figure 19: Condren Sandstone Member, Condren Pinnacles.

45 feet Sandstone - fine to medium-grained, current-bedded, massive, white in colour, with interbedded claystone and shale. It contains clay pellets and wood. Some scattered large mica flakes are larger than the quartz grains of the rock.

5 feet Sandstone - medium-grained, dark red ferruginous, with large clay pellets and some large pebbles and wood remains; forms a bench on hill slopes.

40 feet Sandstone - fine-grained, well-bedded, violet and white, with interbedded shale. Very little mica is present. It contains plant remains.

In general there are less clay pellets in the top-most beds and the rock is generally friable and porous. The thin claystone beds are often mottled violet and white.

Evans (1948) describes a 50 foot glacial boulder bed, south of Balgo Mission, 100 feet above the top of the 'Upper Ferruginous' (Liveringa Formation); the surface is strewn with cobbles of granite, quartzite etc. up to 6" across. They are probably derived from conglomerate beds in the Condren Sandstone or the Grant Formation.

In the Gordon Hills (L11) plant remains occur 35 feet from the top of the 65 foot section in a limonite bed. Outcrops, such as L11 which are near (10 miles west of) the Precambrian rocks, are cross-bedded, clay pelleted and micaceous; more mica is found as the rock becomes coarser-grained.

At Mt. Erskine (M18) a similar 140 foot section to that at Mt. Bannerman is capped by 20 of a pallid laterite zone; plant fossils occur 50 feet from the top, and siltstone and interbedded sandstone with large mica flakes occur at the base of the hill (fig. 17).

The 60 foot section at M30, 9 miles west of Chungla Well and 23 miles south-east of Mt.Erskine is capped by dark, ferruginous sandstone overlying a 20 foot pallid zone; sandstone and siltstone occur at the base where slumping has produced a false dip.

At Black Rocks (M27) the dark ferruginous coarse-grained sandstone with clay pellets, current bedding, lenses of conglomerate and containing some plant remains is probably equivalent to the ferruginous cap at M30 above, and maybe younger than the Condren Sandstone.

Plant fossils are found at M47, 8½ miles east of Tula Yard in the Christmas Creek area, and at M48, 6 miles south-west of McDonald Spring where 60 feet of ripple marked sandstone (fossil wood near the top) overlies 50 feet of micaceous sandstone, greywacke and siltstone of the Lightjack Member; pebbles of quartz and quartzite cover the ground in this area.

At C39, 4 miles north-east of Mt. Fotheringham, 70 feet of sandstone containing beds with sharp ripple marks overlies 40 feet of brown micaceous sandstone. Cross-bedding, intraformational slumping, clay pellets and mica (in lower part) is common in the section.

The Stansmore Range has good outcrops of the Condren Sandstone and at S10, 3 miles north of Warrie Peak it conformably overlies the Balgo Member. The sandstone in this area, and at S2 near White Hill, contains conglomerate beds (pebbles up to 6" in diameter), many ripple marks (1 ft. wavelength, 1½" amplitude), wood fragments (up to 1 foot long), worm tracks, and beds with clay pellets, 1-2" in length. Wood fragments of a similar size occur at M56 (north-west of Mt. Bannerman Sheet).

The Condren Sandstone is in contact with the Balgo Member as Condren Pinnacles and at S70 (30 miles west-south-west of Carnegie Bluff) where nearly 100 feet of section is exposed above the marine fossiliferous Balgo Member. At S70 the sections is, from the top down:-

2 feet <u>Sandstone</u> - red-brown, well-sorted, slightly silicified. Contains a clay pellet bed with clay lenses and laminae;

40 feet <u>Sandstone</u> - massive, micaceous, blocky, white and light brown. Muscovite is abundant and sometimes causes thin lamination in the sandstone. Rare rounded cobbles of quartzite and some granite up to six inches in diameter occur near the top;

50 feet <u>Sandstone</u> - both massive and soft, with ripple marks and worm tracks; white, weathered surfaces are dull, pale red brown; current bedded; muscovite abundant. Bedding is good compared with the overlying more massive sandstone.

5 feet Claystone - fine, white, massive, laminated in places. Exposed in a creek bed near the hill.

In the many sections measured over widespread localities, the Condren Sandstone was remarkably uniform in lithology. Plant remains were nearly always present; mica is common and in some cases the flakes were considerably larger than the sand grains; the sand is usually well-bedded, in places laminated and even rhythmically bedded; current bedding is common, and ripple marks occur but not abundantly; clay pellets occur but the sandstone matrix is rarely clayey; conglomerate is common either as thin beds, or as scattered pebbles (up to 6" diameter) consisting of quartz, quartzite and rarely granite; the sandstone is fairly well-sorted, medium to fine-grained, rarely coarse-grained; weathering is blocky and some interbeds are soft and porous; worm tracks and concretions are rare; the fresh rock is white, buff or light brown and rarely ferruginous or dark brown.

Outcrops south-east of Godfreys Tank are not as prevalent as elsewhere. Well-jointed sandstone, containing plant remains in places, in the Southesk Tableland is probably Condren Sandstone.

The lithology and flora suggests the Sandstone was deposited in a shallow water, estuarine, brackish or lacustrine environment.

The maximum thickness measured was 150 feet, but air photo-interpretation in the Stansmore Range area, suggests about 500 feet of section.

Formations below are conformable, and at least the Triassic (in the one outcrop) above is conformable.

Geological maps of the Fitzroy Basin do not differentiate this plant-bearing member of the Liveringa Formation, although similar beds do occur there.

Guppy et al., (1958) estimated the plant-bearing beds were 900 feet thick at Christmas Creek where they contain: Bothrodendron sp, (see Teichert, 1939), ?Gangamopteris sp. and Glossopteris indica (Brong.). Apart from these M. White (Appendix A) has described the following from the Condren Sandstone: Schizoneura sp., Glossopferis communis Feist., Gangamopteris cyclopteroides Feist., Samaropsis sp., Vertebraria australis, Lycopodiopsis pedroanus Carr, Carpolithus sp., Noeggerathiopsis hislopi, Vertebraria cf. indica, Royle, and Phyllotheca cf. australis Brongn. All give a Permian age.

Hardman Member:

Outcrops of the Hardman Member are confined to a small area near Boundary Hill (M50) in the north-west corner of the Mt. Bannerman Four Mile Sheet. The outcrops are small and have no characteristic physiographic expression. The sediments are hard, moderately well indurated, and form the prominent Boundary Hill. The Hardman Member was originally named from Mt. Hardman (18°18'S., 124°39'E.) in the Fitzroy Basin and was defined by Guppy et al., (1958).

At Boundary Hill, 60 feet of mottled white, grey and ferruginous medium-grained flaggy sandstone and siltstone crops out; they dip 2-5° to the south-south-west, and are poorly sorted with grains up to 3 mm. in diameter, but average 0.5 mm.; some mica flakes are 4 mm in size.

Poorly preserved marine fossils were found here, and they were determined by G. Thomas as Aulosteges sp. and Conularia sp.

The Aulosteges species appears nearest to a species in the Hardman Member of the Liveringa Formation. The Conularia species is fragmentary, but it is like a species occurring in the top beds of the Port Keats Group which is the same age as the Hardman Member, (Thomas, pers. comm.).

The age is provisionally regarded as Upper Permian (Tartarian).

To the south, honeycombed, friable, dark ferruginous, medium-grained, clayey sandstone and some unsorted conglomerate crop out, which may however be equivalent to the Condren Sandstone Member. The Hardman Member probably lies conformably on the Condren Sandstone Member. The absence of the Hardman Member over a large area to the east and south suggests that it was never deposited, rather than that it was completely removed by erosion. There are no indications as to the source of the sediments or conditions of deposition, or of any contacts with underlying and overlying rocks.

Triassic

Blina Shale:

The Blina Shale is defined in the Fitzroy Basin as the basal Triassic siltstone, shale and sandy shale which probably unconformably overlies the Permian Liveringa Formation (Guppy et al., 1958). The Blina Shale has been mapped in the north-east Canning Basin in the Bishop Range, Chilpada Chara (in the Minnie Range), Stretch Range and Bishops Dell areas. The Formation underlies many of the black soil areas near Lakes Lonergan, Betty and McLernon; two outcrops were photo-interpreted in the Stansmore Range. The Formation overlies the Lightjack Member, Condren Sandstone Member and the Noonkanbah Formation.

Outcrops of the Formation are poor, except in the Bishop Range, where it is folded with dips up to 30°. Elsewhere the Blina Shale crops out as scattered rubble on plains, or as small scarps a few feet high. It is composed predominantly of highly micaceous shale and fine sandstone with some medium sandstone; the rock is pale brown to white when fresh, but weathers ferruginous. In some sections the shale has a "squeezed" appearance with undulating laminae. No complete section of the Blina Shale was measured as the top of the formation is eroded, but total thickness is probably less than 150 feet, although air photo-interpretation of sections in the Stansmore and Stretch Range suggest greater thicknesses.

In the Bishop Range, the Blina Shale is cut by small faults. At C12, where the following section is exposed, the sediments dip at 12° to the south-west:-

10 feet <u>Sandstone</u> - medium-grained, yellow, clayey, micaceous; many clay pellets, particularly at the base where a breccia occurs;

5 feet <u>Shale</u> - violet and white, micaceous;

15 feet <u>Sandstone</u> - fine, with interbedded <u>shale</u>.

15 feet <u>Sandstone</u> - fine to medium-grained, micaceous, (large mica flakes), current bedded, clay pellets, common in thin beds.

In a nearbye 25 foot section at C13, marine fossils occur in a red nodular shale, underlying a medium-grained micaceous sandstone 5 feet below the breakaway. Below the fossiliferous shale is interbedded red and white micaceous shale and beds of sandstone, one foot thick. Plant remains in the debris on the valley floor are probably from the Condren Sandstone.

At C14, 40 feet of medium-grained sandstone and shale is exposed along a north-west fault displaces the beds;

they dip 2-3° north-west, and are equivalent to the top part of the C12 section;

The Estheria-bearing shale at Bababaru Rockhole(L33) crops out in the west side of a north-west fault; there is no outcrop on the eastern (downthrow) side. The shale dips at 35° towards the fault, but west away from the fault, the dips are only 7°. It conformably overlies current bedded, medium-grained sandstone of the Condren member here.

In the Minnie Range, at Chilpada Chara, Isaura*-bearing shale and sandstone overlies the plant bearing Culvida Sandstone. The Culvida Sandstone is Upper Triassic or Jurassic in age and may be equivalent to part of the Erskine Sandstone of the Fitzroy Basin. The section at C31 is:-

15 feet Sandstone - clay pellets, medium to coarse-grained. Isaura occurs in a ripple marked micaceous, well bedded, fine grained sandstone;

5 feet Claystone - violet and white with worm tracks and markings.

30 feet Sandstone - massive, medium-grained, unsorted, dark coloured, ferruginous.

This section overlies 40 feet of the Culvida Sandstone. The sediments dip at 2° to the north-east, and are cut by small faults about ¼ mile to the east of this section.

The Isaura-bearing sandstone is downfaulted and topographically lower in outcrops to the east. It also overlies the Culvida Sandstone at M29.

Stratigraphic relationships of the Blina Shale will be discussed under Geological History.

Outcrops on the Mt. Bannerman Sheet are very poor. At M13, a 40 foot section of well-bedded, micaceous sandstone and shale has a bed containing Lingula, 15 feet from the top of the hill, and this is immediately below a 2" bed of white and yellow micaceous sandstone which has numerous vertical worm burrows. A similar section, 45 feet thick at M14 consists of well bedded, micaceous sandstone and shale with massive sandstone near the top, and also contains Lingula.

The thickest measured section of the Blina Shale is at Brown's Lookout (M15). The sequence is:

15 feet Sandstone - bedded.

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* Isaura is the correct genera for the Estheria forms.

5 feet <u>Sandstone</u> - micaceous, fine, containing *Isaura* (*Estheria*), wood and seed remains in an interbedded massive sandstone. Three half-inch beds of ironstone laminae occur near the top and a mottled violet sandstone below.

80 feet <u>Sandstone and Shale</u> - interbedded, well bedded. Friable sandstone and ferruginous thin shale at the base.

The sediments dip 2° to the south-south-west.

At M22, the typical well-bedded, violet, yellow and white micaceous shale and sandstone with lamellibranchs crop out. Some worm tracks and wood remains occur in the breakaway which is 30 feet high.

Outcrops of the Blina Shale also occur at M51 and M52 where abundant *Isaura* remains are preserved. At M52 the rock is a fresh, white, medium to fine-grained friable sandstone, 15 feet thick; it approaches a coquinite in places and, as well as *Isaura*, it contains vertical worm markings of *Diplocraterion* (A.A. Öpik, pers. comm.). The sediments here dip at 4° to the west-north-west. The laminae have a "squeezed" appearance perhaps due to interference ripple marks or penecontemporaneous slumping. At M51 the *Isaura* occurs in a laminated, fine, micaceous sandstone with some interbedded, medium-grained sandstone. The sediments in this area west of Mt. Bannerman are friable and produce a clay soil, which has a characteristic pattern on the aerial photographs.

The Blina Shale was probably deposited in brackish water, either in a lagoonal or estuarine environment, favourable for the accumulation of the abundant *Lingula* and *Isaura*. The water was moderately shallow, possibly a shelf environment. Triassic sediments are restricted to the Fitzroy Basin and to the north-east Canning except for a thin section penetrated in the Bureau of Mineral Resources No. 4A Wallal bore which contained possible Triassic spores.

No unconformity was observed with the underlying Permian rocks but the aerial extent of the formations indicate that an unconformity may be present. The lamellibranch in the Blina Shale in the Fitzroy Basin is a different form to the one in the north-east Canning Basin, and has been termed aff. *Pseudomonotis* by R.O. Brunnschweiler (pers.comm.) The abundance of *Isaura* often constituting coquina beds, indicates an Upper Triassic Age according to Brunnschweiler (1954).

Upper Triassic-Jurassic

Culvida Sandstone (New Name):

The Culvida Sandstone is the formation of richly fossiliferous plant-bearing sandstone which either overlies the Blina Shale or Condren Sandstone Member, and is overlain by the ?Cretaceous Godfrey Beds. The plants (see Appendix A) indicate an Upper Triassic or Jurassic age. It maybe in part similar to the Erskine Sandstone (Guppy et al., 1958) of the Fitzroy.

Outcrops of the formation are confined to the Cornish Sheet, at Culvida Soak in the Minnie Range, and near Well 50 on the Canning Stock Route.

The best exposure is at Culvida Soak, in a small water course that flows eastwards and drains onto a small claypan, and in a small group of hills nearbye. The breakaway is terminated on its eastern edge by a north-south trending fault, which has produced dips of up to 20° to the south-east in sediments; the following 60 foot section is exposed, ½ mile south of Culvida Soak:

30 feet Siltstone - white, fine, massive;

5 feet Sandstone - medium-grained, hard, dark-brown highly ferruginous;

10 feet Sandstone - massive, white, with abundant plant stems;

5 feet Sandstone - coarse, dark brown, highly ferruginous, massive;

10 feet Sandstone - finely, laminated, micaceous, white.

At Culvida Soak a massive, current-bedded sandstone is exposed which contains beds rich in clay lenses, laminae and pellets. The current beds in the coarse sandstone often show laminae of grit, with angular grains up to 5 mm. in diameter. The sandstone weathers reddish brown; the fresh rock is lighter coloured; muscovite is present but not abundant. Upstream from Culvida Soak, the coarse sandstone is interbedded with 10 feet thick sections of white, massive fine siltstone which contain plant fossils. At C63, in a hill 100 feet high plant fossils occur in ferruginous sandstone and in white sandstone; the sandstone at the base of the section here, shows current bedding, clay lenses and pellets, and is very similar to the sandstone at Culvida Soak; 20 feet from the top of the hill, worm tracks, infilled mud cracks, and ripple marks are common; the sediments dip to the north at 10°. Plant fossils were also found in an adjacent hill where the following section is exposed.

40 feet <u>Siltstone</u> - white, brittle, hackley fracture, some muscovite, in part massive, ripple marks;

15 feet <u>Sandstone</u> - white to grey, fine-grained, contains plant remains.

10 feet <u>Sandstone</u> - medium-grained, highly ferruginous;

40 feet <u>Sandstone</u> - white, friable with bands of clay pellets and lenses of fine sediments.

The lithology is much more variable than in the Blina Shale. Infilled mudcracks found in the shale indicate periods of dessication when pieces of the shale were incorporated in the interbedded sandstone which contains abundant clay pellets.

The formation does not form typical breakaways, but low hills, and sometimes isolated high peaks such as those present at Chilpada Chara. The slopes of these peaks give a characteristic smooth pattern on the aerial photographs.

The maximum thickness of the formation is probably less than 200 feet.

Cyclic sedimentation occurs in the sequence exposed at Culvida Soak.

The formation is apparently unconformable with the Blina Shale; there may be an unconformity with the Permian Condren Sandstone Member.

The Culvida Sandstone may be equivalent in age to part of the Erskine Sandstone (Brunnschweiler, 1954) of the Fitzroy Basin. It may also be equivalent in part to the Mudjalla Sandstone (Guppy et al., 1958) and the Parda Formation (Lindner and Drew, in McWhae et al., 1958). However, recent collections of plant fossils made from Myroodah Ridge and the Erskine Range in the Fitzroy Basin by WAPET geologists are probably Permain, and not Triassic in age (White, 1958).

Further collecting will be necessary to be sure that these outcrops are not inliers of the Liveringa Formation in the Erskine Sandstone. These plant fossils are very similar to those collected from the Condren Sandstone Member of the Liveringa Formation at M24 and M23 on the Mt. Bannerman Sheet. The assemblages recorded by Brunnschweiler (1954) however, bear little similarity to those given by White (1958). Brunnschweiler (1954) gives the principle elements of the Erskine Sandstone as: Thinnfeldia (Dicroidium), Gleichenites, Otozamites, Schizoneura, Pleuromeia (probably exclusively Triassic in age). White (1958) gives the following determinations -

Erskine Range:

Equisetalean stems (cf. Schizoneura gondwanensis)
Lycopod stem (cf. Lycopodiopsis pedroanus Carr.)
?Glossopteris

Myroodah Ridge:

Small Equisetalean stems.
?Winged seeds (cf. Samaropsis milleri)

Plant fossils from the Culvida Formation determined by M. White (See Appendix A) indicate that the formation is uppermost Triassic or Jurassic in age.

Godfrey Beds:

The Godfrey Beds (Elliott, Casey & Wells, 1958) are beds of massive, in places shaley, sandstone with some interbedded conglomerate which are confined to the Godfreys Tank area (lat. 20°12'S, long. 126°33'E.) where the maximum thickness exposed is 200 feet. They do not show any contacts with proven younger or older strata. The sediments crop out as prominent breakaways, and many promontories and prominent peaks have been named in the Godfrey's Tank area by early explorers. Steep sided narrow valleys have been eroded in the rock and these sometimes terminate in a large rockhole or natural tank that has been enlarged by a small water-fall. Two such gnamma holes are Godfreys Tank and Breadens Pool. Generally, the breakaways are capped by a very massive sandstone up to 20 feet thick, which is underlain by bedded comparatively softer sandstone; rockholes thus form readily in this softer unit.

In general the beds consist of massive, both hard and friable, quartz sandstone with minor thin laminae of poorly sorted conglomerate. Very minor laminated sandstone and siltstone occur. The rock is usually even textured, white or pale yellow-brown when fresh, and weathers red-brown or orange-brown. The ripple-marked surfaces often show worm tracks. The sandstone has many tracks and burrows of the

Figure 20: *Rhizocorallium* in the Godfrey Beds, Godfreys Tank.

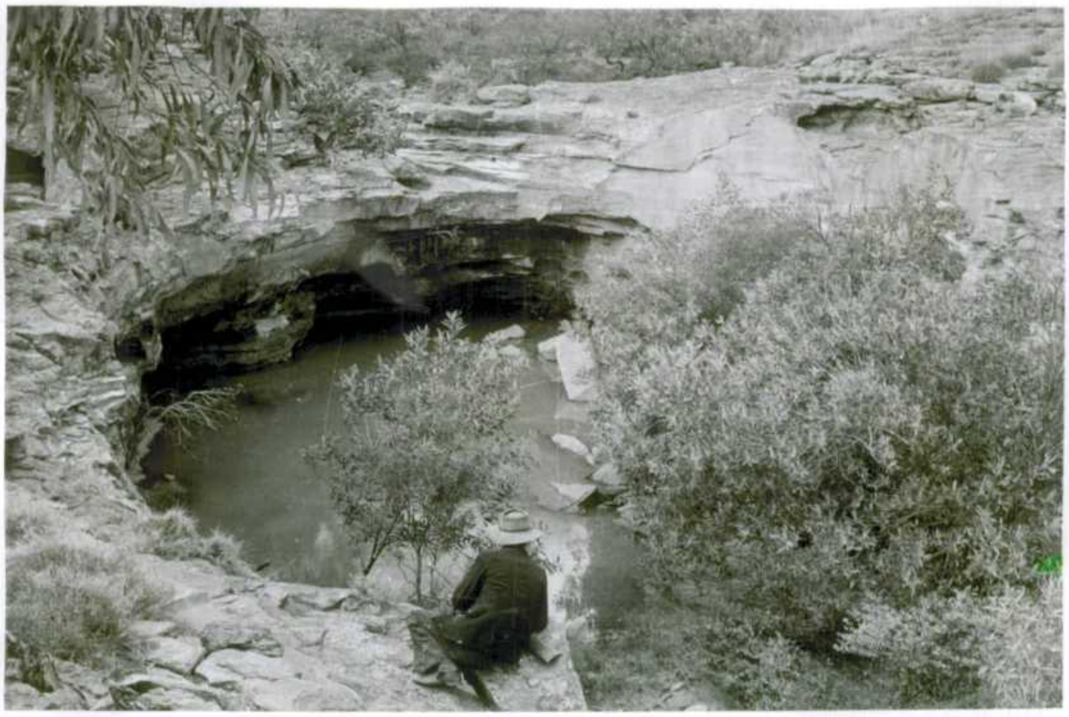

Figure 21: Flaggy sandstone of the Godfrey Beds, Godfreys Tank. The rockhole is Godfrey's Tank.

Figure 22: Cretaceous Godfrey Beds, near Godfreys Tank.

worm Rhizocorallium (see fig.20) which make U-shaped forms parallel to the bedding. The sandstone is normally micaceous but the percentage of mica is generally low.

The type section of the Godfrey Beds as measured by WAPET and Bureau of Mineral Resources geologists in 1955 is at C3a, three quarters of a mile south of Godfreys Tank at lat. 20°12'35"S, long. 126°33'00"E (approx.). The sequence from the top down, is as follows -

1 foot Sandstone - brown, weathers red-brown, crudely thin bedded, coarse, poorly sorted, conglomeratic with pebbles up to 4" long of white and grey quartzite;

13 feet Sandstone - pale brown and greyish brown, sometimes golden brown, fine-grained, weathers red-brown, thin-bedded, some worm markings as below, often laminated in the thin beds; contains fragments of ?Cretaceous pelecypods;

121 feet Sandstone - pale reddish and yellowish brown, weathers red-brown, fine grained, thin bedded to laminated, some beds soft, others hard particularly on top of hills where unit tends to form cliffs; cross-bedded, numerous worm trails of Rhizocorallium, few thin beds of siltstone, dark brown, thin bedded;

6 feet Sandstone - yellow brown, weathers red brown. coarse, poorly sorted, crudely bedded, weathers into slabs about four inches thick, a prominent bench marker around the hills; at C2, where it dips 1½° south-west, it contains worm trails, Rhizocorallium and pelecypods.

38 feet Sandstone - pale yellow brown, weathers red brown or original colour, fine-grained, soft and crumbly, thin bedded; near top occasional bed of sandstone brick red, medium-grained, soft and crumbly. Many rockholes form in this unit.

At Breaders Pool (C57) about half a mile to the north of C3a, the following 150 foot section is exposed -

5 feet Sandstone - hard, siliceous, pale brown, fine-grained, massive, sometimes finely laminated;

25 feet Sandstone - massive white, with ripple marks, and some clay pellets; some obscure fossil remains;

80 feet Sandstone - light brown, massive, with silty intercalations. Several coarser grit beds up to two inches thick with grains up to 3 mm. in diameter, but generally averaging 2 mm.;

40 feet Sandstone - white, with muscovite and silty intercalations and many worm tracks; the beds at the top of this unit form a distinct bench around the hill.

At C58, towards the northern end of the range at Godreys Tank and about 3½ miles north-north-west of Godfreys Tank itself, tracks of Rhizocorallium are very abundant.

At Crown Head a bed very rich in clay pellets occurs about 15 feet from the top of the hill and has only been recorded from this locality. The sediments here dip at about 4° to the south-west. The apparent unconformity between the more massive upper sandstone and the lower sands with silty intercalations rocks when viewed from No.48 Well was discounted on closer examination, and the upper sandstones dip uniformly in the same direction. The section exposed at Crown Head is 300 feet thick and consists of -

30 feet Sandstone - massive, irregularly jointed;

70 feet Sandstone - silty intercalations with muscovite and ripple marks;

100 feet Sandstone - pale brown, massive, intercalated with finer silty beds; muscovite, ripple marks and clay pellets are present;

100 feet Sandstone - white, medium-grained, with ripple marks and cross bedding, mica absent.

At Mt. Elgin, C53, finely laminated, highly micaceous sandstone interbedded with a more massive sandstone crops out. Ripple marks, worm tracks and current bedding are common.

At C54 the sediments have been tilted by faulting and dip 17° to the east. The section consists of -

20 feet Sandstone - light-brown, micaceous, silty intercalations;

60 feet Sandstone - white, massive, micaceous, silty in places; small graphite particles are scattered through the rock; worm tracks up to ⅛" in width are present.

Irregular concretionary structures and ripple marks are common throughout the sequence.

At C55, 1½ miles west of C54, sandstones dip 5° east and are much coarser-grained, ferruginous and contain sub-rounded quartz grains, ripple marks, and clay pellets; no mica is present. These sandstones could be Permian.

In the Bishop Range, at C23, a small outlier of Godfrey Beds contains an incomplete Rhizocorallium, and the beds overlie Noonkanbah Formation or Balgo Member.

At Mt. Cornish, where the sediments are probably the same age as those at Godfreys Tank, the following sections being exposed -

15 feet Sandstone - hard, highly ferruginous, medium-grained, massive; no mica;

40 feet Shale - pale brown, micaceous, ripple marks on the bedding planes;

40 feet Sandstone - light brown, medium-grained, with some small mica flakes on the bedding planes.

Worm tracks were found in some beds. The sediments dip at about 3° to the east.

Probable Cretaceous rocks occur near Brookman Waters on the Stansmore Sheet. A cream siltstone from this area (S60) yielded indeterminate radiolaria cf. Cenosphaera which may represent the topmost part of the Lower Cretaceous and probably equivalent of the Albian Stage (Crespin, per.comm.). At S60 the section is -

10 feet - "Billy", and hard, fine, siliceous cherty material with breccia at the top;

15 feet - Claystone - white, fine, massive, with grains of very fine sand.

At S61, similar but coarser-grained, thin bedded sediments lap against the Precambrian rocks and dip at 25 to 35° to the west.

Several other photo-interpreted outcrops of Cretaceous rocks have been mapped north of Brookman waters and in the Murabba Range.

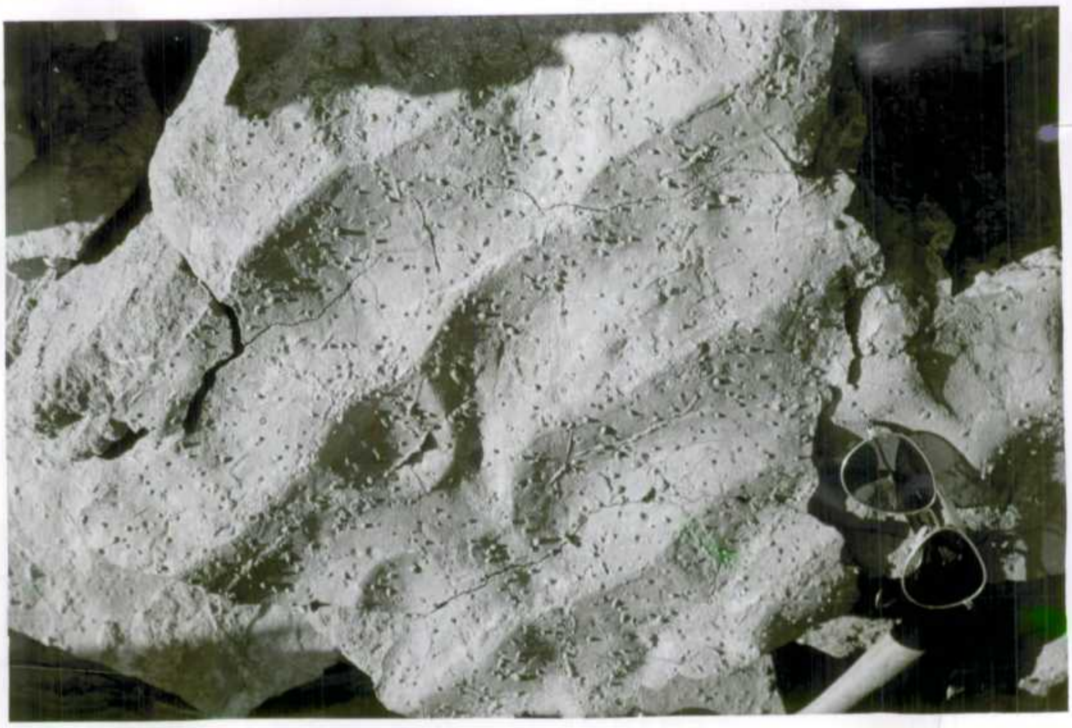

Figure 23: Ripple marks with worm trails and burrows in the Cretaceous Godfrey Beds, Mt. Cornish.

Figure 24: Honeycomb weathering in the Grant Formation, Mt. Mueller.

Figure 25: Cretaceous Godfrey Beds; Crown Head on the right.

Figure 26: Irregular contact of the Permian Condren Sandstone Member (Pr) with an overlying conglomerate possibly of the Godfrey Beds (Kg) at C59.

The contact of the Godfrey Beds with possible Permian rocks is exposed at C59 (fig.26). The section exposed is -

40 feet Conglomerate - very coarse, pebbles and boulders (up to 2 ft. in diam.) rocks predominate; Marked Kg in figure 26;

20 feet Sandstone and Shale - micaceous, medium-grained, light brown colour, current bedding, with ripple marks in the interbedded shale; marked Pr in figure 26.

The horizontal lower sandstone and finely laminated shale have a very irregular and ill defined contact with the overlying conglomerate. The conglomerate is a very irregular deposit clinging to the surface of the sediments below. In some small sections a coarse, hard, medium-grained, irregularly jointed, massive, siliceous sandstone is exposed under conglomerate. When the section is viewed from a distance the conglomerate appears to wedge out towards the east.

Two outcrops of the Godfrey Beds (mapped by photo-interpretation only) occur east of Godfreys Tank, one small outcrop overlying the Triassic Culvida Sandstone near Culvida Soak, and a second larger outcrop showing trend lines to the east of Astrofix Station N10.

The thickest section is exposed at Crown Head, where it is 300 feet thick; this is probably the maximum thickness; the flat country around and to the west of the Godfreys Tank area is probably overlying Permian as possible Permian fossils have been reported from Well 47 on the Stock Route.

The Godfrey Beds are a near shore sediment; most of the clay and fine sand has been winnowed away; ripple marks, worm trails and mica add evidence for near shore conditions.

No younger rocks were found overlying the Godfrey Beds, which are unconformably (at least with an erosional break, see C59) above Permian.

Cretaceous foraminifera and Rhizocorallium were found in the Anketell Sandstone in the south-western Canning Basin (Traves et al., 1956). The Godfrey Beds are tentatively correlated with the Anketell Sandstone based mainly on the presence of Rhizocorallium.

Although no foraminifera were found in the Godfrey Beds, poorly preserved lamellibranchs were found in 1955 by WAPET geologists from "Catspaw Hill" at C2a - they are a small group of 5 hills, north-west of Godfreys Tank. at lat. 20°17'12"S, long. 126°37'52"W, which resemble a cats paw on the air photos. A single species has been identified as Etea? sp. (Dickins pers.comm.). The genus Etea occurs in the Cretaceous of North America.

A probably Cretaceous age is given to the Godfrey Beds.

Tertiary

Laterite and Pisolitic Ironstone:

Laterite deposits are not widespread and there is no evidence to suggest that laterite covered the whole of the area. Laterite and pisolitic ironstone have not been differentiated on the four-mile maps. Remnants of a thick dissected laterite surface occur on the Precambrian sediments north of Christmas Creek on the Mt. Bannerman Sheet. Near Kai Ki yard at M37, the following section is exposed in one of these remnants:-

10 feet Laterite - dark coloured, honeycombed, with scattered subrounded quartz and quartzite pebbles ½" to 6" in diameter;

20 to 30 feet Laterite - pallid, honeycombed with a few pebbles.

This section overlies almost vertical Precambrian schist and interbedded quartzite. Similar sections occur in other areas, and the laterite often contains boulders and pebbles as at M39 on the Mt. Ramsey Sheet.

A laterite profile is not well developed on any of the desert breakaways, which are usually capped by resistant pisolitic ironstone. The laterite profile is better developed on the finer grained shale, claystone and quartz greywacke rather than the quartz sandstone.

An interesting derivative of the laterite occurs at B24, near Mt. Muller. Here the laterite capping of the sediments has been eroded and a detrital laterite deposited in the bed of a small creek. The original laterite has been eroded, transported to the stream bed and incorporated with sand grains and rock fragments to give a semi-indurated deposit.

No laterite has formed on the Upper Proterozoic quartzite or sandstone but some of the Lower Proterozoic rocks are overlain by a leached cap rock which is up to 5 feet thick. This was observed on the Halls Creek Metamorphics just south of Mt. Stubbins.

The two isolated occurrences of massive ironstone are different in origin to the pisolitic ironstone capping on many desert breakaways. At the north end of the Gardiner Range, about 7 miles south-west of Mt. Brophy Spring, dark brown almost black ironstone overlies a medium - grained Upper Proterozoic sandstone. The deposit is probably not more than 10 or 15 feet thick; it is vuggy and breaks easily; it is pisolitic but differs from the pisolitic ironstones by not forming a flatlying deposit which caps hills, but rather forms undulating hills on the valley floor. The deposit may be a thick detrital laterite. A second small deposit of ironstone occurs in the Sydney Margaret Range at S54, where the deposit is about 40 feet thick and consists of limonite and limonitic breccia overlying silicified sandstone. This deposit of very dark-brown massive limonite may be part of a lake deposit formed by the damming back of a small stream, or a spring deposit; it also forms a small undulating hill with no obvious relation to any structural feature of the underlying rocks.

Lawford Beds (New Name):

The Lawford Beds are massive marl and limestone, with chalcedony capping, which crop out in the Lawford Creek area; some conglomerate and pisolitic ironstone occurs at their base. They are correlated with the Oakover Beds (Maitland 1904) in the south-west Canning Basin.

Near M38, 5 miles downstream from Kai Ki Yard, on the banks of Christmas Creek, mesas of massive calcareous and siliceous sediments of the Lawford Beds, unconformably overlie steeply dipping chocolate-brown shale of the Precambrian.

At M40, a small hill of marl and chalcedonic limestone overlies brown to purplish shale of the Upper Proterozoic Mt. Frank Shale (Maddox, 1941).

In the type section at Lawford Creek (M41), bedded chalcedony crops out in the banks of the stream and in small cliff sections. The section exposed is as follows:

20 feet Chalcedony - hard, massive, vuggy in places, most likely lacustrine in origin;

60 feet Earthy lateritic material - mottled, pisolitic pallid, some conglomerate possibly derived from the surrounding lateritic material or older conglomerates; in places it is marly and is probably a river channel deposit.

Laterite and pisolitic ironstone, up to 20 feet thick, are exposed in the valley. The laterite contains numerous pebbles from one half-inch to eight inches across of red siliceous sandstone, quartz and quartzite but no chalcedony. This indicates that the laterite was formed prior to the deposition of the lacustrine deposits.

The Lawford Beds have been deposited in a valley in the dissected laterite crust. The Devonian conglomerate, which covers a great deal of this area, was probably lateritised and eroded and the surface left covered in pebbles; the surface was dissected by an ancestral Christmas Creek which formed stream deposits consisting of boulders set in earthy lateritic material. The Creek was dammed either by differential erosion of the Precambrian rocks or by tilting, and slow evaporation formed the marl and chalcedony deposits of the Godfrey Beds, which were later dissected to give the existing mesa and butte topography.

The Oakover Beds in the south-west Canning Basin, are very similar in both lithology, thickness and position to the Godfrey Beds, and are thought to be co-eval. Thin-shelled ostracods and a doubtful foraminifera were recently found from concretionary limestone in the Oakover Beds at Upper Carawine Gorge; however, no definite age can be given. They are post, at least one period of laterite, and are regarded as Tertiary, probably late Tertiary.

Wolf Gravel (New Name):

The Wolf Gravel is defined as the unconsolidated gravel, conglomerate, and sand of unknown thickness along the banks of Wolf Creek. The age of the deposits is uncertain but they have been tentatively correlated with the Warrimbah Conglomerate of the Fitzroy Basin (Guppy et al., 1958). Diprotodon australe reported from the bed of the Lennard River, just below the "Devil's Pass" by Hardman (1884) occurs in the Warrimbah Conglomerate, and the conglomerate is therefore possibly Pleistocene in age. The Wolf Gravel is

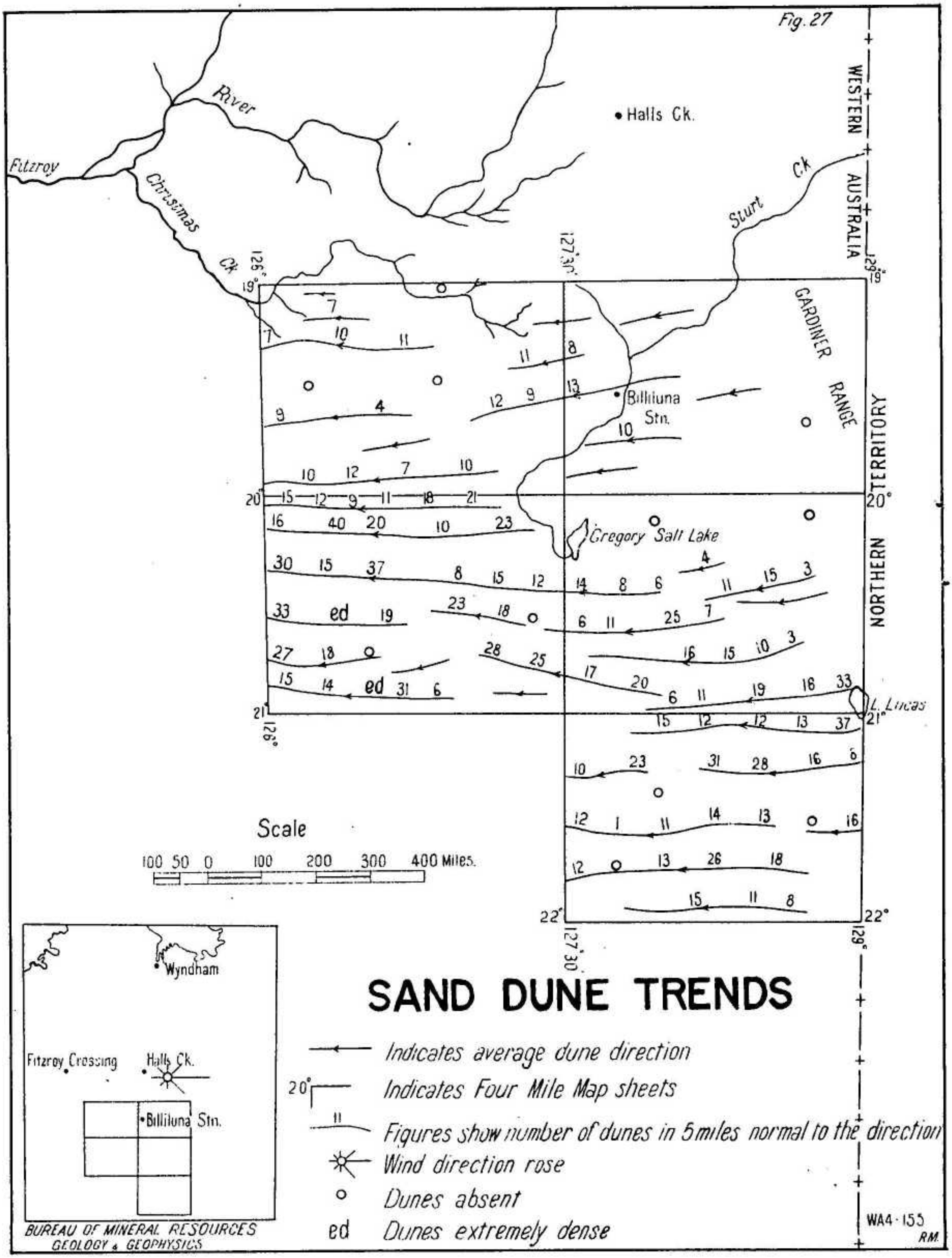
Fig. 27
WESTERN AUSTRALIA
NORTHERN TERRITORY
Fitzroy
River
Christmas Ck
Halls Ck.
Sturt Ck
GARDINER RANGE
Billiluna Stn.
Gregory Salt Lake
L. Lucas
126° 19°
127°30'
129° 19°
20°
21°
22°
Scale
100 50 0 100 200 300 400 Miles.
Wyndham
Fitzroy Crossing
Halls Ck.
Billiluna Stn.
BUREAU OF MINERAL RESOURCES GEOLOGY & GEOPHYSICS
SAND DUNE TRENDS
Indicates average dune direction
Indicates Four Mile Map sheets
Figures show number of dunes in 5 miles normal to the direction
Wind direction rose
Dunes absent
ed Dunes extremely dense
WA4-155
RM

undoubtedly a stream deposit probably from a larger ancestral stream of the Wolf Creek, as the present deposits of Wolf Creek are mostly sand and gravel, and very few large boulders occur in the stream course.

In the Christmas Creek area bedded, unsorted, sandstone and conglomerate, up to 15 ft. thick, form the banks of the creek; these deposits may be the same age as the Wolf Gravel.

Quaternary

Recent Deposits:

Recent deposits in the area include aeolian sand, travertine and caliche, evaporites, river alluvium, gravels and sand and alluvial black soil. Aeolian sand is the most widespread of all these deposits and covers large tracts of the desert as sand plains or east-west trending seif dunes (see fig.27) The seif dunes are particularly numerous in areas occupied by post-Precambrian rocks. The theory of the formation and description of similar dunes is discussed in Traves et al., (1956). Samples of the sand were collected and analysis made by G. Brown in 1959 (Record 1959/82). Almost all samples have a grain size less than 1 mm., and are generally coarser than sands from other deserts; heavy minerals constituted less than 1% of the sample; zircon, tourmaline, hornblende, andalusite, black iron ores, and rutile were the most plentiful. A haematite coating on the grains gives the sand a prenounced red to orange colour.

Travertine and caliche deposits are more commonly found in salt lake areas, but their occurrence in isolated sand plains may indicate areas where salt lakes or rivers once existed. The travertine may be formed at or near the surface by deposition from ground water near the margin of the lake, or it may form as a direct lake deposit. The travertine consists of massive, white limestone which weathers to a dull grey colour, and is often interbedded with massive or rarely laminated chalcedony which is often brecciated. The brecciation may be caused by insolation of a thin laminae of chalcedony, the fragments being later incorporated in later deposition of limestone. The powdery caliche that is prevalent at the margin of the salt lakes appears to represent a stage in the transition to indurated travertine. At Lake White large pieces of friable travertine occur embedded in a thin crust of powdery caliche.

At C11, between Minnie and Bishop Range a coquinite of small freshwater turritellid gastropods occur in travertinous material and pinkish limestone; these are the first recorded Quaternary(?) gastropods from the Canning Basin.

Evaporites occur in the salt lakes, and are described under the section dealing with economic deposits. The evaporites are not very thick.

Alluvial gravel, sand, and black soil deposits are limited to the large stream valleys particularly those on the Billiluna Sheet. The deposits are thin. Numerous small alluvial fans occur where short streams drain low mountain ranges and breakaways in the sand plain areas.

STRUCTURE.

The area mapped includes parts of two major structural units: the Canning Basin and sections of both the Warramunga (Noakes, 1953) and King Leopold (Traves, 1955) Mobile Zones.

The King Leopold and Warramunga Mobile Zones.

The south-eastern extension of the King Leopold and western extension of the Warramunga Mobile Zones probably meet in this north-east Canning area.

The Lower Proterozoic Metamorphics south of the Gardiner Range may represent the western end of the Warramunga Mobile Zone which passes through Tanami and continues to Tennant Creek and the Davenport Range; where the Lewis granite fits is not certain, but it probably represents a younger phase than granites at Tanami and Tennant Creek, and maybe equivalent to some of the younger granites in the Davenport Range.

In general, the Upper Proterozoic sediments have low dips (10° or less) in comparison with the Halls Creek Metamorphics with dips up to 90°, but, where Upper Proterozoic sediments have been laid down in these Mobile Zones, they have been more strongly folded and faulted (cf.Kearney Beds) than their time equivalents (cf. Gardiner and Phillipson Beds) laid down on stable blocks such as the Kimberley (Gentilli and Fairbridge, 1951) and Sturt Blocks (Noakes, 1953); younger sediments on the stable blocks show broad synclines and anticlines only, whose fold axes are usually parallel to the regional trend of the nearest Mobile Zone.

Fold axes and faults in the Upper Proterozoic sediments trends generally east-west in the northern part of area (i.e. are parallel to the Mobile Zones), but in the south-eastern area (Lake Hazlett - Red Cliff Pound) they trend north-south and have influenced the shape of the Canning Basin.

Canning Basin:

Not enough is known about the sub-surface of the Basin to be sure of the pre-Palaeozoic surface, but it seems to be an intracratonic Basin, with a floor showing marked structural relief. Several smaller basins, separated by sub-surface ridges are known from aeromagnetic, gravity and drilling. The largest sub-basin is the Fitzroy, which seems to continue into the north-east Canning.

The southern limit of the Fitzroy Basin, defined in Guppy et al., (1958), is the Fenton Fault or "hinge"; as later work has established that a ridge south-west of and parallel to the Fenton Fault, called the Broome Ridge, is a major tectonic unit it is better to extend the Fitzroy Basin to the Broome Ridge; the ridge runs from east of Broome to Dampier Downs and then south-east towards Godfreys Tank.. On the north-eastern margin of the Fitzroy Basin a shelf (called the Lennard Shelf in the north-west) is divided in two by the Precambrian of the Bulka Hills.

The major structures in the Fitzroy Basin in the Fitzroy River area, are the Pinnacle and Fenton Faults or "hinge lines"; in the north-east Canning, these features break up into a series of parallel fractures affecting the Palaeozoic and Mesozoic sediments, and the fractures persist as far to the south-east as the Stansmore Range; this suggests that the Fitzroy Basin extends diagonally across the Mt. Bannerman Sheet to the Stansmore Range area. The Broome Ridge, on aeromagnetic evidence, passes through the south-west corner of Mt. Bannerman, probably west of Mt. Ernest.

Seismic evidence across the Pinnacle Fault, near Prices Creek, predicts 18,000 feet of sediments to the south-west.

The regional gravity map of the north-east Canning shows a relatively large positive anomaly from Bulka Hills, through Minnie Range to Gregory Salt Lake, and then possibly extending to east of the Stansmore Range. The "high" is marked on the surface by many small faults, with a predominance of small faults on its western side; this "high" maybe continuous with a similar "high" on the north-east side of the Pinnacle

Fault or "hinge" in the Prices Creek area. The gravity information west of this "high" suggests a sedimentary thickness of the order of 15,000 feet.

Faulting in the Palaeozoic and Mesozoic sediments usually trends north-west, with the fault planes dipping steeply to the south-west; the throws is normally less than 200 feet, except on the Stansmore Fault.

Along the north-east half of the Mt. Bannerman sheet, the gravity contours follow the structural trend of the Precambrian rocks; an elongated negative anomaly is parallel and adjacent to this trend and coincides with the easternmost extent of Permian sediments and may indicate an Upper - Proterozoic - lower Palaeozoic Basin. Gentle folds occur between Godfreys Tank and the Stansmore Range, and towards the Stansmore Range the intensity of folding and faulting increases towards the Stansmore Fault. The throw of the Stansmore Fault has been calculated as 7,800 feet (downthrow to the west) by Garrett (1956), assuming a density contrast of 0.4 gm/cc. This steep gravity gradient is colinear with a zone of steep gradient east of Balgo Mission which coincides with the Precambrian - Palaeozoic contact, but the reduced gravity relief suggests a reduced sedimentary section to the north. The Stansmore Fault trends north-west and it has intermittent exposure to Well 50 on the Canning Stock Route; the sharp gravity gradient across the fault at the Stansmore Range is not apparent in the Well 50 area.

No sharp gradient occurs across the Precambrian - Palaeozoic contact near the junction of Wolf and Sturt Creeks; here the increase in thickness of the sedimentary section to the south-west is probably more gradual, (or the basement dips more gently) than in areas further to the south.

The west side of the large positive gravity anomaly which crosses the north-east half of the Mt. Bannerman Sheet marks the "hinge" between a shelf area with thin Palaeozoic sediments of sandstone-limestone lithology, disconformities and little tectonic disturbance to the east from a trough or basin to the west with thick sediments of shale-greywacke lithology, few disconformitites, and greater tectonic disturbance. Although no closed anticlines are visible in outcrop, the spot heights on various formation outcrops suggest fold structures are present.

The north-east Canning contrasts with the tectonics of the south-west Canning Basin, where many inliers of Lower Proterozoic Metamorphics protrude through near the margin of younger, undeformed sediments, whereas marginal areas in the north-east Canning are composed predominantly of Upper Proterozoic rocks, with younger sediments showing a continuation of similar folding and faulting as shown by sediments in the Fitzroy Basin.

The Upper Proterozoic sediments were probably derived from the denudation of once high areas of Lower Proterozoic rocks now concealed by Palaeozoic sediments, to the south. Gravity results indicate that the thick Upper Proterozoic sediments in the north-east Canning is a southward extension of similar sediments in the Ord-Victoria region.

The Canning Basin submerged at least by Ordovician times; Upper Proterozoic sediments were then probably the main sources of terrigenous sediments so characteristic of later sediments in the basin. Magnetometer and gravity data indicates that the sedimentary thickness in the north-east Canning are such as to indicate both a shelf and a hinge-trough environment. The shelf type is affected by even minor fluctuations of sea level, and disconformities in sedimentation may not occur in central or trough type areas of the basin. The environment in the centre of the basin is conjectural, but it was probably an area of continuous deposition rather than one with intermittent periods of denudation.

The major orogeny occurred prior to the deposition of the Upper Proterozoic rocks; a second orogeny folded both the Upper and Lower Proterozoic rocks before deposition began in the Palaeozoic. The intracratonic trough, in which Palaeozoic sedimentation proceeded, was a pronounced feature formed after the deposition of the Upper Proterozoic rocks.

A small orogeny took place before the Mesozoic, which resulted in an emergence or submarine erosion of the Permian rocks. Triassic sediments are affected by faulting and folding, but the laterite and Tertiary deposits have not been disturbed. Faulting was probably initiated after the Upper Proterozoic with renewed movement occurring along these old fractures.

GEOLOGICAL HISTORY.

The Lower Proterozoic Halls Creek Metamorphics were deposited in a geosyncline as evidenced by the large thickness of quartz-greywacke and slate; they underwent an intense orogeny with folding, faulting, granitic intrusion and metamorphism (although the degree of metamorphism is less than the equivalent rocks in the Halls Creek area).

The Metamorphics were eroded, almost to a peneplain before Upper Proterozoic sediments were deposited; in the Lewis Range area this peneplain surface dips 3° to the east.

The Upper Proterozoic sediments were deposited under uniform conditions, and Traves et al., (1956) suggested the source was from uplifted areas of granite and metamorphics which now forms a large part of the Canning Basin floor.

The Upper Proterozoic sediments, although not generally strongly deformed, have been intensely folded in the Halls Creek and King Leopold Mobile Zones, and the strongly folded Kearney Beds suggest an extension of these Zones to the south.

Erosion since the deposition of the Upper Proterozoic sediments has left them as large isolated ranges with surrounding plaines of sand underlain by Lower Proterozoic rocks.

The Canning Basin began to form in the Ordovician, with coarse-grained sandstone and conglomerate sediments deposited under shallow marine shelf-type conditions.

No Silurian rocks are known, in the sub-surface or in outcrop, from the Canning Basin, and none seem to have ever been deposited.

Devonian sediments, other than those in the main Fitzroy Basin, are only known in the north-east Canning, where small areas of sandstones of Upper Devonian (or Lower Carboniferous) age crop out near Knobby Hills and east of Balgo Mission. However, the Devonian biostrome and bioherm deposits of the Fitzroy could continue south-east into this area, and bioherms could develop along the trough-shelf junction or hinge which is suggested by gravity results, and which runs south-east through Mt. Bannerman Sheet (viz. in the Lake

Lonergan - Mt. Erskine area).

No Upper Carboniferous is known from the north-east Canning, but the Fitzroy Trough contains nearly 8000 feet of Upper Carboniferous (Mt. Anderson formation) in sub-surface, and some Upper Carboniferous might be expected in the south-east continuation of this trough into the north-east Canning.

Permian sedimentation began with aqueo or fluvio-glacial sediments of the Grant Formation, followed by alternating marine and brackish water sediments; the richly fossiliferous Noonkanbah Formation follows the Grant Formation with a hiatus only, and marine conditions continued during the basal Liveringa Formation (Balgo and Lightjack Members); then followed a period during which the lacustrine or brackish water plant-bearing Condren Sandstone was deposited, and marine conditions again prevailed, but of less extent, during the deposition of the Hardmen Member. The Condren and Balgo Members are widespread, and both may have overlapped the Noonkanbah Formation, and both certainly are in contact with the Grant Formation.

Erosion, and probably only gentle folding of the Permian sediments occurred before the Triassic Blina Shale was deposited in brackish to estuarine conditions; the plant-bearing Culvida Sandstone was deposited on the landward side, further to the east, and may have been (at least in part) contemporaneous with the Blina Shale.

Further erosion, and probably more folding and faulting occurred before the marine Cretaceous Godfrey Beds were deposited on the Culvida Sandstone and eroded Permian sediments (see fig. 26).

The faults (which were probably active until late Cretaceous or early Tertiary) and monoclinal folds are related to similar structures in the Fitzroy Basin; the Precambrian basement, its structure and topography, no doubt influenced the shape of the Canning Basin and the trend of folds and faults in the basin.

After, or even during the deposition of the Tertiary Lawford beds, the present period of erosion was initiated, with dissection of the laterite surface and the development of mesa and butte topography in the sediments.

ECONOMIC GEOLOGY.

Evaporites:

Deposits of evaporites are confined to the dry salt lakes and salt pans in the central and south-eastern portion of the area. The largest salt lakes occur on the eastern part of the Stansmore Sheet, and several of these lakes were crossed by the Bureau of Mineral Resources geological party in 1956.

The deposits on the bed of Gregory Salt Lake, consist predominantly of fine, white silt and powdery caliche with minor amounts of salt. On some small areas of the lake bed the proportion of salt is greater, particularly at the lake margin or where small streams flow into the lake. The fine, white silt covering most of the lake bed is derived from the suspended load of Sturt Creek, the largest stream draining into the lake.

Lakes Hazlett, Wills and White lying in Terry's (1934) Hidden Basin and Weston Basin, near the Western Australia - Northern Territory Border, present a shimmering picture of white salt. Samples of the saltcrust were collected to a depth of about three inches from the bed of Lake White. The top half inch consists of white, powdery, calcareous material which is underlain by a layer of salt crystals about two inches thick. Lumps of white, porous, homogeneous, calcareous travertine, up to six inches in diameter, are scattered on the soft caliche layer at the surface. Below the layer of salt crystals, soft brine-saturated sand and silt of unknown depth occur. The bed of Lake Lucas on the other hand has a very thin crust of salt, and below this thin beds of chocolate coloured sand and silt overlie the Lucas Beds; in this respect Lake Lucas differs from most other salt lakes, which are usually underlain by thick deposits of brine-saturated black mud and sand. In rare cases such as near S55, where a small arm of an unnamed salt lake was crossed, the foundation of the lake is quite hard. At S55 water had recently flowed on the lake surface and the top eighteen inches consisted of soft briny sand and silt underlain by cemented pebbly deposits.

Terry (1934) reported a sample from Lake Mackay to consist of 20.08% $CaSO_4$, 4.17% NaCl and 0.93% KCl.

On the margin of Lake Lucas near L18 a small deposit of pink barite was found. It occurs as a small line of boulders in weathered sandstone and shale of the Lucas Beds. The barite was probably deposited as a small lensing bed in the Lucas Beds.

Metallic Deposits:

No metallic deposits are being worked commercially within the area examined. Near the Gardiner Range, traces of gold were reported by Davidson (1905) from quartz veins cutting the Lower Proterozoic Halls Creek Metamorphics. The metamorphics are exposed at several localities underlying the Upper Proterozoic Gardiner Beds. The Halls Creek Metamorphics show few signs of hydrothermal action; quartz veins are only up to a foot wide and are not numerous. However, the area appears worthy of further prospecting particularly south-west and south of Larranganni Bluff and east of the Lewis Range. In both areas quartz veins are more numerous and considerable areas of granite occur; some crystalline hematite is associated with the quartz veins. The Halls Creek Metamorphics were tested in several areas with a Geiger counter but yielded no significant results. Green coloured Upper Proterozoic shales at the south end of the Gardiner Range were tested for radioactivity but also gave negative results.

Gold has been worked spasmodically since 1880 at the Ruby Queen mine 20 miles south of the old Halls Creek township. Numerous quartz reefs cut interbedded schists and quartzites and the lode varies from a few inches to 15 feet wide, and yield an average of 12 to 15 dwts per ton; depth of the workings are 200 feet. Total production has been 6,250 ozs.

Some manganese staining and a few pieces of solid manganese ore occur in granitised quartzites about 4 miles east of M35 on the Mt. Bannerman Sheet. Interpenetrating vuggy quartz veins are common here, and the rock is strongly sheared with cleavage trending north-east.

Petroleum Prospects.

The sediments of the north-east Canning Basin have almost the same chances of containing an oil pool as do those farther to the north-west, because the lithologies, sequence, structure and geological history are similar in the two areas.

In this area any continuation of Ordovician rocks from the Fitzroy Basin would probably be the best source rocks for petroleum. Ordovician calcareous source beds containing traces of petroleum crop out at Prices Creek (Guppy et al., 1958), 20 miles north-north-west of the north-west corner of the area. Possible Ordovician sandstone and conglomerate crop out in the Cummins Range area and west of the Wolf Creek Meteorite Crater. Devonian calcareous rocks within the basin may be source beds. Upper Devonian or Lower Carboniferous rocks that crop out at Knobby Hills may have suitable source rocks as their deeper water equivalents. The Permian sediments have no good source rocks except some shale beds in the Noonkanbah Formation.

Carbonate and sandstone reservoir rocks are known in the Ordovician, Devonian and Permian elsewhere in the Fitzroy Basin and probably extend into this area. Devonian reefs known in outcrop farther north-west are good reservoirs especially for petroleum migrating from the basin.

Shale cap rocks as are probably present in the pre-Permian rocks and are present in the Noonkanbah Formation and Blina Shale.

The "hinge", as evidenced from the gravity results near Lake Lonergan, may include areas of closed anticlines, and Ordovician and Devonian organic reefs may have developed along it. If, as seems likely, this hinge is the area dividing the shelf type sedimentation from the trough it is a very attractive area for petroleum exploration, combining drainage from a thick sequence of trough sediments (probably containing many source-bed formations) with structural relief on the shelf and the likelihood of reservoir rocks along the edge of the shelf.

Until more is known about the structural cause of many of the anticlines in the southern part of the north-east Canning (i.e. whether or not the folding persists with depth, or whether a basement uplift or salt intrusion has been responsible for their formation), they cannot be condemned as prospects; but the further south away from the Fitzroy Basin, the less attractive seem the chances in this part of the Canning Basin; but, a complete appraisal of this area of the Canning Basin is not possible until more detailed geophysical work has been carried out.

The main problems arising from the geological reconnaisance are (1) what is the subsurface configuration of the basement rocks and what is its effect on structure of the sediments, (2) whether pre-Permian rocks, particularly Ordovician and Devonian, occur beneath the Permian and Mesozoic sediments within the basin and if so, what is their distribution. The total thickness of Palaeozoic and Mesozoic sediments measured in this area amounts to only 3,000 feet, but the gravity information to date suggests that deep troughs are present with up to five times this thickness of sediment. Faulting is common in the area but no traces of oil seepages occur and no signs of oil in water issuing from springs and seepages along these faults was found.

The reconnaissance of this area has enabled elucidation of the stratigraphic succession and it will be helpful in establishing the geology of adjacent areas that may also be important for further petroleum prospecting.

Hydrology

The low rainfall and high evaporation has meant that full use must be made of underground, as well as surface water supplies. Surface waters in the area are very limited, and consist chiefly of the semi-permanent pools (Ima Ima etc.) in Sturt Creek on the Billiluna Sheet; this lack of good water has naturally restricted the pastoral development of the area. Sturt Creek is the largest stream draining the north-eastern part of the Canning Basin and flows inland into Gregory Salt Lake. Other streams, such as Christmas Creek and its tributaries, drain the breakaway country south of Christmas Creek Station, and Derbai Creek drains the area near Balgo Mission. In some places, small earth tanks have been constructed next to the stream courses to provide a better water supply. Small rock holes in the desert area are used by a few nomadic aborigines and Breadens Pool is used by stock on the Canning Stock Route. Godfreys Tank is another large rock hole near Breadens Pool but it is too inaccessible for stock. The rock holes in the Godfrey area have been formed by deep dissection and scouring of the softer sandstone and shale which underlies the more massive sandstone here. When full, Breadens Pool holds about 20,000 gallons and Godfreys Tank 40,000 gallons. Probably the largest stretch of surface water is Ima Ima Pool, six miles above the junction of Sturt Creek with Wolf Creek, and is sometimes over 3 miles long and up to half a mile wide. Lake Stretch is a similar smaller pool 10 miles south of Billiluna Homestead.

Numerous springs occur in the Permian sediments south of Christams Creek (e.g. McDonald Spring) and they seem to be controlled by small faults cutting these sediments. The water from these springs is alkaline, but is good for stock. Other springs occur in the Upper Proterozoic sediments in the Gardiner Range (Brophy Spring) and in the Denison Range (Palm or Banana Spring).

Underground water has been used for stock, particularly along the Canning Stock Route, and a subsidiary stock route between Christmas Creek Station and Godfreys Tank. These wells have struck good supplies of water generally at depths from 20 to 80 feet, mostly in Permian sediments. Details of these wells, some of which are taken from Canning's original Stock Route map, are as follows:

Well No.	Depth (feet)	Supply gals./hr.	Remarks
44	43	1000	Excellent water
45	28	1000	" "
46	?	2000	" "; called Kuduarra Well.
47	24½	1500	" "
48	65½	130	Excellent water in friable white sandstone, water level 55 feet in 1955. Caved in 1957.
49	50	500	Excellent water in sandstone with Tertiary chalcedony nearby. Water level 30'. Grave of Jack Smith, died 1939.
50	62	500	Excellent water.
51	22	900	Poor quality water; gypsum and travertine nearby. Water level 15' but fallen in; called Weriadoo.

Well No1 on the stock route from Christmas Creek to Well 49 has a water level of 46 feet and excellent water; pisolitic ironstone is on the surface, with spoils of fine to medium friable sugary sandstone, micaceous, ripple marked with clay pellets and worm trails; a native soak is nearby.

The spoils from Well 51 are largely hard sandy clay with large amounts of gypsum, which are probably part of the evaporite deposits in Gregory Salt Lake. The well is very close to samphire-covered marshy areas next to the salt lake.

Wells and bores sunk in the Noonkanbah and Balgo units, near Balgo Mission, have yielded poor supplies of poor quality water; the water is generally saline or alkaline, and in most cases, is unsuitable for human consumption. Better bore sites are available in older sandstone beds, east of the Mission near Kearney Range. The Noonkanbah and Balgo units often have a salt encrustation on weathered outcrops. The old well at Dooma Dora has a water level of 60 feet.

Billiluna Station has several good sub-surface water supplies. The bore at the homestead gives a good supply of fresh water from the Grant Formation and overlying sands; total depth of the bore is 120 feet. Good water is obtained from No.2 bore, probably also from the Grant Formation, and from the well at Old Billiluna Station (probably from the Condren Sandstone or Balgo Member). Djaluwon Bore is probably in the Balgo Member. Limestone Well is 36 feet deep and sunk in Tertiary limestone and travertine with bands of chalcedony; the water was struck below a "hard band" at 29 feet; it is salty (600 grains per gallon) and suitable only for sheep and cattle, not horses. Chungla Well is 30 feet deep, with a water level at 6 feet, but during the wet season, the water reaches the surface; it is sunk in travertinous sandstone or "river sand". Many shallow (less than 15 feet) salt bores were drilled near Nully Waterhole, where white sand occurs on the surface.

On Sturt Creek Station some good supplies of water are obtained from the Gardiner Beds, but several dry or salty bores result in areas where shale, presumeably in the Gardiner Beds sequence, has been encountered. Sturt Creek Dud No.8, 12 miles south-south-east of the homestead (near B13) struck salt water; the spoils are calcareous reddish brown shale, and chalcedony has been used to pack around the bore hole. Dud No.9 is 16 miles south-south-east of the homestead, and struck salt water in brown shale at 257 feet. A 300 feet dud, 7 miles from the homestead on the direct road to Flora Valley, struck salt water at 60 feet. Another salt water dud, 300 - 400 feet deep is on a black soil plain north of Bindi. A dud bore, about 40 miles from the homestead on the middle road to Flora Valley reached 300 feet in "blue rock" - probably basalt. Sturt Creek 26 mile bore is 160 feet deep and has a good supply. The semi-permanent pools in Sturt Creek help to alleviate the water shortage resulting from the unsuccessful drilling.

ACKNOWLEDGEMENTS.

The authors wish gratefully to acknowledge the hospitality and assistance given to the party by the various station managers within the area, and the staff at the Balgo Mission. In particular, thanks are due to Mr. Len Brown of Billiluna Station, and Father Kearney of Balgo Mission.

The four-mile photo-mosaics used for the map compilation were prepared by the National Mapping Division of the Department of National Development from vertical airphotos taken by the R.A.A.F. in 1949 (Billiluna and Mt. Bannerman) and 1953(Cornish, Lucas, Stansmore) at a scale of 1 : 50,000.

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APPENDIX A

PLANT FOSSILS FROM THE NORTH-EAST CANNING BASIN, WESTERN AUSTRALIA.

by Mary E. White.

A large collection of some two hundred plant fossil specimens was made in the north-east Canning Basin of Western Australia by J.N. Casey and A.T. Wells of the Bureau of Mineral Resources in 1956, from beds of Palaeozoic and Mesozoic age. Some of the material is excellently preserved and of considerable botanical interest.

An account follows of the species of plants which can be identified from the various localities and of the age determinations which are possible from a study of the flora.

All specimen numbers mentioned (e.g. L10) are marked on the individual four mile to one inch sheets.

Locality L.10. Specimens no. F 21581.

An Equisetalean stem cast showing three nodes at 1½-2cm intervals and with about 14 vertical ridges to the 1.75cm width, is referred tentatively to Phyllotheca cf. australis Brongn. The preservation is poor and the fossil is a pith cast. No age determination is possible.

Locality B.2. Specimens no. F 21582.

The stem impressions which occur in these specimens are indeterminate.

Locality B.4. Specimen no. C.P.C. 2835 (Figure 1, Plate 2).

This specimen shows an impression of a stem with a regular rhombic pattern similar to that seen in Leptophloeum australe (M'Coy). Leaf trace scars are present in the upper angles of the rhombs. The specimen represents a slightly decorticated form and is similar to commonly occurring decorticated forms of Leptophloeum australe. With only the one specimen available it is not possible to give a positive identification as Leptophloeum australe (M'Coy).

In lepododendroid fossils different species can and do have similar decorticated forms. It is unwise to attempt a positive identification on a single specimen unless that specimen shows a surface view of a mature stem. The present specimen is therefore assigned only doubtfully to Leptophloeum australe (M'Coy). L. australe is a most typical Upper Devonian-Lower Carboniferous plant fossil; it is not definitely known above the Lower Carboniferous.

At the present state of knowledge therefore, the fossil in specimen no. C.P.C. 2835 must be dated by other means if possible and cannot be used itself as a reliable indicator of age.

Locality B.14. Specimens no. F 21583

The stem impression occurring in this coarse-grained sandstone is indeterminate.

Locality B.24. Specimens no. F 21584

These specimens contain one determinate fossil which is referred to Vertebraria sp., cf. V. indica Royle. Figure 2. Plate 1, Specimen C.P.C. 2844. This specimen resembles closely specimens of Vertebraria indica from the Lower Gondwana series in the Raniganj field. (Plate XIV A, Pal. Indica III). The range of this type of fossil is Permian. Vertebraria is usually present with Glossopteris, and is believed to be part of the rhizome of Glossopteroid plants.

Locality B.25. Specimens no. F 2185

The plant remains in these specimens are largely fragmentary and indeterminate. Two identifications are possible:-

1. On seed of the Samaropsis type is present. (Figure) C.P.C. 2845. The dimensions of this oval seed are 10mm long with a maximum width of 8mm. The apex is divided for 4mm, and there is a prominent median ridge below. Faint striations are visible on either side of the central ridge. The species is not determinate, but this type of seed is common in Permian horizons.

Samaropsis sp.

NATURAL SIZE

Fig 1

2. A fragment of leaf referable to Noeggerathiopsis hislopi (Bunb.) showing the characteristic strong parallel venation is present. This is a Permian plant fossil.

Locality B.29. Specimens no. F 21586

Several indeterminate wood and stem impressions occur in these specimens. A tentative determination of an impression with strong parallel venation as a portion of a leaf of Noeggerathiopsis suggests a Permian or Carboniferous age for the specimens.

Locality L.11. Specimens no. F 21587

The layer of shale in these specimens is highly fossiliferous but there is a great deal of powdery iron-rich material incorporated which has largely obliterated details. The plant remains are mostly indeterminate but fragments of leaves occur which show venation characteristic of Glossopteris. There is a recognisable portion of a scale leaf of the Glossopteris type in one specimen.

The age of these specimens is Permian.

Locality M.5. Specimens no. F 21588

Some of these specimens show only indeterminate plant remains. Others show leaf impressions referable to Glossopteris cf. indica, but insufficiently preserved for accurate determination. There is one clear example of a seed of the Carpolithus type. (Figure 2). Spec. C.P.C. 2846. The degree of preservation is insufficient for specific determination.

The age of these specimens is Permian.

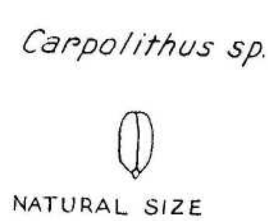


Fig.2

Locality M.6. Specimens no. F 21589

Two lepidodendroid type of stem impressions are present in these specimens. C.P.C. 2847. They are both of small areas of Lycopod stems. Figures 3 and 4, Plate I.

They show leaf cushions which are horizontally extended. One impression has roughly the appearance of a cone with a stem portion below but this arrangement seems to be coincidental as there are leaf trace scars on each cushion in the upper obtuse angle, and this feature is inconsistent with any arrangement seen in a surface view of a cone. The other impression is slightly decorticated and each cushion has a central pit for the leaf trace bundle.

Both impressions are assigned tentatively to Lycopodiopsis pedroanus Carr. which is a Lower Permian Lycopod which occurs associated with the Glossopteris flora in South Africa, Brazil, and Western Australia (Poole Range, Edwards, 1952). There is insufficient material in this case for the identification to be completely positive.

Locality M.18. Specimens no. F 21590

Badly preserved and largely indeterminate leaves similar to Glossopteris indica and Gangamopteris cyclopteroides occur in these specimens, denoting a Permian age.

Locality L.44. Specimens no. F 21591

Glossopteris indica Sch. (Spec. C.P.C. 2848 and 2851) and Glossopteris communis Feist. (Spec. C.P.C. 2849) occur together in these specimens, (Figures 6,7 and 8, Plate II) and association similar to that which occurs in the Raniganj Flora in India. Vertebraria australis M'Coy (Figure 5, Plate I, C.P.C. 2850), is present and also leaves determined as Gangamopteris cyclopteroides Feist. Vertebraria is believed to be part of the rhizome of Glossopteroid plants and is usually associated with Glossopteris leaves. The specimen of G. communis is unusual as the midrib is very broad.

The flora in these specimens is a typically Permian assemblage.

Locality M.23. Specimens no. F 21592

These specimens contain most interesting plant fossils in an excellent state of preservation. Equisetalean stems, of the Schizoneura type (with no alternation of ridges at nodes) are present alone in some specimens (Figure 10, Plate II, Specimen C.P.C.

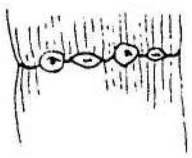


Fig 3

Node of Schizoneura

Specimen C.P.C. 2852) and associated with wide wrinkled stems in others. The genera Phyllotheca, Schizoneura and Equisetites are all very similar in the appearance of their stem casts. Text Figure 3 shows a node of a stem of the species with an arrangement of branch scars most typical of the species. (Specimen C.P.C. 2853).

Transversely wrinkled Lycopod stems (Figure 11, Plate III.) are present as casts and impressions, Specimens C.P.C. 2854. They resemble Lycopodiopsis referred to by Edwards (1952).

It is possible that they should be referred to the Triassic Lycopod genus Pleuromeia, which also has wrinkled stems. However, Dr. A.B. Walkom, whose opinion was sought, does not think these stems can be referred to Pleuromeia. He regards the impressions as pith casts of a Cycad and says they are similar to specimens examined by him from Jurassic strata of Western Australia where they were associated with typically Jurassic plants. He refers the stems to Artisia alternans Lignier, although none of Lignier's example are as wide as the present stems.

Locality M.24. Specimens nos. F 21593, C.P.C. 2855.

Winged seeds of the Samaropsis type occur plentifully in a zone in these specimens. There appear to be three distinct species. The smallest variety, A. in Text Figure 4, have a roughly circular wing with a slight point above, and are emarginate below. The seed portion is diamond-shaped with a circular inclusion and is situated slightly below the centre point of the wing. This seed with its relatively large wing is similar to Samaropsis moravica (Helmhacher) which is a very common Permian and Upper Carboniferous type in Europe.

Far larger winged seeds, B. in Text figure 3, occur in the specimens. These are probably referable to Samaropsis milleri Feist.

A third type of winged seed has marked radiating striations on the wings and has not been identified.

Numerous small spherical bodies, E. in Text figure 4, occur in some of these specimens (Spec. no. C.P.C. 2856). Their average diameter is 1mm and the degree of preservation is insufficient for any determination to be made. These small bodies may be seeds but could possibly be fresh water Ostracods. (P. Jones, personal communication.).

Indeterminate Equisetalean type stem fragments and linear impressions which seem to be roots are present and there are a few scale leaves, D. in Text figure 4, of the Glossopteris type.

The age of these specimens appears to be uppermost Carboniferous or Permian.

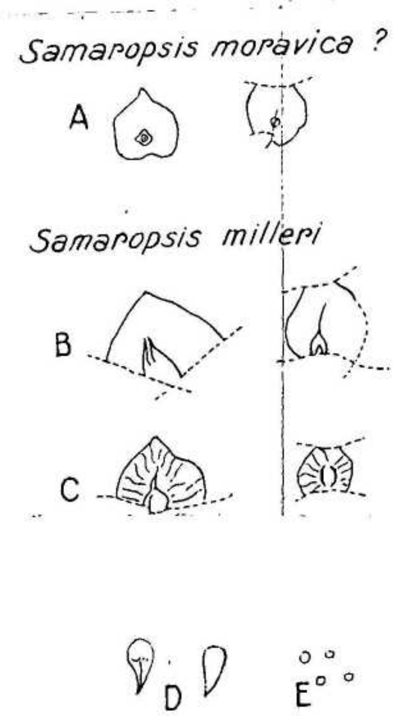


Fig. 4.

Locality M.30. Specimens no. F 21594.

Well preserved leaves of Gangamopteris cyclopteroides Feist. occur in these specimens, (Figure 9, Plate II. Specimen C.P.C. 2857) associated with Glossopteris indica Sch. and Glossopteris communis Feist., denoting a Permian age. Small triangular scale leaves referable to Glossopteris are also present.

Locality M.47. Specimens no. F 2195.

Gangamopteris cyclopteroides Feistm., Glossopteris indica Sch., Glossopteris communis Feistm. and Glossopteris scale leaves (C.P.C. 2858) denote a Permian age for these specimens.

An organ, believed to be a large seed or a fruit, is illustrated in Figure 12, Plate III, C.P.C. 2859. It is over an inch in length, and is half an inch wide at the middle. The affinities of this specimen are uncertain.

Locality C.1. Specimens no. F 21596.

Equisetalean stems referable to Schizoneura sp. are the only determinate plant remains in these specimens. They denote a Permo-Triassic age for the specimens.

Locality C.6. Specimens no. F 21597

No determinate plant fossils are present in these specimens.

Locality C.7. Specimens no. F 21598

Indeterminate roots are present in these specimens and give no indication of the age of the rocks.

Locality C.46. Specimens no. F 21599

Fragments of leaves of Glossopteris indica Sch. and an Equisetalean stem fragment referable to Schizoneura denote a Permian age for the specimens.

Locality C.3. Specimens no. F 21600

A stem of Brachyphyllum sp. is present with two other indeterminate stem casts in these specimens. The presence of Brachyphyllum suggests an age younger than Permian.

Locality L.35. Specimens no. F 21601

Triangular cone scales of Araucarites, of the same general type as Araucarites cutchensis, occur in these specimens. (Figure 13, Plate III, CP.C. 2860). Cone scales of this type have a wide range from Triassic strata. It is possible that such scales could have been borne by Late Permian Conifers, but there is no evidence of their association with such forms, and the distribution is generally assumed to be Triassic-Jurassic.

Locality M.12. Specimens no. F 21602

Indeterminate stems occur in these specimens and there is no indication of their age.

Locality M.15. Specimens no. F 21603.

A cone scale, Specimen C.P.C. 2861, of Araucarites sp. distinct from that present at locality L.35, is associated with indeterminate roots in these specimens. The age as indicated by the cone scale is probably Triassic - Jurassic, or possibly from Late Permian. (Figure 14, Plate IV).

Locality M.29. Specimens no. F 21604

The following identifications of plant fossils have been made in these specimens:-

1. Small portions of a frond of a fern Stenopteris elongata Carr. (figure 15, Plate IV). This fern has a Triassic - Jurassic distribution and occurs in the Ipswich and Walloon Series in Queensland. C.P.C. 2862.

2. Very large fronds, in an excellent state of preservation of Dicroidium feistmanteli (Johnston) Gothan (Figure 16, Plate IV) Age Triassic - Jurassic. C.P.C. 2863.

3. Large leaves of a frond referable to Danaeopsis hughesi Feist. (Figure 17, Plate V. Specimen C.P.C. 2864). This species occurs in Rhaetic strata in Australia, South Africa and India.

4. Equisetalean stems in the form of casts and impressions. Some of these stems are large, with a flattened diameter of about three inches. The ribs do not alternate at the nodes. (Figure 19 and 20, Plate V. C.P.C. 2865). These stems are referred to Equisetites sp. on the evidence of the cones and leaf sheaths associated with them.

5. Equisetalean Cones (Figure 18, Plate V. Specimen C.P.C. 2866). These cones appear to be referable to Equisetites woodsi Jones and Jersey which occurs in Jurassic strata in Queensland. They are associated with Equisetalean leaf sheaths similar to those found with Equisetites woodsi in the Brighton Beds, Queensland.

6. Equisetalean Leaf Sheaths. (Figure 21, Plate V. Specimen C.P.C. 2867). The evidence of the cones and leaf sheaths in association with the Equisetalean stems suggests that the stems should be referred to Equisetites.

The age of these Equisetalean fossils is most probably Late Triassic - Jurassic.

7. Cycadolepis sp. These thin, bract-like leaves have been wrinkled transversely during preservation. (Figure 22, Plate V. Specimen C.P.C. 2868). They are of a type common in the Late Triassic and Jurassic eras.

8. Fronds of the fern Callipteridium stormbergense Sew. (Figure 23, Plate VI. Specimen C.P.C. 2869). One portion of the frond shows the main rachis and this bears pinnules. The v nation is of the Cladophlebis type as far as can be seen.

This is a fern with a Rhaetic distribution.

9. An obsure form similar to the problematical "Eury-Cycadolepsi from the Wealden Beds in England occurs in specimen C.P.S. 2870, fig. 25, plate VI; it shows two woody organs with what appears to be a cork layer exposed by partial decortication. The nature of these organs is uncertain, but they seem most likely to be woody bract structures attached to a stem.

A study of the flora from Locality M.29 suggests that the age of the plant-bearing beds is uppermost Triassic, or represents a transition from Upper Triassic to Lower Jurassic.

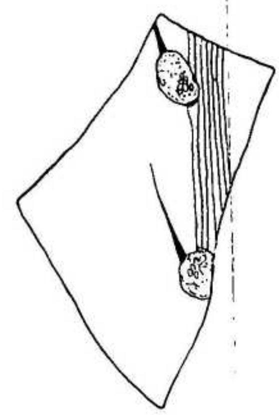
Locality C.8. Specimens F. 21605, C.P.C. 2871, 2871a.

In the specimens from this locality a few examples of fragments of fronds of Dicroidium odontopteroides (Morr) Gothan are present with small portions of leaves of Taeniopteris sp. denoting a Rhaetic or Jurassic age.

The majority of the plant remains, however, appear to be referable to a single species of Equisetites. They are all fragments of a small herbaceous Equisetalean in a highly fertile state. (Figure 26, 27,28,29, Plate VII).

Stem impressions vary from 3 - 10 mm in width and most show strong vertical ribbing. There is no indication of noding of the stems. A few of the stem impressions, as in figs. 27 and 28, show no surface ribbing and these have a ribbon-like appearance with slightly undulating margins. The leaf-like appearance of several of these ribless impressions is striking and some show a median groove like a midrib.

Fig 5.



Two cones in axes of bracts or leaves.

Small cones are present in numbers, attached to the stems and fossilised separately. The diameter of the cones is from 2 - 5 mm. Complete examples suggest that each is composed of an aggregation of oval bodies. Some of the cone impressions show a central hollow and in these cases the cone seems to have been broken off partially. There is one case where two cones are borne laterally on a stem in the axes of needle-like bracts or leaf sheath segments. (Text fig. 5, C.P.C. 2871a). This appears to be an unrecorded species of Equisetites.

Locality C.31. Specimens no. F 21606

The following plant species occur at this locality, denoting a Triassic or Jurassic age for the fossil horizon:-

1. Equisetalean Cones. (C.P.C. 2872. Figure 31, Plate VIII).

These cones are similar to those referred to Equisetites woodsi Jones and de Jersey from Jurassic strata in Queensland. Unidentified cones of this type are illustrated from the Rajmahal beds in India (Jurassic) by Feistmantel (1877).

2. Equisetalean stem fragments.

3. Fragments of leaf of Yabiella ? and Thinnfeldia sp.

4. Linear leaves and "cones" are present as from locality C.8. and referred to as Equisetites sp. nov.

Locality C.62. Specimens no. F 21607

The specimens from this locality are mainly well preserved and the age as determined by the flora is Upper Triassic or Jurassic.

1. Specimens of Dicroidium odontopteroides (Morr) Gothan are present. (Figure 30, Plate VIII, C.P.C. 2874). Dicroidium is regarded by Townrow (1957) as indicating a middle Triassic, not Rhaetic age as previously believed. It persists into the lower Jurassic but with a flora different from the present time.
2. An impression of a cone, Figure 32(A) Plate VIII, C.P.C. 2873, is referred to the genus Lycopodites. In the absence of material sufficiently preserved for detailed study only a tentative determination can be made. Lycopodites has been recorded from the Walloon Series in Queensland.

3. Linguifolium sp. A terminal portion of a leaf with undulating margins and a very clear venation of the Linguifolium type is seen in specimen C.P.C. 2873, Figure 32(B). Plate VIII. It is imilar to Linguifolium denmeadi which also occurs at this locality.

4. Linguifolium denmeadi Jones & de Jersey. Specimen C.P.C. 2875.

5. A leaf of Ginkgoites antarctica Saporta is seen in specimen C.P.C. 2876. Figure 33, Plate IX. Range Rhaetic - Jurassic.

6. Pinnules of a frond of Danaeopsis hughesi Feist. occur in specimen C.P.C. 2877. (Figure 34, Plate IX.). The range of this species is Rhaetic - Jurassic.

7. Indistinct impressions which appear to be referable to Baiera sp. occur in specimen C.P.C. 2878. (Figure 35, Plate IX.). Each frond has much contorted laminal segments attached to the top of the rachis.

Locality C.63. Specimen no. F 21619

Specimens from this locality show indeterminate stem impressions. Some possibly with Equisetalean affinites, and no age determination is possible.

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(iii)

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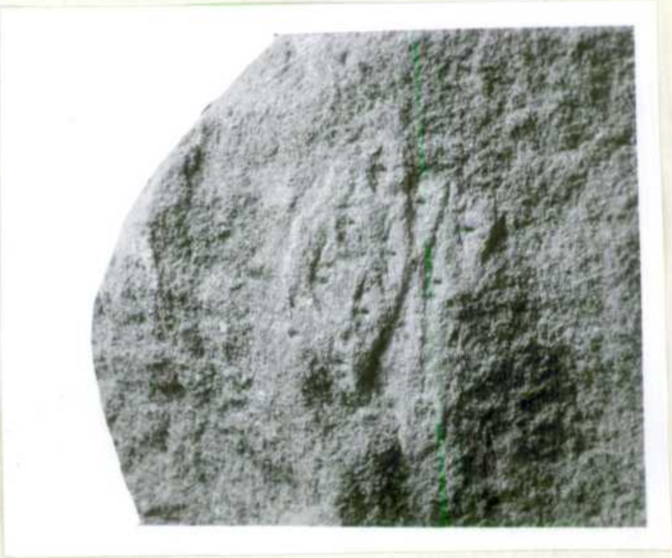
PLATE I.

Fig. I: Leptophloeum australe (M'Coy) ? Loc. B.4. C.P.C. 2835. Decorticated stem impression.

Fig. 2: Vertebraria sp. Loc. B.24. C.P.C. 2844.



Figs. 3 & 4: Lycopodiopsis pedroanus Carr. ? C.P.C. 2847. Locality M. 6.

Fig. 5: Vertebraria australis M'Coy. Loc. L.44. C.P.C. 2850.

PLATE II.

Fig. 6: Glossopteris indica Sch.
C.P.C. 2848. Loc. L.44.

Fig. 7: Glossopteris indica Sch. C.P.C. 2851.
Loc. L.44.

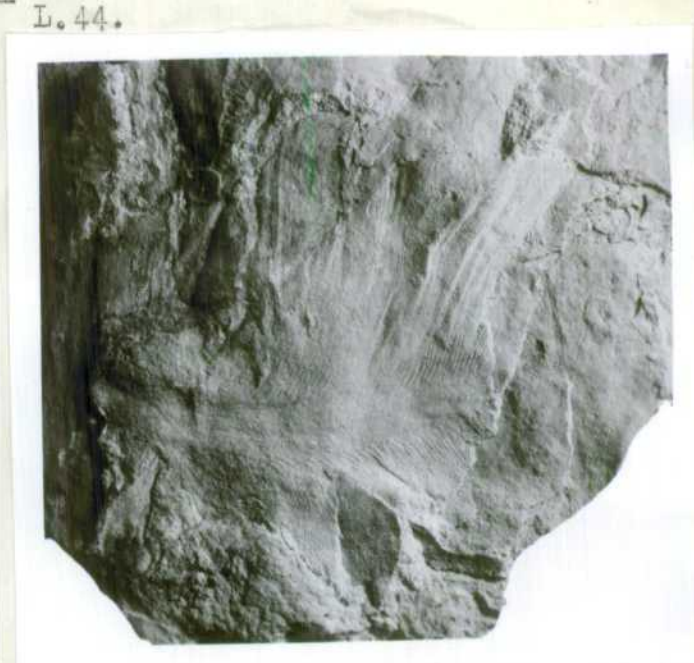


Figure 8: Glossopteris communis
C.P.C. 2849. Loc. L.44.

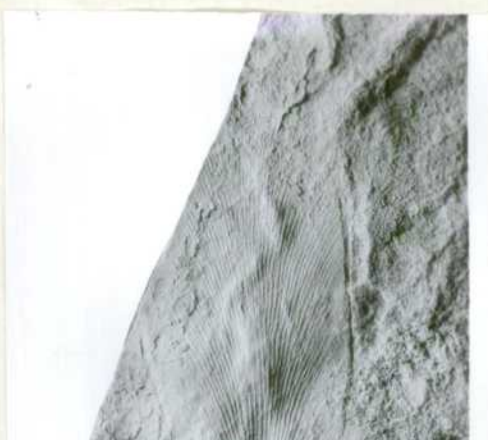


Fig. 9: Gangamopteris cyclopteroides Feist. Loc. M.30.
C.P.C. 2857.

Fig.10: Schizoneura

Approx. ½ size. Loc. M.2
C.P.C. 2852.

PLATE III.

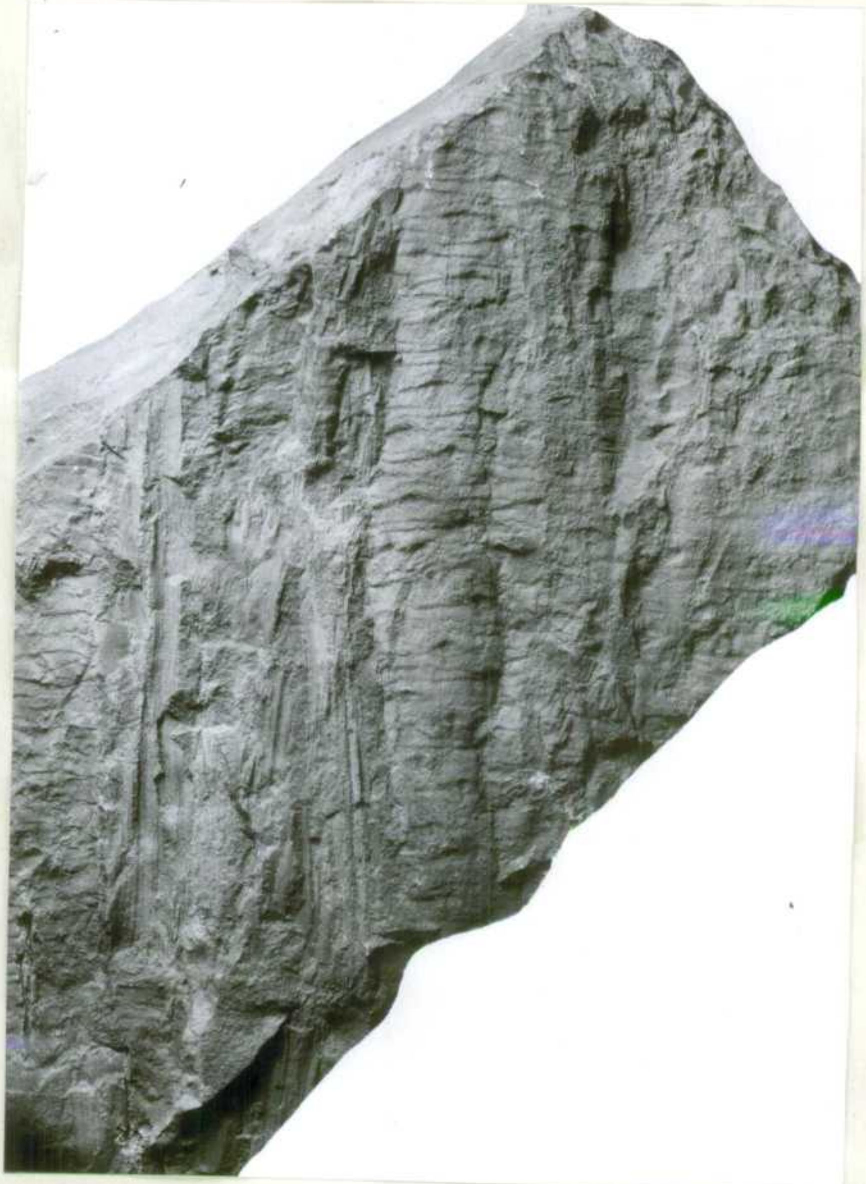


Fig.11: Lycopodiopsis sp. Transversely wrinkled Lycopod stems with Equisetalean Stems.
Loc. M.23. C.P.C. 2854.

Fig.12: Large Winged seed or fruit ?
C.P.C. 2859.
Loc. M.47.

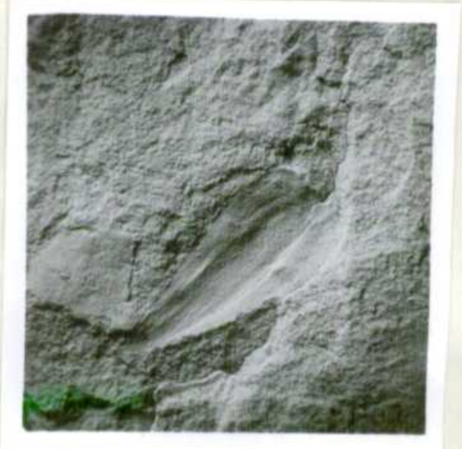


Fig. 13: Araucarites sp.
Cone scale.
Loc. L.35.
C.P.C. 2860.

PLATE IV.

Fig. 14: Araucarites sp.
Cone scales.
C.P.C. 2861.
Loc. M.15.

Fig. 15: Stenopteris elongata
Carr. C.P.C. 2862.
Loc. M.29.

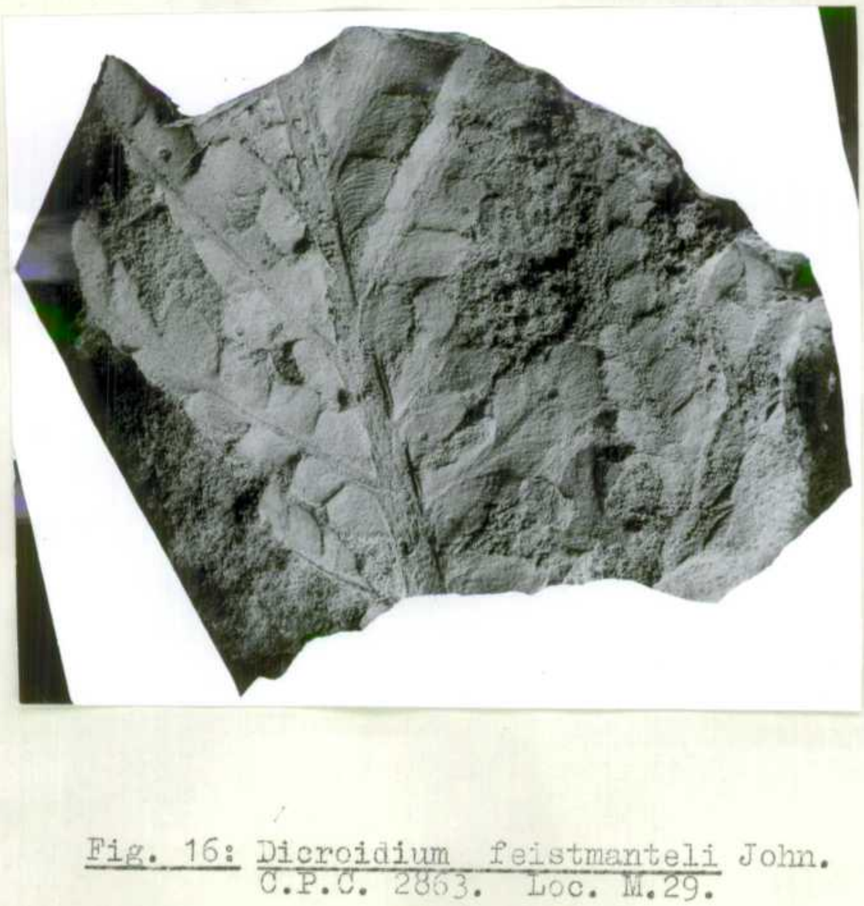
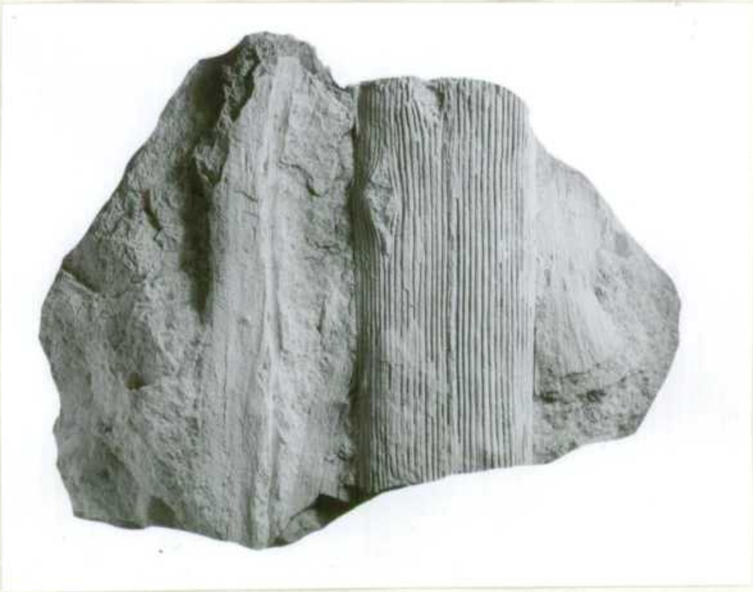


Fig. 16: Dicroidium feistmanteli John.
C.P.C. 2863. Loc. M.29.

PLATE V.

Fig. 17: Danaeopsis hughesi Feist.
C.P.C. 2864. Loc. M.29.

Fig.18: Equisetalean Cone. X3.
C.P.C. 2866.
Loc. M.29.



Figs. 19 & 20: Equisetalean stems.
C.P.C. 2865. Loc. M.29.

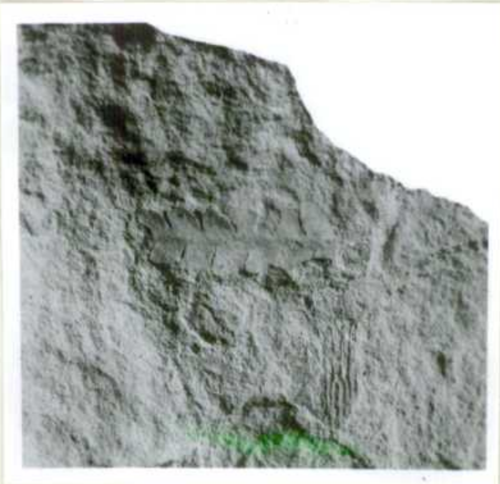


Fig.21: Equisetalean leaf sheath with Thinnfeldia pinnules.
C.P.C. 2867. Loc. M.29.

Fig. 22: Cycadolepis.
C.P.C. 2868.
Loc. M.29.

PLATE VI.

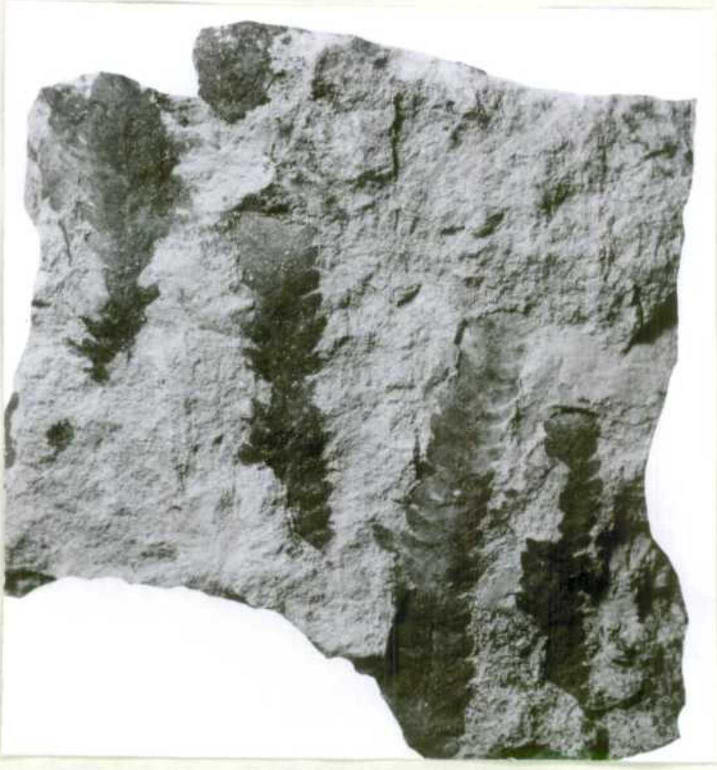


Fig. 23: Callipteridiym stormbergense Sew.
C.P.C. 2869. Loc. M.29.

Fig. 24: Callipteridium stormb-
ergense Sew.
C.P.C. 2869. Loc. M.29.
Pinnules on rachis.

Fig. 25: Eury - Cycadolepis.
C.P.C. 2870.
Loc. M.29.

PLATE VII.

Fig.26: Equisetalean stem with cone attached. X 2. C.P.C. 2871. Loc. C.8.

Figs. 27 & 28: Stems without ribbing. C.P.C. 2871. Loc. C.8. X 2.

Fig. 29: Equisetalean stems with cones attached. C.P.C. 2871. Loc. C. 8. X 2.

PLATE VIII.

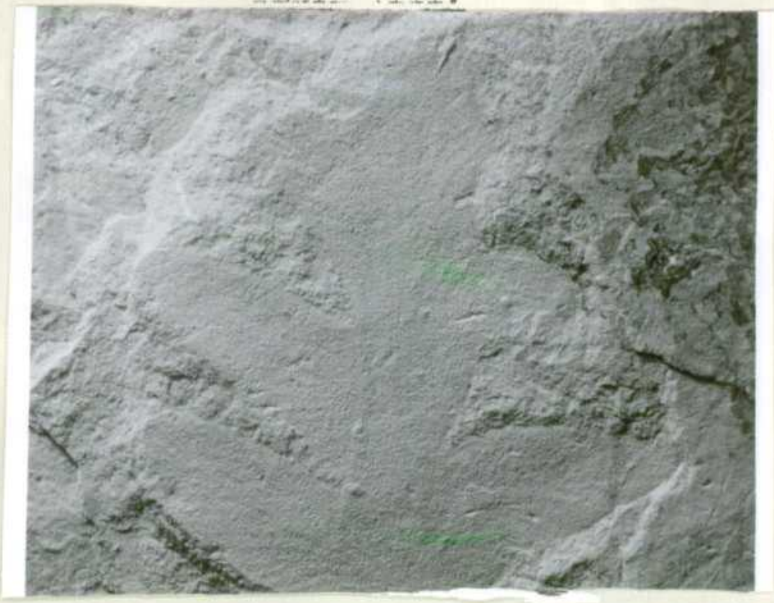


Fig. 30: Dicroidium odontopleroides (Morr.) X3.
C.P.C. 2874. Loc. C 62.

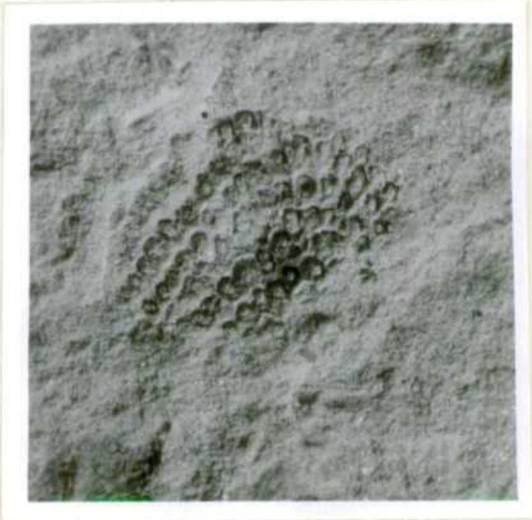


Fig. 31: Equisetalean Cone.
C.P.C. 2872.
Loc. 31. X3.

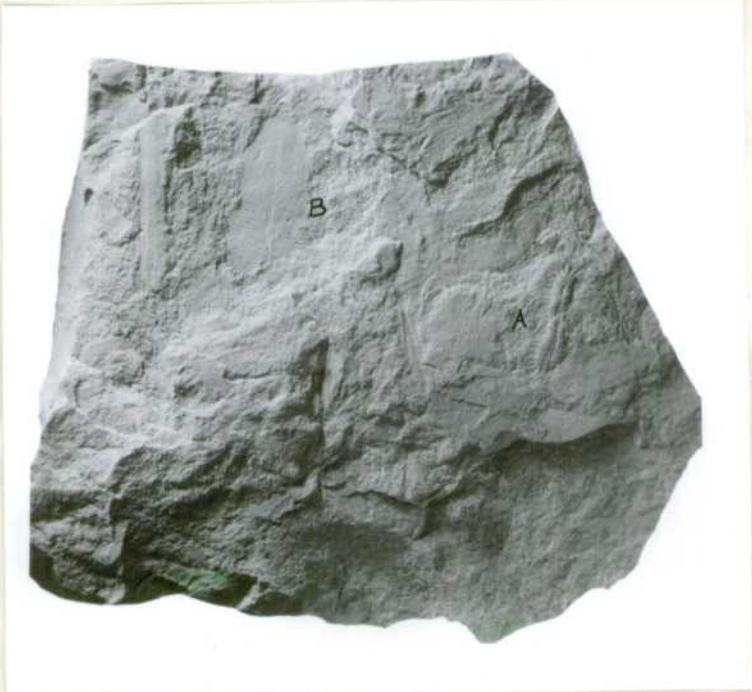


Fig. 32: A. Cone of Lycopodites.
B. Leaf of Linguifolium ?
C.P.C. 2873. Loc. C. 62.

PLATE IX.

Fig. 33: Ginkgoites antarctica Saporta.
C.P.C. 2876. Loc. C 62.

Fig. 34: Danaeopsis hughesi Feist.
C.P.C. 2877. Loc. C 62.

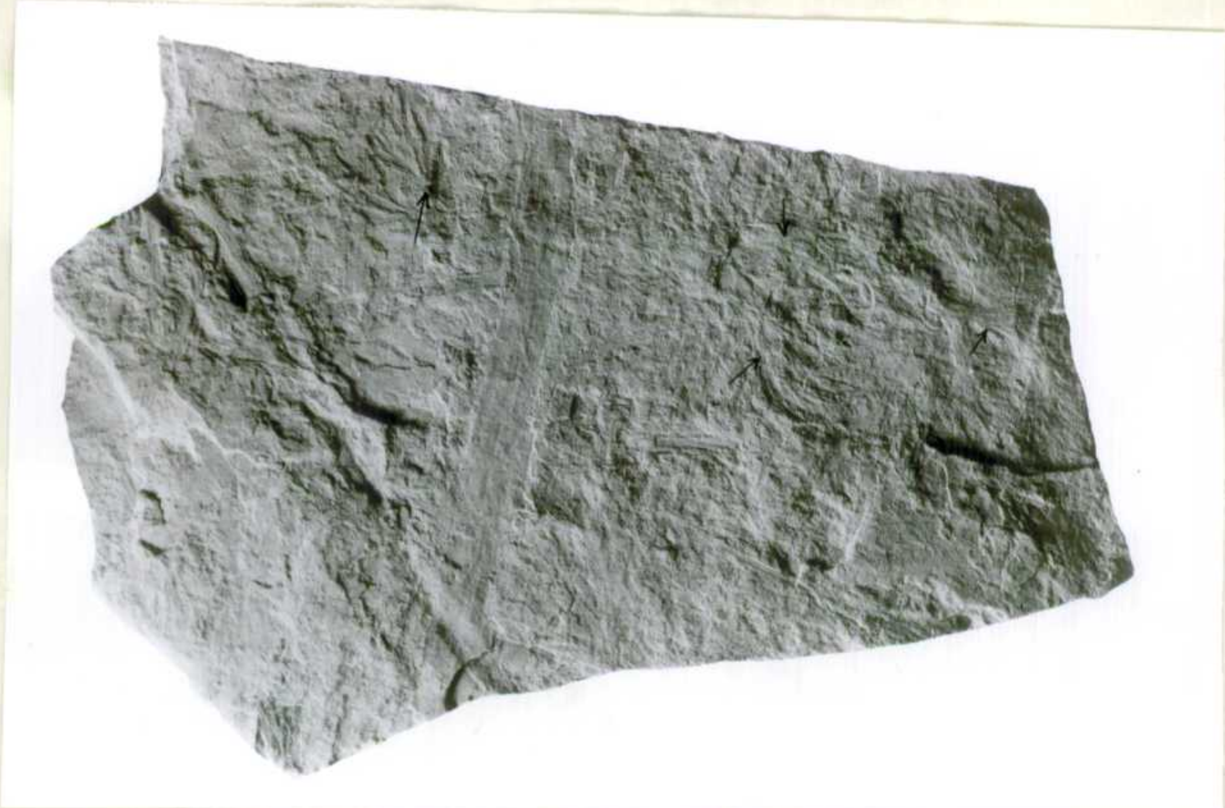


Fig. 35: Baiera sp. ?
C.P.C. 2878. Loc. C 62.

APPENDIX B.

PERMIAN FOSSILS FROM THE CANNING BASIN, WESTERN AUSTRALIA.

by

J. M. Dickins

INTRODUCTION

The fossils were collected by Bureau field parties in 1955 (J.N. Casey and A.T. Wells) and in 1956 (B.H. Stinear and A.T. Wells). All the samples are from the north-eastern part of the Canning Basin.

The localities are considered in order of stratigraphical position according to information supplied by the field parties. In many cases the preservation is so poor, or the collections so small, that it is not possible to indicate any correlation within the Permian. The correlations based on the diagnostic samples show agreement with the stratigraphical positions supplied. The Balgo Member can be correlated with the Lightjack Member of the Liveringa Formation and is thus of Upper Artinskian to Kungurian age.

IDENTIFICATIONS

Doubtful Grant Formation

M.44 (Long. 126°27', Lat. 18°58').

Unidentifiable shell fragments.

Noonkanbah Formation

B.21 (Long. 127°50', Lat. 19°55').

Brachiopods: "*Chonetes*" sp. (sulcate form)

Gastropods: *Bellerophon* sp.

These fossils at present, are of little value for correlation.

B.22 (Long. 127°51', Lat. 19°55').

Brachiopods: "*Chonetes*" sp. (sulcate form)

Pelecypods: "*Heteropecten*" sp. nov.

"Heteropecten" sp. nov. is common in the Cundlego Formation of the Carnarvon Basin and some specimens from the Wandagee Formation can be doubtfully referred to it. It has not been found in higher beds and this is the first record in the Canning Basin. The present occurrence would suggest these beds are equivalent in age to the top part of the Noonkanbah Formation.

L.4 (Long. 127°56', Lat. 20°12').

Gastropods: Bellerophon sp. ind.

The fossils in this sample are of no value for correlation.

L.29 (Long. 127°54', Lat. 20°8', 2¼ miles east-north-east of Balgo Mission).

Brachiopods: "Chonetes" sp. ind.

Pelecypods: Streblopteria? sp., cf. S?. sp. nov. from the Noonkanbah Formation.

S? sp. nov. has been found to be an important marker fossil for distinguishing the Noonkanbah Formation from Lightjack Member (lower part) of the Liveringa Formation in the Fitzroy Basin. Unfortunately the present specimens cannot be certainly identified as S? sp. nov., but as no similar species is known to occur in the Permian rocks of Western Australia it seems likely that these beds are of the same age as the Noonkanbah Formation.

Doubtful Noonkanbah Formation.

C.47 (Long. 127°13', Lat. 20°57').

Pelecypods: Edmondiidae gen. et sp. ind., Atomodesma sp. ind., Stutchburia muderongensis Dickins 1956

Gastropods: Bellerophontacea gen. ind.

In samples from the Canning Basin, whose stratigraphical position is known without doubt, S. muderongensis is known only from the Lightjack Member. In the Carnarvon Basin, however, S. muderongensis occurs not only in the Coolkilya Greywacke but also in the Norton Greywacke which is regarded (Thomas and Dickins, 1954, p.220) as older than the Lightjack Member. Thus, although the presence of S. muderongensis in this sample might be considered as suggesting a correlation with the Lightjack Member, it cannot be regarded as conclusive evidence.

Liveringa Formation

Lightjack Member.

M.49 (Long. 126°11', Lat. 19°17').

Unidentifiable shell fragments.

M.56 (Long. 126°4', Lat. 19°2')

Pelecypods: Stutchburia mudorongensis Dickins 1956

Poorly preserved pelecypods and gastropods.

Doubtful Lightjack Member.

M.55 (Long. 126°5', Lat. 19°16').

Pelecypods: Atomodesma mytiloides Beyrich, 1865.
Stutchburia muderongensis Dickins 1956.
Leiopteria? sp.
Streblopteria sp. (Streblochondria sp. of Guppy et al., 1958, p.53)
Aviculopecten? hardmani Etheridge 1907

Gastropods: Warthia sp., Stachella? sp.

Atomodesma mytiloides has not been recorded from beds which can be referred without doubt to the Lightjack Member. It occurs, however, in the Noonkanbah Formation and apparently also in the Hardman Member (upper part) of the Liveringa Formation.

Balgo Member

S.4 (Long. 127°45', Lat. 21°15').

Pelecypods: Atomodesma exarata Beyrich 1865
Astartila fletcheri Dickins 1956

Gastropods: Warthia sp.
Indeterminate spired and bellerophontid gastropods.

In the Canning Basin Atomodesma exarata is known only from the Lightjack Member and the occurrence of this form together with A. fletcheri indicates that these beds can be correlated with the Lightjack Member.

S.6 (Long. 128°10', Lat. 21°30').

Pelecypods: Atomodesma exarata Beyrich 1865
Stutchburia sp. ind.
Astartila fletcheri Dickins 1956
Streblopteria sp.

Pectinid gen., sp. nov. (for discussion of this form see under S.9).
Aviculopecten? *hardmani* Etheridge 1907

Indeterminate gastropods and a brachiopod.

Large animal trails or castings.

For reasons stated above, the beds at S.6 can be correlated with the Lightjack Member.

S.9 (Long. 128°6', Lat. 21°28').

Peleaypods: *Atomodesma exarata* Beyrich 1865
Astartila fletcheri Dickins 1956
Astartila? sp. nov. - form with large prominent beak.
Stutchburia muderongensis Dickins 1956
Aviculopecten sp. nov. (form from the *subquinquelineatus* line, cf. species from Wandagee Formation - distinct primary and secondary ribs with a large number of tertiary).
Pectinid gen., sp. nov. (large primary ribs with secondary ribs developed in grooves. Outline wavy, possibly a new genus).
Streblopteria sp.

Gastropods: *Ptychompalina* cf. *P.* sp. nov. from S.67.
Warthia sp.

Brachiopods: "*Martiniopsis*" sp.

Plants: *Gangamopteris* sp.

The beds at S.9 can be correlated with those at S.4 and S.6 and in turn all can be correlated with the Lightjack Member.

S.12 (Long. 128°4', Lat. 21°16').

Animal tracks or burrows.

These tracks at present do not allow any correlation of these beds.

S.67 (Long. 127°58', Lat. 21°49').

Pelecypods: *Stutchburia muderongensis* Dickins 1956
Pseudomonotis? sp. ind.
Pectinid gen., sp. nov. (as in S.6 and S.9).
Streblopteria sp.

Gastropods: Ptychomphalina sp. nov. (whorl section more rounded than P. maitlandi Etheridge 1903)

Brachiopods: "Martiniopsis" sp.

Large animal trails or castings.

S.68 (Long. 127°57', Lat. 21°49'50").

Pelecypods: Streblopteria sp. (specimens show a central ligament pit)

Gastropods: Warthia sp., Ptychomphalina sp. nov.?

?Corals: Khmeria? sp. (Khmeria is finger-shaped organism which is thought to be a coral - see Gallitelli 1956).

S.77 (Long. 127°58'30", Lat. 21°49').

Pelecypods: Stutchburia muderongensis Dickins 1956
Pseudomonotis? sp. ind.
Pectinid gen., sp. nov.? (shows hinge of right valve with a ligament pit).

Gastropods: Ptychompalina sp. nov.?

S.4, S.6, S.9, S.67, S.68 and S.77 all contain a similar fauna and can be correlated with each other. Of the twelve species in the Balgo Member which are regarded as identifiable, eight also occur in the Lightjack Member of the Liveringa Formation. Included amongst the eight is Atomodesma exarata which was previously known only from the Lightjack Member of the Liveringa Formation and is regarded as marker fossil for the Lower Liveringa. In addition, Stutchburia muderongensis, Astartila fletcheri and Aviculopecten? hardmani Etheridge are characteristic of the Lightjack Member. At present the remaining four species are known only from the Balgo Member but from the occurrence of related forms they are of type which could be expected to occur in the lower part of the Liveringa Formation. On the other hand none of the characteristic forms of the Noonkanbah Formation are present and the fauna of the upper marine part of the Liveringa is quite distinct. On the basis of its fauna the Balgo Member can be correlated with the Lightjack Member and is thus Upper Artinskian to Kungurian in age (see Thomas and Dickins, 1954).

Doubtful Balgo Member

L.5 (Long. 127°57', Lat. 20°13').

Pelecypods: Aviculopectinidae gen. et sp. ind.

Indeterminate gastropods.

The fossils from this locality are of little use for correlation.

L.6 (Long. 127°56', Lat. 20°13').

Gastropods: Ptychomphalina? sp. ind.
Bellerophontidae gen. et sp. ind.

The fossils are of little use for correlation.

L.28 (Long. 127°57', Lat. 20°11').

Pelecypods: Atomodesma sp. ind.
Pectinid gen. ind.
Aviculopecten sp. (A. subquinquelineatus line, ribbing not as complexly developed as for A. sp. nov. from S.9, but may be an immature specimen).

Brachiopods: Strophalosia sp. ind.
"Chonetes" sp. ind.

The presence of Aviculopecten sp. would suggest this locality is of Upper Noonkanbah or lower Liveringa (Lightjack Member) age.

L.30A (Note book mileage 384.1) (Long. 128°4', Lat. 20°55', 3 miles north-north-west of Thomas Peak).

Pelecypods: Atomodesma sp. ind.

The specimens are of no value for correlation within the Permian.

L.44 (Long. 127°41', Lat. 20°7').

Pelecypods: Nucula? sp.
Stutchburia sp. ind.

The fossils present are of little value for correlation.

Doubtful Condren Sandstone Member of Liveringa Formation.

C.39 (Long. 126°41', Lat. 30°38').

Fragments of indeterminate pectinid shells.

L.37 (Long. 127°50', Lat. 20°16').

Pelecypods: Stutchburia? sp. ind.

Gastropod gen. et sp. ind.

The fossils are of no value for determining the age of the sample.

Hardman Member of Liveringa Formation.

M.50 (Long. 126°12', Lat. 19°22').

Pelecypods: "Allorisma" sp.

Brachiopods: Aulosteges cf. fairbridgei Coleman 1957 (G.A. Thomas - pers. comm.).

Conulariids: Paraconularia? sp.

Aulosteges fairbridgei is a marker fossil for the Hardman Member.

Permian Undifferentiated

C.38 (Long. 126°37', Lat. 20°37').

Pelecypods: Aviculopectinidae gen. et sp. ind. (a right valve with a large anterior auricle.

Animal tracks or castings.

The fossils are of no value for correlation.

C.49 (Lat. 127°27', Lat. 20°58').

Indet. invertebrate exoskeleton remains.

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THE PERMIAN FORMATIONS OF THE NORTH-EAST CANNING BASIN AND THEIR CORRELATION

AGE	CARNARVON BASIN (North end of Kennedy Ra.)	FITZROY BASIN		NORTH-EAST CANNING BASIN	
TARTARIAN		HARDMAN MEMBER		HARDMAN MEMBER	
KAZANIAN	BINTHALYA SUB-GROUP	LIVERINGA FORMATION	Plant Beds*	LIVERINGA FORMATION	CONTREN SANDSTONE MEMBER
KUNGURIAN	COOLKILYA GREYWACKE				
?	BAKER FORMATION		LIGHTJACK MEMBER		LIGHTJACK & BALGO MEMBERS
	NORTON GREYWACKE WANDAGEE FORMATION QUINANNIE SHALE CUNDLEGO FORMATION BULGADOO SHALE MALLENS GREYWACKE	NOONKANBAH FORMATION		NOONKANBAH FORMATION	
ARTINSKIAN	COYRIE FORMATION				
	MOOGOOLOO SANDSTONE (="WOORAMEL SANDSTONE")	POOLE SANDSTONE		No definite outcrop of Poole Sandstone recognised.	
	CALLYTHARRA FORMATION		NURA NURA MEMBER		
(Approx)					
SAKMARIAN	LYONS GROUP	GRANT FORMATION		GRANT FORMATION	
?					

Solid lines mark the most reliable correlations

* In the Talbot Syncline there may be a disconformity at the base of the plant beds.

APPENDIX C.

PETROGRAPHIC DESCRIPTION OF SELECTED ROCK SPECIMENS FROM THE CANNING BASIN. W.A.

by

J. Kerry Lovering.

The specimen localities are marked on Plate I. The respective letter symbols for each four mile sheet are:-

B = Billiluna; C = Cornish; L = Lucas;
M = Mt. Bannerman; and S = Stansmore.

LOWER PROTEROZOIC - HALLS CREEK METAMORPHICS AND LEWIS GRANITE.

B32: Quartz Greywacke (Larranganni Bluff)

The hand specimen is pale pinkish grey, and consists of fine grains of quartz cemented by a fine matrix.

The rock is a quartz greywacke (Condon, 1953).

It is fairly well-sorted. Angular, irregular sized quartz grains range from 0.1 mm to 2 mm. They occur with quartzite grains and hematite fragments in a matrix of sericitic and chloritic material.

B33. Crushed Greywacke (Larranganni Bluff)

The reddish hand specimen contains coarse to fine fragments in a fine reddish groundmass.

Crushed grains of quartz, and some altered biotite and ferromagnesian minerals, occur in a matrix of fine crushed quartz grains and altered biotite fragments, together with magnetite grains and particles and films of hematite, as well as accessory apatite, tourmaline and zircon. Chlorite and hematite replace much of the biotite, and together with quartz, pseudomorph the ferromagnesian minerals.

Many of the crushed quartz grains have authigenic outgrowths of clear quartz.

M33: Quartzite (Six miles south of Bulka Hills)

The pinkish specimen is fine-grained. There is a quartz-rich vein running through it.

In thin section grains of quartz are closely packed; sericite fibres fill the spaces. Most quartz grains show uneven extinction indicating that they have been subjected to stress.

The quartz of the quartz vein has grown perpendicular to the sides of the vein. These anhedral grains are 5 mm. long and 0.5 to 1 mm. wide, and have uneven extinction.

M34: Quartzite (10 miles South of Bulka Hills)

The hand specimen is a hard, medium-grained rock which almost entirely of quartz. It has a white to pink blotchy colour.

The rock consists mainly of very irregularly-shaped quartz grains which range from 0.5 mm. to 2 mm. The quartz is clear with very few dust inclusions. The grains generally have a wavy extinction; some grains have thin films of leucoxene.

The rock has formed mainly by compaction. Most grains show, by wavy extinction, the effects of pressure. Some re-crystallisation of the grains has occurred.

M36: Sandstone. (8 miles south of Christmas Creek)

The hand specimen is a reddish, fine-grained sandstone.

Angular and irregularly-shaped quartz grains occur in a matrix of hematite-stained clay minerals, with a little chlorite. Most of the quartz and magnetite grains are extensively shattered, and some grains have been partly resorbed. Even the matrix reflects the pressure to which the rock was subjected.

M37: Quartz Greywacke (Christmas Creek)

The hand specimen is a pale grey rock. Fine grains occur in a homogeneous fine grey groundmass.

The thin section reveals irregular-shaped quartz grains (50%) which range from 0.1 mm. to 2 mm., and a few shreds of muscovite and some fragments of amphibole, set in a fine sericitic fibrous groundmass.

The rock is a quartz greywacke (Condon 1953).

L25. Muscovite Granodiorite (Lewis Range)

The hand specimen is a red muscovite granodiorite and appears to be weathered.

The thin section reveals typical granitic texture. The grains are medium in size ranging from 1 to 2 mm. in macro-diameter.

The rock consists of quartz (50%), plagioclase (22%), and muscovite fragments (10%), and magnetite (3%).

The quartz grains are clear with lines of minute dust inclusions. The plagioclase is well twinned and altered to sericitic material. The grains of alkali feldspar are generally recognised by their alteration to clay minerals. Muscovite fragments show a little alteration.

L42. Chert (Kearney Range)

The fine-grained white hand specimen has large quartz crystals and micaceous shreds.

The thin section shows that the quartz fragments and shreds of muscovite are set in a very fine groundmass. The groundmass consists almost entirely of fibrous aggregates of kaolinite which, in part of the rock, are in layers suggesting lamination or flow movements. Sections of this layered material truncate the lines of flow. The flow movements disappear where the kaolinite becomes medium-grained around quartz fragments and mica shreds.

UPPER PROTEROZOIC - KEARNEY BEDS, GARDINER BEDS, PHILLIPSON BEDS, AND UNDIFFERENTIATED.

B9. Silicified quartz sandstone (Pyramid Hill)

The hand specimen is a buff-coloured, fine-grained rock with a conchoidal fracture. The texture is saccharoidal. There is an effect of colour banding, where silicification of the rock has occurred.

In thin section, smoothly rounded, clear, clean quartz grains are closely packed together; the grains are very well-sorted with an average grain size of 1 mm. There are some rock fragments of quartzite which are well rounded and about 1 to 1.5 mm. in diameter. Between these grains are small angular quartz grains about 0.1 mm. in size, which have many dust particle inclusions. Filling in the spaces is a greenish yellow clay, which constitutes about 5% of the rock.

There is, as accessory, less than 1% of hematite.

Where the colour banding is seen in hand specimen, there is a band of very fine quartz material.

The rock is a very well-sorted quartz sandstone, silicified by compaction. Authigenic quartz has cemented the closely packed rounded grains. The band of fine angular almost brecciated quartz is probably the result of compaction. In the hand specimen this band divides a portion which is more silicified from the rest of the rock.

B10. Silicified quartz sandstone (Near Tent Hill)

The rock is coarse-grained and pale pinkish grey and consists mainly of quartz. It appears to have been silicified.

In thin section highly compacted quartz grains are the main constituents of the rock. The grains are cemented together by authigenic outgrowths of quartz. The grains are regular in size about 1 mm. in macro-diameter, and are angular in shape due to authigenic outgrowths. Dust particles outline the original rounded shapes.

Other than a fragment of amphibole, several grains of quartzite and several patches of chlorite, the rock consists of quartz only.

B30(a) Sandstone (18 miles north-east of Mt. Brophy).

This dark reddish-grey rock is a fine-grained, well laminated sandstone.

The rock consists of irregularly-shaped grains about 0.3 mm. in diameter, of quartz (75%), sericite and muscovite (10%), hematite (10%) and altered grains (5%).

B30(b) Silicified quartz sandstone (18 miles north-east of Mt. Brophy)

The hand specimen is a quartz-rich rock.

The thin section reveals that the originally smoothly rounded quartz grains are cemented together by clear authigenic quartz growths. The original grains are cloudy and weathered in part, and vary in size from 0.1 mm. to 2 mm. The original outline is preserved by dust particles. There are a few quartzite grains which contain some tourmaline.

The rock as a whole has been subjected to stress; uneven extinction is seen in most of the quartz.

B31. Quartz-tourmaline Hornfels (Fort Hill).

The rock is dark-grey, homogeneous, and fine-grained.

The thin section reveals the development of a granoblastic texture. The original sedimentary textures are clearly seen. The original lamination is demonstrated by the sub-parallel arrangement of large elongate grains. Some of the quartz grains have been recrystallised although blastoporphyritic grains are common.

Euhedral tourmaline (schorlite) grains, about 0.1 mm. long, have grown from the original sedimentary matrix in which the quartz was distributed. The matrix then probably consisted of fine quartz grains (now recrystallised), and aluminous minerals such as clay and sericitic material. With the introduction of boron during metasomatism of the sediment, clay minerals and sericitic material were converted to tourmaline with the removal of potash.

The rock was probably originally an argillaceous sandstone. It is now approaching a quartz-tourmaline hornfels, after the metasomatic process.

The specimen is a pebble taken from the basal conglomerate of the Gardiner Beds.

B36 Sandstone (Gardiner Range)

The dark reddish-grey rock is fine-grained and laminated.

The thin section reveals a markedly even-grained rock consisting of angular quartz, about 0.1 mm. in size, in a sericitic matrix.

There are several porous bands in which the pores are rimmed with clay minerals.

B40(a) Sandstone (Gardiner Range)

The hand specimen which greatly resembles B40b, is reddish and laminated. There is a large amount of muscovite in each lamina.

Large quartz grains, about 0.7 mm. to 2 mm. in size, are scattered at random in a groundmass of fine quartz grains, magnetite grains, hematite particles and films, muscovite fragments, zircon and tourmaline grains.

B40(b) Silicified quartz sandstone (Gardiner Range)

This hand specimen is a reddish fine-grained laminated rock.

The rock is mostly composed of quartz grains 0.2 mm. in size, which are well rounded and partly cemented together by clear authigenic quartz. Grains of magnetite and hematite grains and films also cement quartz grains. There are rounded accessory grains of tourmaline, chlorite and zircon and fragments of muscovite.

B40(c) Silicified quartz sandstone (Gardiner Range)

The hand specimen appears to be quartz.

The thin section reveals that rounded grains of quartz about 0.5 mm. in size are cemented together by outgrowths of authigenic quartz. The quartz grains contain dust inclusions and their original shape can be easily seen against the clear quartz. Films of hematite surround many grains.

B41. Magnetite-Quartz Rock (Gardiner Range)

The hand specimen appears to be extensively replaced by an iron-rich band about 1½ inches thick. It varies from a dark reddish to a yellow colour. The rock is porous in texture but is nevertheless heavy.

The thin section reveals rounded quartz grains about 0.5 mm. in diameter are set in a matrix of yellowish chalcedony. Some of the original clean re-crystallised quartz has a crystallo-blastic texture. Magnetite oxidised to hematite on its borders, is associated with the chalcedony; that the iron and the chalcedony crystallised at about the same time in this rock and replaced the original matrix in which the rounded quartz grains are set.

B42. Quartz Sandstone (Gardiner Range)

The chrome yellow hand specimen is a fine-grained sandstone. In parts, the yellow colouration is absent and the original white colour is seen.

Smoothly angular quartz grains, about 0.5 mm. in diameter, are set in a matrix of brown prochlorite and limonite.

A few grains of tourmaline are accessory.

B43(a) Silicified Quartz Sandstone (Wolf Creek - west branch).

The hand specimen is a dark red medium-grained compact rock. Pebbles define a slight lamination.

The rock consists of rounded quartz grains, from 0.5 mm. to 1 mm. in size, cemented together by authigenic quartz outgrowths. The outlines of the original grains are emphasised by films of hematite. Other grains present are magnetite and quartzite.

B43(b) Silicified Quartz Sandstone (Wolf Creek - west branch)

The grain size is regular with a diameter of 0.2 mm. Accessory tourmaline and zircon was noted.

The hand specimen is finer grained than B43(a). Pebbles of quartz and altered felspar are scattered at random.

B43(c) Quartz Sandstone (Wolf Creek - west branch)

The hand specimen is a fine-grained yellow sandstone.

The rock consists of quartz grains about 0.2 mm. in diameter. These are cemented together with chlorite and some authigenic quartz.

B44 Silicified Quartz Sandstone (5 miles west of Astro W.H., Wolf Creek).

The rock is a pale orange colour. It is hard and very fine-grained with a quartz vein running through it.

Thin section reveals a crystalloblastic texture.

Quartz grains are irregular in shape, about 0.5 mm. in diameter, and show wavy extinction. They contain many dust inclusions, around the margins, and were incorporated in authingenic outgrowths of the original sand grains. Limonitic particles give the orange colour to the rock.

Besides the effects of compaction and cementation, this rock has been compressed.

L16. Sandstone (Phillipson Range)

The rock is a well-laminated fine-grained sandstone.

The thin section shows that it is composed of rounded irregularly-shaped quartz grains about 0.3 mm. in diameter. The rock is fairly porous but some interstitial spaces are filled with brownish chlorite and quartz fragments.

Accessory grains of quartzite are found, and fragments of hematite and ilmenite.

L22. Silicified Quartz Sandstone - (North of Lake Lucas)

The hand specimen is a very fine-grained, pinkish rock. It is compact with an even fracture.

The thin section shows a remarkably even-grained sandstone. Angular quartz grains make up 95% of the rock and they are all about 0.3 mm. in diameter. The quart is generally very clear, with some dust particles around the margins which have been included in authigenic outgrowths.

There are a few grains of quartzite and sericite and some biotite fragments and hematite particles.

Rounded grains of zircon are accessory. One inclusion in the rock consists of a fine sandstone in which the individual grains are coated with a thin film of hematite material. These inclusions are seen as deep pink spots in the hand specimen.

The rock has been compacted and recemented to form silicified sandstone.

M39. Siltstone (Christmas Creek)

The hand specimen is an extremely fine-grained laminated rock with a sub-conchoidal fracture. The lamination is due to colour banding effects. Most of the rock is a bright reddish brown; part is a chalky white.

In thin section, the rock is extremely fine-grained. It consists mainly of sericitic and chlorite material with some very fine fragments of mica and some dust particles.

The colour is due to films and bands of hematite.

S8. Silicified quartz sandstone (20 miles east of Stansmore Range)

The rock is a fine-grained whitish quartz sandstone. The rounded grains appear to be cemented by a siliceous matrix.

The thin section reveals the closely compact nature of this well-sorted quartz sandstone. The rock consists almost entirely of quartz grains, ranging from 0.5 mm. to 1.5 mm. in size, which were originally smooth. Their former outlines are preserved by lines of dust particles which divide the original quartz grains from their authigenic outgrowths. Compaction of the grains has caused the solution and recrystallisation and cementation of quartz grains to form this silicified quartz sandstone.

Discussion -

The quartz sandstones (B9, B10, S8, L22) are very similar petrographically although the hand specimens have different colorations. The original quartz sandstones, were very well-sorted with very regular grainsize, generally about 1 mm. in diameter; L22 is very fine grained, with grain diameters about 0.5 mm. The original quartz grains were round and smooth, and their former outlines are preserved by lines of dust particles which divide the quartz grains from their authigenic outgrowths.

UNDIFFERENTIATED PALAEOZOIC - LUCAS BEDS

L17. Calcareous Sandstone (Lake Lucas)

The hand specimen is a dark reddish brown, fine-grained, homogeneous rock. It effervesces strongly with cold dilute HCl.

In thin section, it is notable that the grainsize is very iniform. Irregularly shaped quartz grains are about 0.5 mm. in macro-diameter, and are uniformly distributed about 0.5 mm. apart. Other similarly shaped grains consist of quartzite and hematised fragments.

The groundmass consists of irregularly shaped grains of calcite. Many of these are coated with a film of hematite.

DEVONIAN

M38. Limestone (Christmas Creek).

The massive greyish hand specimen contains stringers of calcite. The whole rock effervesces with dilute HCl.

The rock consists of microcrystalline calcite and disseminated clay minerals. Grains of coarse-grained calcite permeate spaces in the limestone. These stringers of coarse calcite are frequently bordered with limonite particles and hematite aggregates.

UPPER DEVONIAN - LOWER CARBONIFEROUS

B1. Silicified quartz greywacke (Knobby Hills)

This yellowish rock is very fine-grained, compact, and has a sub-conchodial fracture.

The thin section reveals that angular grains, from 0.5 to 1.5 mm. in macro-diameter, are closely compacted and are cemented by authigenic intergrowths of quartz. The rock consists mainly of quartz with some micaceous rock fragments, microcline, microcline perthite, muscovite, chlorite, zircon and clay minerals.

The rock is a silicified quartz sandstone or even a quartz greywacke.

B4. Sandstone (Knobby Hills)

The hand specimen is a hard medium-grained white stratified rock which is slightly porous. It consists mainly of quartz with some altered white material.

The thin section reveals angular quartz grains about 0.5 mm. in diameter, in a matrix of fine quartz grains and limonite particles. Chlorite replaces the few grains of other minerals.

L40. Laminated Sandstone (Kearney Range)

This salmon-coloured rock is laminated; the laminae, 2 to 4 mm. thick, are alternatively very fine-grained and medium-grained; one lamina is yellow.

The base of each laminae can be easily distinguished in thin section. Rounded irregularly-shaped quartz grains about 0.5 mm. in diameter are near the base; very fine quartz and sericite fragments are near the top. Some laminae contain quartz grains about 0.5 mm. in size, in a very fine quartz matrix, throughout the width of the laminae. The pink colour is given by fine limonite films and particles.

The yellow laminae consists of medium-sized quartz grains in a matrix of limonite.

PERMIAN - GRANT FORMATION

B24. Sandstone (Mt. Mueller)

The rock is a reddish porous sandstone.

Rounded, irregularly-shaped, quartz grains about 0.3 mm. in size, are randomly oriented. Interstitial space is filled with prochlorite, fine quartz grains, muscovite shreds, fragments of sphene, tourmaline and ilmenite. Films of limonite coat the grains.

M7. Sandstone (4 miles west of Mt. Bannerman)

The hand specimen is a yellowish, medium-grained sandstone composed mainly of quartz grains.

Rounded irregularly-shaped quartz grains, about 0.7 mm. in diameter, are cemented together by fine quartz grains and prochlorite. Most quartz grains have uneven extinction indicating that they have been subject to stress.

Accessory grains include magnetite, altered plagioclase and quartzite.

PERMAIN - UNDIFFERENTIATED

C15. Siltstone (Bishop Range)

The rock is extremely fine-grained. It is reddish brown with some wavy bands of yellow colour. The rock is laminated; lamination is at an angle of about 45^{o} to the general direction of the colour banding. Fine quartz-rich bands define the lamination.

The rock consists of fine quartz grains, (about 0.1 mm. in size), and fine muscovite fragments in a sericitic groundmass. Hematite particles and films coat grains and give the red colour to the rock. The colour bands occur where the hematitic material, concentrated in bands, is oxidised to limonite.

QUATERNARY - TRAVERTINE ETC.

B20. Opal (8 miles south of Mt. Mueller)

The distinctive hand specimen consists of smoky white opal in a porous reddish brown matrix.

The thin section shows that the rock consists almost entirely of opal with the inclusions of hematite flakes, some chalcedony granules and clay minerals around small pores.

C45. Porcellanite. (French Hills)

The pores of this white porous hand specimen are rimmed with reddish-brown material.

The rock consists of fine granular chalcedony which appears to have been precipitated when the lake was drying up. Clay material rims every pore and must have come into the deposit when the supply of chalcedony was almost exhausted.

L7(a) Porcellanite (7 miles south-east of Balgo Mission)

The hand specimen is a porous rock with an irregularly shaped surface. It is white and opaque in the centre but toward the outside there is a clear rim up to half inch in width, containing opaque blobs.

The thin section shows that the white material is composed of fine chalcedony aggregates and disseminated clay particles. Pores in this material are surrounded by rims of radiating chalcedony.

Throughout the chalcedony are blebs of high relief which are opaline silica. Towards the surface of the deposit, opal rims most of the pores and fills in large spaces. The amount of clay particles diminishes towards the surface of the deposit.

L7(b) Pisolite (7 miles south-east of Balgo Mission)

The hand specimen consists of reddish-brown ooliths and pebbles in a brownish clay matrix. The ooliths range from 0.5 mm. to 15 mm. in size.

The oolites consist of hematite and chamosite. Grains of quartz are also present. All these minerals are surrounded by red flakes of hematite and are set in a groundmass of opal.

L21. Porcellanite (6 miles north of Lake Lucas).

This white porcellanite is a fine-grained mixture of chalcedony and clay, which grades upwards to a clear chalcedony with a dusty red clay surface.

In the white rock are fragments composed of chlorite, chamosite and calcite pseudomorphs in a groundmass of fine-grained clay and granular calcite. These fragments, blebs, and flakes of clay, arranged to give a slight lamination to the rock, are in a matrix of fibrous chalcedony and calcite grains. Radial aggregates of chalcedony fill in spaces in this matrix.

L21(b) Porcellanite (6 miles north of Lake Lucas)

The junction of the white porcellanite and the clear surface is examined in this section.

The white porcellanite with its high percentage of clay gives way to granular chalcedony with a very little clay. Finally the clay disappears entirely.

S3. Marl (11 miles south-east of White Hills)

The yellowish hand specimen is compact, laminated and fine-grained. It contains several large grains. The specimen effervesces with cold dilute HCl.

Under the microscope the rock is extremely fine-grained; the microcrystalline material consists of calcite and clay and is arranged in fibrous and radiating masses.

The laminae are effected by the layering of limonite films and clay minerals. The laminae curve around the large grains which are about 4 mm. in diameter and which seem to be completely replaced by clay minerals.

Throughout the rock are angular fragments of quartz, usually less than 0.1 mm. in size. Grains of hematite, biotite and epidote are accessory.

S3(a) Argillaceous limestone (11 miles south-east of White Hills)

The rock is a massive yellow-coloured limestone which effervesces with cold dilute HCl.

Clay nodules and fine layers of clay lie in the limestone, which consists mainly of fine calcite. The clay minerals give a lamination to the rock; the laminae probably represent surfaces of a lake into which the clay minerals were deposited.

S3(b) Argillaceous Limestone (11 miles south-east of White Hills)

The hand specimen is a massive white rock containing clear glassy "inclusions" of fine granular chalcedony, which are surrounded by white clay which form a white rim.

The main part of the rock consists of fine calcite and clay minerals.

DISCUSSIONS OF SPECIMENS: A POSSIBLE LACUSTRINE ORIGIN.

The pisolite specemen, L7(b), is typical of the surroundings of the lake; this specimen was found at the bottom of the lake sediments and was presumably washed into it.

Marls and limestones lie above the lake bottom, and, following an increase of silica in the lake, the marls and limestones grade into white procellanite, clear chalcedony and opal in some instances.

The marls and argillaceous limestones probably formed when clay particles were blown or washed into the lake while calcium carbonate was being precipitated by chemical or organic means.

As silica, precipitation by chemical or organic processes became dominant, the white porcellanites formed, and graded into chalcedony. Finally, perhaps in hydrous conditions, opal was deposited.

At first it was thought that silica was replacing carbonate, but further examination made it clear that this was not so. However, if deposition was by organic processes, silica-depositing organisms might have replaced carbonate-depositing ones.