COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 49

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

BY

J. N. CASEY AND A. T. WELLS

Issued under the Authority of the Hon. D. E. Fairbairn,
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Secretary: SIR HAROLD RAGGATT, C.B.E.

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SUMMARY

The Palaeozoic and Mesozoic stratigraphic units and major structures recognized in the Fitzroy Basin by earlier workers continue into the north-east Canning Basin. Ordovician(?), Devonian, Permian, Mesozoic, and Tertiary sediments rest with an angular unconformity on the Upper and Lower Proterozoic rocks; the succession contains only slight unconformities.

The 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 2000 feet. The sediments do not appear to have a well established regional dip, but they are interrupted by a network of north-easterly faults and arcuate structures. Gravity traverses across the Stansmore Fault have been interpreted as showing a displacement of 7800 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 containing a good deal of clayey material as well as feldspar grains predominate. The probable Ordovician sediments contain marine organisms and are probably shelf deposits. The Grant Formation was laid down during a period of glaciation, and is the oldest Permian formation 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.

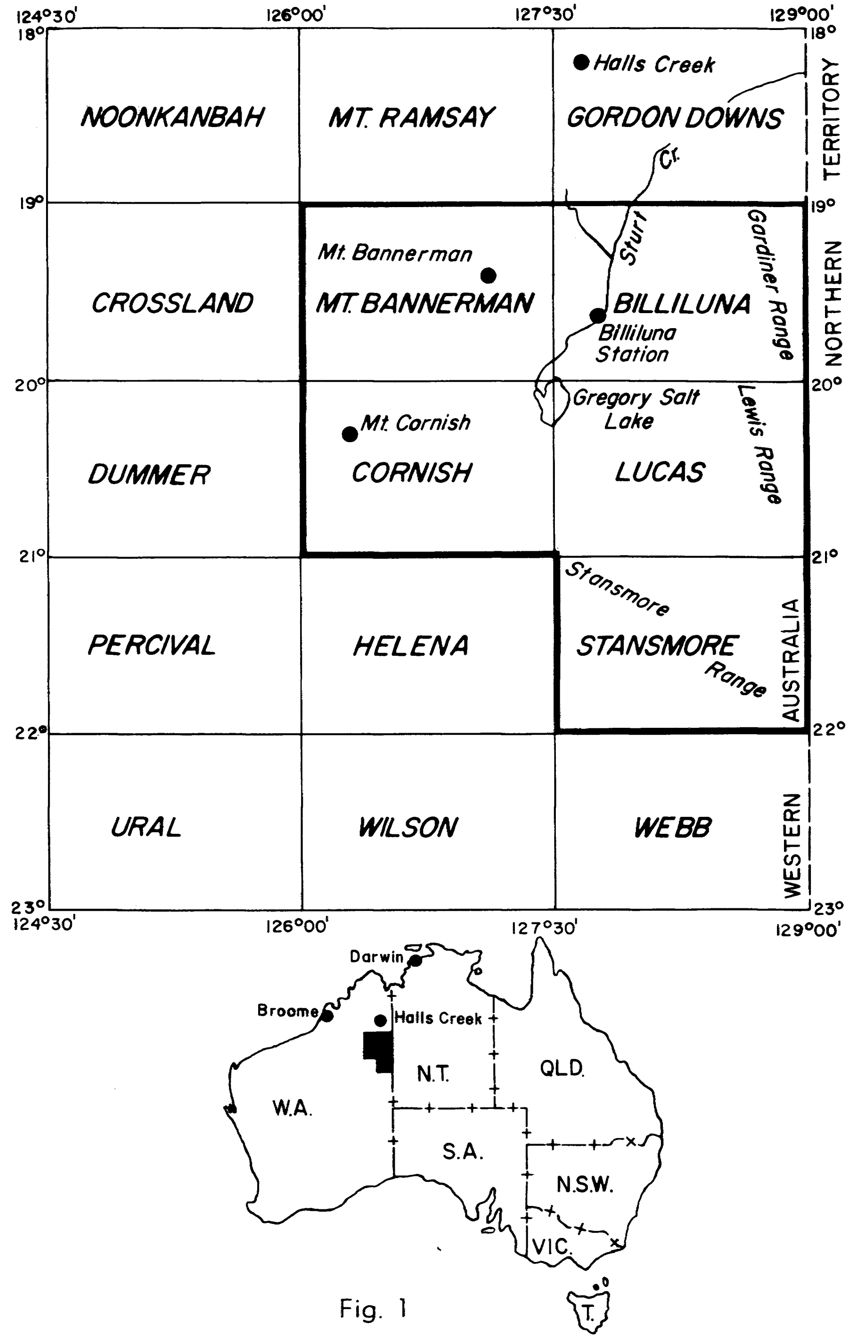

Fig. 1

LOCALITY MAP

AND 1 : 250,000 SHEET INDEX

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INTRODUCTION

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-east Canning Basin, the Mount Bannerman, Billiluna, Cornish, Stansmore, and Lucas four-mile map sheets were mapped in 1955. The south-western part of the Canning Basin was mapped in 1954 (Traves, Casey, & Wells, 1956), and further land traverses were made in the southern and eastern part of the basin in 1956 by B.H. 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 35,000 sq. miles): an effort was made to take nine astrofixes per sheet, positioned along the margins, through the centre of the sheet, and on the photo tie-runs. From these, semi-controlled mosaics of Stansmore and Cornish and distorted grids of Mount 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 Godfreys 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 reconnaissance geological and geophysical survey of the Canning Basin by helicopter (Veevers, 1957). These results were combined with those determined in 1956 by J.H. van Son of the Bureau of Mineral Resources to produce a gravity contour map of the north-east Canning Basin.

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

It is several years since the field investigation was made; and some of the material presented in this Report has been used for the bulletin on the Canning Basin (Veevers & Wells, 1961), 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 by either the inland or the coast road to Port Hedland, then via Broome and Fitzroy Crossing to Halls Creek. The total distance from Perth to Halls Creek is about 2000 miles. Derby and Wyndham are the nearest 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 Godfreys 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 area. 'Smokes' from spinifex burned by nomadic aborigines were seen throughout the southern and north-east Canning Basin. Signs of recent native habitation were also seen around rock holes and wells.

The party was equipped with Traeger 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 temperatures 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 °F								90.2	96.6	103.0	106.5	114.7	
Min. t °F								50.9	55.6	58.0	61.7	59.9	
Rainfall (points)	5	169	156	no record	296	9	no record	0	8	304	151	290	1388
1951													
Max. t °F	108	108.6	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 (points)	104	324	31	120	0	160	0	0	14	0	11	70	834
1952													
Max. t °F	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 (points)	156	129	61	139	9	0	0	15	0	2	68	52	629
1953													
Max. t °F	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 (points)	351	200	20	6	0	0	13	44	0	0	144	673	1451
1954													
Max. t °F	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 (points)	213	0	4	251	0	19	0	37	0	67	64	no record	749
1955													
Max. t °F	112	107	105	102	93	90							
Min. t °F	71	73	68	55	50	49							
Rainfall (points)	192	67	139	70	47	39							

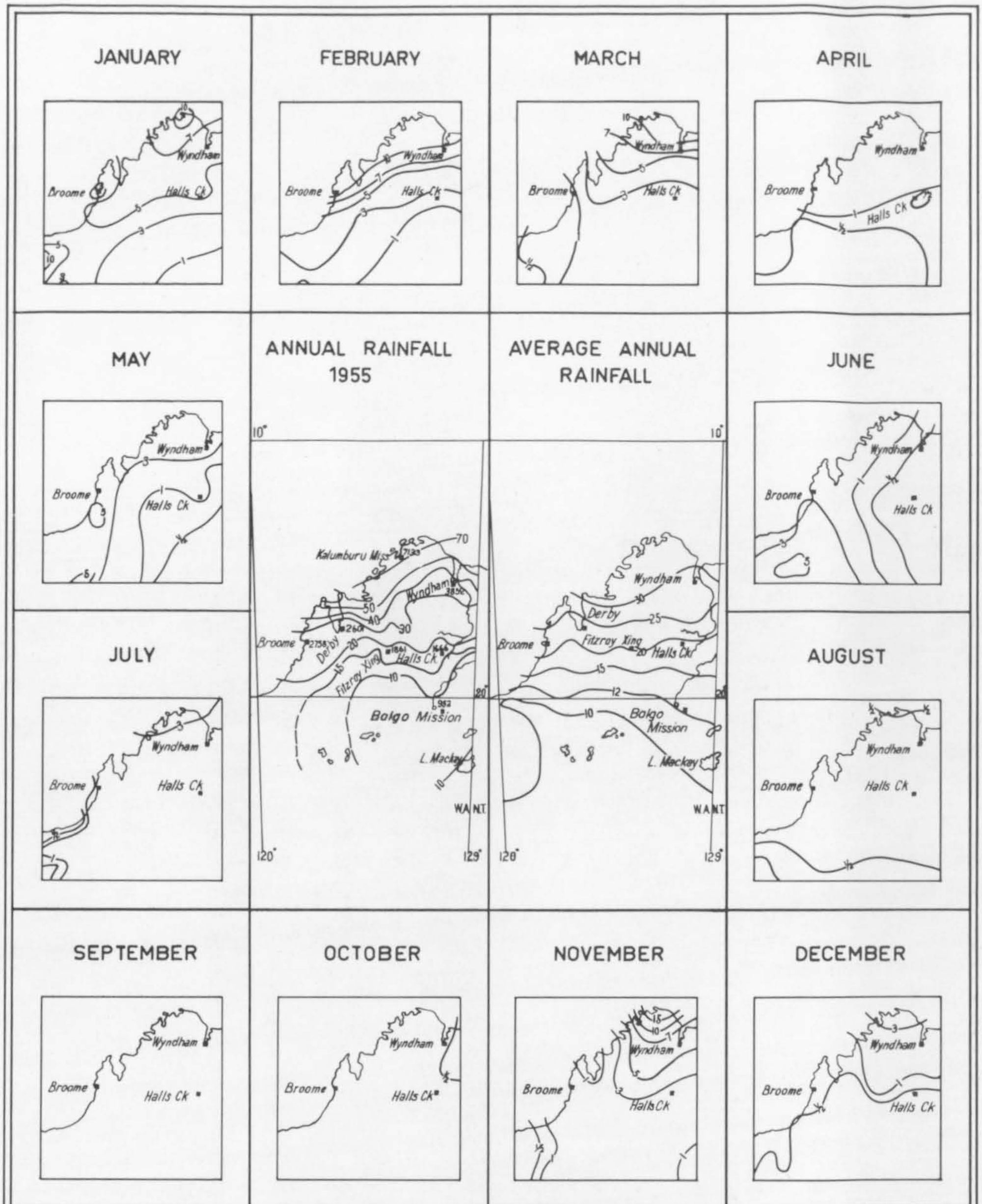

Fig. 2 COMPARATIVE RAINFALL MAPS OF THE NORTHERN PART OF WESTERN AUSTRALIA

Isohyets in inches ——25——

Numbers at stations show rainfall in points 2758

(After Commonwealth Bureau of Meteorology. Melbourne 1955)

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W-13

The regional distribution of rainfall is shown in Figure 2. The annual rainfall decreases southwards from 60 inches at Wyndham to less than 10 inches 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.

The daily maximum temperatures during the winter months vary 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 inches 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 consists of areas of sandy soil with summer rain. The red sand supplies its edaphic requirement, except in the north, where the formation occurs on stony soil; this is to be 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 predominant *Triodia* becomes.

The Desert Formation - which is characterized 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 devoid of 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 Mr C.A. Gardner (Government Botanist, Western Australia): *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 Formation are derived from a stock indigenous to the south-west, but now growing on barren, dry, sandy soil; other plants have a northern origin, but have now developed a covering of epidermal hairs which protects 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.

Animals were not as rare as might have been 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. The many birds near Sturt Creek include brolgas, cockatoos, and pigeons. Flocks 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. In the West Kimberley region, on the other hand, more sheep than cattle are raised. 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 & 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 the Division of National Mapping, were used in the field. Geological information was transferred from the air photographs (scale 1: 50,000) directly on to the four-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 resumé of operational problems are given by Casey & Wells (1956).

Previous Investigations

A.C. Gregory was probably the first to investigate the area; in 1856 he 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 (Gregory, 1857, 1898).

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 Northern Territory border, to as far south as Mount 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'S, which was later named Lake Mackay after D.F. Mackay. 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, in 1906-7. In 1908, H.W.B. Talbot (1910) accompanied Canning when the stock route was opened, and 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. 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 Godfreys Tank as part of an exploration and prospecting trip. (Godfreys Tank was dry when visited by this party.) In his 1928 expedition during the course of an investigation in the Tanami-Granites district, Terry prospected the area near the Gardiner Range at Larranganni Bluff (Terry, 1932). 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. Air photographs were taken and a topographic 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 pertinent to this report. W.H. Maddox (1941) carried out geological reconnaissance in the north-eastern part of the Fitzroy Basin, including a traverse to Godfreys 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 a structure plunging at 2^{o}-3^{o} east-south-east at Godfreys 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; the 50-foot glacial boulder bed he describes south of Balgo Mission and 100 feet above the 'Upper Ferruginous' (Liveringa Formation) are probably beds in the Condren Sandstone or Grant Formation.

In 1948, during their investigation of the Mount Ramsay four-mile Sheet area, Matheson & Guppy (1949) made a traverse to the Wolf Creek Meteorite Crater and later described it (Guppy & 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.

The Sturt Plateau was defined by Paterson (1954) in the Ord-Victoria region, and includes only a small area in the north-east Canning Basin. The Plateau is nearly flat, with 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 the Mount Bannerman Sheet area and as flat plains merging into the Semi-Desert on the northern part of the Billiluna Sheet area.

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. Mount 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 Mount Rosamund.

The Semi-Desert is composed of flat sand plains (Fig. 4) with east-west seif dunes (Fig. 3), 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; many are more than 50 miles long. The slopes are fixed by sparse vegetation and their tops are nearly bare, except for spinifex clumps and isolated large gum trees. The Semi-Desert is underlain by Phanerozoic sediments, more easily eroded than the 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 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 a stream are in the rugged Precambrian, run-off is heavy; but in other streams (e.g. those draining into Lake White) the run-off is insufficient to form large continuous channels.

(2) Streams draining into the sand plain have short courses and alluvial fans, and some form narrow alluvial piedmont deposits. Their tributaries form a dendritic pattern, and where the distributaries debouch on to alluvial flats after draining from small hills, they also are dendritic. These streams were probably never very large.

The drainage system is internal, and is dominated by Sturt Creek, which flows south-west and terminates in Gregory Salt Lake, 900 feet above sea level. It is probably a consequent stream. It rises 20 miles north-east of Mount Wittenoom. The gradient of Sturt Creek between Wolf Creek junction and Stretch Lagoon (35 miles) is 4 feet per mile; between Stretch Lagoon and Gregory Salt Lake (30 miles), 2 feet per mile; between Astrofix N4 and the Wolf Creek junction, 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; its floodwaters are red with detritus from the nearby red sand plains, whereas those from Sturt Creek are generally milky with 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 was probably a peneplain caused largely by lateritization 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 may be part of an exhumed Permian landscape.

Erosion of mountains, ridges, hills, and 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 bidirectional winds, and in length when prevailing winds blew.

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

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

Wolf Creek Meteorite Crater

A prominent topographic feature in the west of the Billiluna Sheet area is the Wolf Creek Meteorite Crater (Fig. 5), first observed from the air by F. Reeves in 1947 (Reeves & Chalmers, 1949; Holmes, 1948), and described by Guppy & Matheson (1951).

It is 65 miles south of Halls Creek (Lat. 19^{o}10'S, Long. 127^{o}46'E); the floor of the crater is 160 feet below the rim, and 70 feet below the level of the sand plain. The inner slope of the rim is 10^{o}-15^{o} and the inner 30^{o}-40^{o}; the rim outline is nearly circular. The flat floor of the crater is 1400 feet in diameter, and the 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 found on the south side of the crater by Guppy & Matheson yielded 1.9% NiO on analysis. The material was magnetic and consisted mainly of hydrated iron oxide, small amounts of silicates impregnated with iron oxide, and a little chalcedony. One specimen gave 0.06% metallic iron retained on a 90-mesh screen.

Cassidy (1954) collected several oxidized specimens weighing over 300 lb. 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', analogous to those found previously at the Barringer and Odessa Meteorite Craters, U.S.A. A few nickel-iron granules and sinuous veins of nickel-iron, 1 inch or more long and up to 1/8 inch across, were found in some sections. The specimens show evidence that they are incompletely oxidized remains of well-oriented iron meteorites. Pressure fissures radiate from 'noses' of masses and extend 4-5 inches into the interior of the masses; the fissures are filled with congealed melt. Zaratite is visible in the outermost 2-3 inches of sections, and in smaller zones in the interior. The density of the matrix is in the basal part of the conoids. The mass was originally sideritic.

The age of the meteorite 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; but it is not apparently included in native legends, so probably was pre-Recent. The aboriginal Djaru tribe call the crater Kandimalal.

STRATIGRAPHY

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,

TABLE III

STRATIGRAPHY OF THE NORTH-EAST CANNING BASIN

AGE		FORMATION	THICKNESS (feet)	LITHOLOGY AND PALAEONTOLOGY	CORRELATION: SOUTH-WEST CANNING BASIN (Traves, Casey, & Wells 1956)	CORRELATION: FITZROY BASIN (Guppy et al., 1958)
QUATERNARY	RECENT		20 + 0-120 + 10 +	Alluvium and black soil Aeolian sand Salt Tufa Travertine	Similar Recent sediments.	Sand, caliche, alluvium etc.
TERTIARY		WOLF GRAVEL	20 +	Alluvial gravel and sand		
		LAWFORD BEDS	100 ±	Lacustrine limestone and marl overlain by hard vuggy chalcedony		
		Laterite and pisolitic ironstone	30 ±	Laterite profile and isolated outcrops of pisolitic ironstone.	Pisolitic ironstone	Pisolitic ironstone
MESOZOIC	CRETACEOUS	GODFREY 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 Dicroidium	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	-	Mount 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 ± (50 measured)	Sandstone and shale with abundant marine fossils. Some calcareous shale and coquinite.	DORA SHALE	NOONKANBAH FORMATION
		GRANT FORMATION	500 ± (150 measured)	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, Leptophloeum australe.	-	-
	DEVONIAN?	LIMESTONE	10 exposed	Blue-grey limestone with much secondary calcite.	-	? BUGLE GAP LIMESTONE
		CONGLOMERATE	50 ±	Oligomictic conglomerate	-	? SPARKE CONGLOMERATE
	ORDOVICIAN		250 exposed	Interbedded medium-grained conglomerate and sandstone with trilobite remains.	-	PRICES CREEK GROUP?
	UNDIFFERENTIATED	LUCAS BEDS	100 exposed	Fontainebleau 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. Lithological similarities to Noonkanbah Formation.	
				UNCONFORMITY		
PROTEROZOIC	UPPER?	PHILLIPSON BEDS	200 +	Soft, current-bedded sandstone, poorly sorted and with dips up to 10°.	Upper Proterozoic sequence	Kimberley Plateau succession.
		GARDINER BEDS	500 +	Hard, silicified, current-bedded, ripple-marked sandstone, strongly jointed and folded, with dips up to 15°. Micaceous shale and fine sandstone are also present. Conglomerate at base, with quartz, quartz greywacke, slate, and quartz-tourmaline hornfels pebbles.		
		KEARNEY BEDS	2000 +	Silicified flaggy sandstone, folded, with dips up to 70°.		
				UNCONFORMITY		
	LOWER?	LEWIS GRANITE		Muscovite granodiorite with pegmatite and quartz veins.	Lower Proterozoic Granite	Granite of LAMBOO COMPLEX
		HALL CREEK METAMORPHICS		Quartzite, quartz-greywacke, slate, laminated claystone, and fine, clay sandstone. Strongly folded, intimately injected by granite and cut by numerous quartz veins.	Lower Proterozoic Metamorphics	HALLS CREEK METAMORPHICS

and which were probably the main source of terrigenous 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' by 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 & 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 north-east 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.

Existing stratigraphic names have been used wherever possible. 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 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.

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 Archaean ('Mosquito Creek Series?') rocks in the Cummins Range, and granitic rocks and Upper Proterozoic quartz sandstone ('Nullagine Series') 15 miles east of Bàlgo Mission. He also described Upper Proterozoic quartzite overlapping older rocks north of Mount Bannerman and in the Lewis, Erica, and Stansmore Ranges. The rocks in the Stansmore Range have since been shown to be Permian.

Lower Proterozoic

Halls Creek Metamorphics

The 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 unconformably overlain by rocks thought to be Upper Proterozoic. Rocks which occupy a similar stratigraphical 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 rocks are not as highly metamorphosed as in the Halls Creek area. Phyllites and amphibolites are absent, and basic lavas have not been recorded; quartzite (granitized in places), sandstone, slate, shale, and micaceous sandstone with quartz veins are common to both areas.

Traves (1955) describes quartzite and greywacke between Ruby Creek and Rock Hole (near the northern edge of the Billiluna Sheet), in outcrops continuous with similar rocks mapped as Halls Creek Metamorphics on the Billiluna and Mount 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 (See Appendix 2).

Slate and quartz greywacke, with dips from 50° to vertical, crop out at Larranganni Bluff, at the south end of Gardiner Range (Fig. 6). Quartz veins with hematite cut these sediments. Similar sediments crop out at B35, where white kaolinized slate, chocolate brown slate, and quartz greywacke are cut by numerous quartz veins. A porous 5-foot cap of weathered rock, which may be a remnant of a widespread laterite profile, caps the metamorphics. Other metamorphic outcrops underlie the Upper Proterozoic Gardiner Beds at Mount Mansbridge in the Gardiner Range, and as scattered inliers to the west and south. In the northern part of the Mount Bannerman Sheet area, Christmas Creek cuts through ridges of steeply dipping, kaolinized, grey to white laminated claystone, sheared pale grey quartz greywacke, and slate. Quartz veins (1/4 inch-12 inches wide) cut these sediments, and they are overlain by Upper Proterozoic dark-coloured shale, similar to that cropping out at Mount Frank to the north (Hardman, 1884; Maddox, 1941).

At locality M36, south of Christmas Creek, lit-par-lit injection has granitized 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). Its age is tentatively regarded as Lower Proterozoic, and although it may be contemporaneous with granitic rocks in the Lamboo Complex, it is normally a very fresh-looking granite, not gneissic, and it may be younger than the mineral-bearing granites of Tanami and The Granites. So far no mineral deposits have been found associated with the Lewis Granite.

In the Lewis Range the granite varies from fine-grained, aplitic, to coarse-grained. A coarser pegmatitic phase contains graphic intergrowths of quartz and feldspar, with plumose aggregates and muscovite 'books' up to two inches across. Rare slickensided fault planes, subsequently filled by crypto-crystalline vuggy silica, have crushed and cut the granite.

The Lewis Granite also crops out at Tent Hill, 15 miles east of Balgo Hills Mission, and at Mount Elphinstone, where it is a biotite granite with large feldspar phenocrysts. At M36, small outcrops of granite intrude quartzite much of which shows signs of granitization.

Figure 3. Sand plain after burning of spinifex

Figure 4. Sand dunes west of Godfreys Tank

Figure 5. Wolf Creek meteorite crater

Figure 6. Angular unconformity between Halls Creek Metamorphics and Gardiner Beds, Larranganni Bluff.

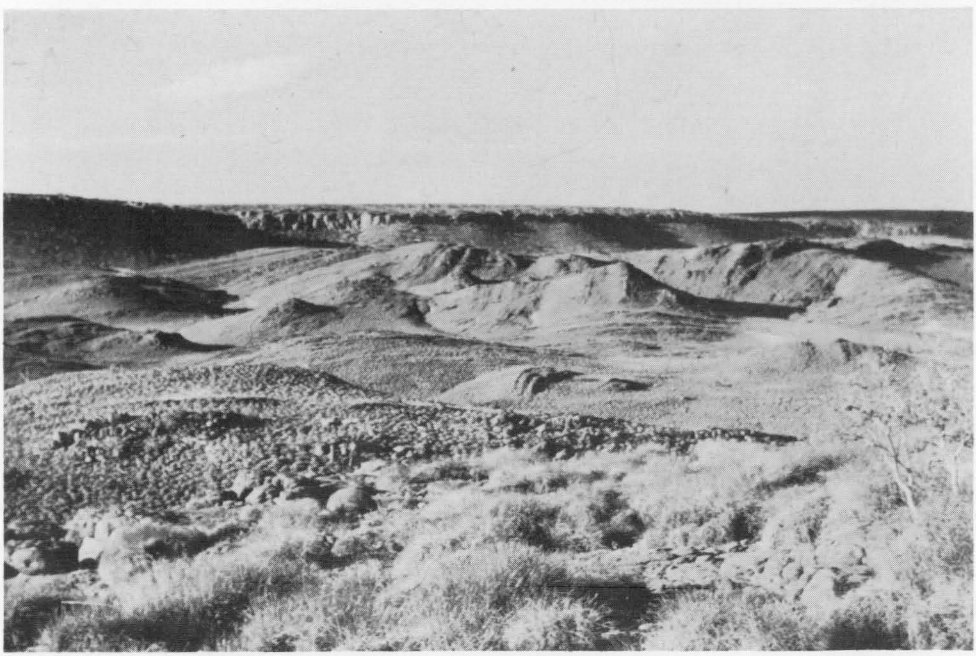


Figure 7. Gardiner Beds, Denison Range.

Figure 8. Drag folding in incompetent shale of Gardiner Beds. 10 miles east of Lake Wills.

Figure 9. Steeply dipping ripple-marked sandstone of Gardiner Beds, 16 miles east of Warri Peak.

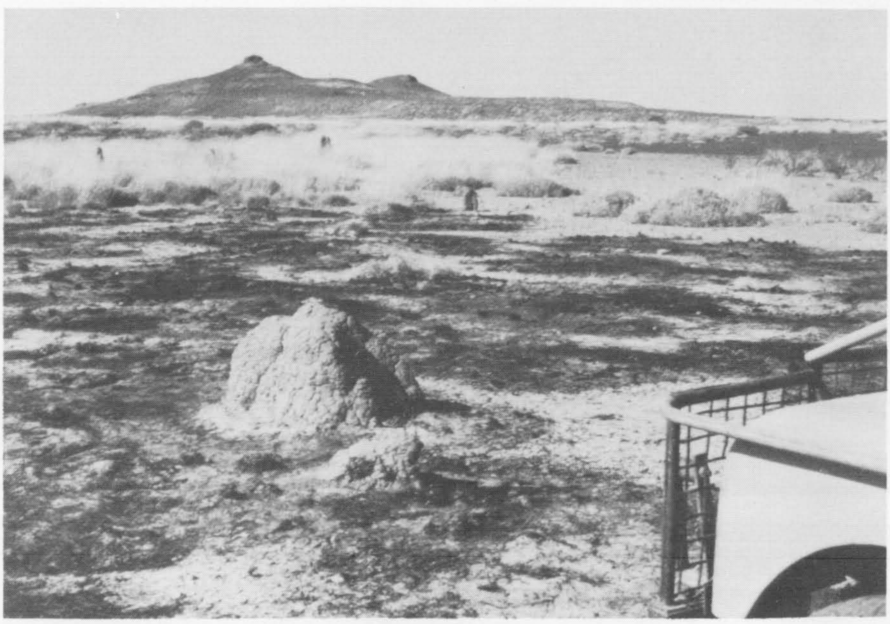
Figure 10. Ripple marks in Phillipson Beds, Phillipson Range

Figure 11. Dikelocephalina from sandstone 31 miles north of Billiluna.

Figure 12. Large-scale current-bedding in Devonian or Carboniferous sandstone, Knobby Hills

Figure 13. Balgo and Condren Sandstone Members, Stansmore Range

Figure 14. Condren Sandstone at Condren Pinnacles



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 Mount Hughes and the Kearney Range. 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 the beds of steeply dipping hard silicified flaggy quartz sandstone cropping out in the Kearney Range (Lat. 20° 08'S, Long. 128°08'E), 20 miles east of Balgo Mission. They are unconformably overlain by Upper Devonian or Lower Carboniferous sandstone at B28, 15 miles east of Billiluna Homestead, and probably lie on the eroded surface of Lewis Granite. The Beds are tentatively regarded as Upper Proterozoic, but no contacts with other Precambrian rocks have been seen.

The sandstone is white, weathering to ochreous yellow, banded in places and of uniform grain size. Depositional features such as ripple marks or current bedding are rare. Thin conglomerate bands are interspersed through the sandstone. The Beds are generally intensely jointed. They crop out typically as low resistant ridges, cuestas, and hogbacks.

Gardiner Beds (new name)

The Gardiner Beds are the 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. 6). 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.

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

60 feet	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 ripples are the more abundant.
100 feet	Sandstone, flaggy, with minor interbedded micaceous shale; much clay pellet conglomerate.
120 feet	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.
40 feet	Conglomerate, boulders up to 1 foot of slate, quartz greywacke, and quartz from underlying Metamorphics. Fragments irregular, subrounded to subangular, average diameter 1 inch. Quartz greywacke fragments generally ellipsoidal and subrounded; quartz pebbles subangular and irregular. Quartz grains of matrix average 1.5 mm. in diameter.

Unconformity

Lower Proterozoic Halls Creek Metamorphics: quartz greywacke, slate, and sub-greywacke intruded by quartz and quartz-hematite veins.

6-3

The surface of unconformity 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 Mount Stubbins. The basal conglomerate crops out at Fort Hill and contains fragments up to a 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 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; but no gold has as yet been found in the conglomerate at the base of the Gardiner Beds (in 1960, New Consolidated Goldfields Pty Ltd discovered uranium in these beds at Killi Killi Hills on the Billiluna Sheet).

The 500-foot section exposed on the southern flanks of Mount 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, wave-ripple-marked, silicified, well jointed, flaggy sandstone with clay pellet beds; the sediments dip 5^{o} north. This section is in turn overlain by micaceous shale at B40 and B41, north of Mount Brophy. The shale at B41 contains a bed rich in magnetite and secondary hematite; the beds here dip 3^{o} to the north-east.

The beds crop out in the Denison Range (Fig. 7), Pyramid Hill, Palm Spring, Mount 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, varying mainly in bedding, fissility, sedimentary structures, and degree of silicification. One exception is the presence of dolomite at Red Cliff Pound (S82) which dips 20^{o} to the west and overlies silicified white shale, laminated sandstone, and very coarse sandstone (1/8 inch - 1/2 inch grain size). The dolomite is laminated, pink or pale purple on a fresh surface, and weathers into circular boulders. It is overlain by hard sandstone, fine and medium grained, variegated, well bedded, and well sorted. 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 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 more shale in the beds than is seen from the outcrop examination.

Smooth bedding-planes and ripple-marked surfaces are common features of the Gardiner Beds. Fissility is well developed in the sandstone at the Wolf Creek Crater, in outcrops on the west bank of Sturt Creek opposite Sturt Creek Station, and in Sydney Margaret Range; the rock can be split into thin large slabs. Well preserved wave 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.

The Gardiner Beds usually show open asymmetrical folds with steeply dipping axial planes and gently dipping beds. The folding seems to become more intense from east to west. 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 steeper dips than elsewhere; eastern flank dips in this area are 5^{o}-35^{o} 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 associated with steeper dips.

At S55 the sandstone and conglomerate form strike ridges with troughs weathered out of the interbedded shale and claystone. This rhythmic alternation of arenites and lutites suggests cyclic sedimentation. Drag folds are present in the soft incompetent shale (Fig. 8).

Sedimentation is uniform 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 areal 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 air photographs and the dips measured in the area, is about 5000 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 coeval. 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.

Phillipson Beds (new name)

The Phillipson Beds are beds of friable current-bedded sandstone, with a basal polymictic conglomerate and a well developed joint pattern. They crop out in the Phillipson Range (Lat. 20^{o}33'S, Long. 128^{o}32'E), and extend as lines of cuestas north to Tent Hill (west of the Gardiner Range); they overlie Lewis Granite in the Lewis Range and at Mount Hughes, and contacts occur elsewhere with beds doubtfully referred to as the Gardiner Beds. No overlying unit has been seen in contact with the Phillipson Beds. They are probably Upper Proterozoic in age.

At Tent Hill (B10) the beds are friable current-bedded sandstone, dipping 5^{o} 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 air 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 constitutes 200 feet of this scarp, and is overlain by a coarse, ill-sorted conglomerate containing angular quartz, muscovite, and feldspar. Above the basal conglomerate is a friable, current-bedded, medium-grained sandstone with some quartz pebbles and muscovite flakes. The granite surface dips 3^{o} east. An almost identical section is exposed at Mount Hughes (L13).

The thickest section of the Phillipson Beds is exposed in the Phillipson Range at L14, 15, and 16, which form a more or less continuous stratigraphic section; from top to bottom:

(L16) 200 feet	Sandstone, white to light brown, medium-grained, ripple-marked in parts, thickly cross-bedded (sets up to 5 feet thick), some beds with clay pellets. Well jointed.
(L15) 50 feet	Sandstone, light brown flaggy to laminated, medium-grained, ripple-marked;
20 feet	Shale, chocolate-brown, fine, micaceous, interbedded with sandstone, light-brown, friable, occasional ripple marks;
20 feet	Sandstone, dark purple-brown, hard, siliceous, massive. Colour probably secondary;
20 feet	Sandstone, dark reddish brown, medium grained, abundant interference and wave ripple marks;
10 feet	Sandstone, variegated, soft, friable, poorly sorted.
(L14) (Thicknesses not measurable)	Sandstone, medium-grained, silicified, waved ripple-marked;
	Conglomerate, angular to subangular chert and jasper fragments, interbedded with sandstone, medium to coarse.

The sandstone at L16 is similar to that at Tent Hill and the Lewis Range.

Unaltered sandstone in the Erica Range, possibly belonging to the Phillipson Beds, 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^{o} to the west-south-west. The sandstone is well sorted, contains no pebbles, and looks 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 rare 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.

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^o and there appears to be a distinct lithological change.

ORDOVICIAN

Outcrops of probable Ordovician age are confined to the north-east part of the Mount Bannerman and north-west part of Billiluna Sheet areas.

The only definite outcrop of this age is on the road from Halls Creek to Billiluna, 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^o-15^o; thickness exposed is 250 feet. The rocks are 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 contains boulders up to 1 foot across. The age of the rocks at B3 is based on a solitary trilobite pygidium, identified by Miss J. Gilbert-Tomlinson (pers. comm.) as Dikelocephalina; it is probably Ordovician (Fig. 11).

One outcrop of questionable Ordovician age west of B3 was visited in 1957 by J.J. Veevers. The rocks are preserved in a syncline, and unconformably overlie the Kearney Beds.

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. Their deeper water equivalents are source beds for petroleum in the Fitzroy Basin, where oil traces were discovered at Prices Creek, north-west of B3. A large negative gravity anomaly, north-west of Billiluna Homestead, suggests either that a considerable thickness of Upper Proterozoic clastic sediments underlies the outcropping Ordovician sandstones, or that a section of sediments (such as Cambrian), hitherto unknown in the area, intervenes between the Proterozoic and Ordovician sandstones.

?DEVONIAN

Limestone

At M38, in the northern half of the Mount Bannerman Sheet area, a small outcrop of unfossiliferous limestone may be of Devonian age, because it lies in the direction of the trend of an outcrop of Bugle Gap Limestone (Guppy et al., 1958) at Pinnacle Spring, north of Christmas Creek Station, and is probably underlain to the south by a conglomerate which may be equivalent to the Sparke Conglomerate of the Fitzroy Basin. It appears to overlie Upper Proterozoic shale and Lower Proterozoic granite to the north and east, and is overlain by the Tertiary Lawford Beds. 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, but the dip or strike could not be measured on the solitary outcrop visited. The thickness of the limestone is not known.

Conglomerate

The conglomerate that probably underlies or interfingers with the limestone is exposed only as a debris of pebbles on the surface. The pebbles and cobbles are 1/2 an inch to 6 inches in diameter, mostly of quartzite, and are well rounded: they were eroded after being lateritized. The nearest comparable rock is the Devonian Sparke Conglomerate, which is a torrential conglomerate abutting the Lamboo Complex about 20 miles north-east of Christmas Creek Station (Guppy et al., 1958); and for this reason, and because the Sparke Conglomerate and Bugle Gap Limestone are in a similar relationship to the conglomerate and limestone at Christmas Creek, the latter are tentatively assigned to the Devonian. The conglomerate is about 100 feet thick.

UPPER DEVONIAN OR LOWER CARBONIFEROUS

Several outcrops of probable Upper Devonian or Lower Carboniferous sediments occur on the Billiluna Sheet area.

The sediments are less than 70 feet thick and consist essentially of sandstone with beds containing subrounded pebbles, and at B27 the basal beds are conglomeratic and interbedded with red shale. The surface of the sandstone is generally silicified and is current-bedded, with clay pellets, mica flakes, and abundant wood fragments.

Plant remains have been found, probably Leptophloeum australe (McCoy) at B4 in the Knobby Hills (see Fig. 12).

Reeves (1949) reports a specimen of Lepidodendron sp. 9 miles north 80^{o} east of Balgo Mission. This specimen was re-examined by Brunnschweiler & Dickins (1954), who considered it to be an impression of a lycopodinaean plant of the genus Leptophloeum, 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 Leptophloeum australe shows that the beds are older than this.

The sandstone beds unconformably overlie steeply dipping Upper Proterozoic quartzite at B28, 10 miles east-south-east of Skeen Hill; no contact with younger rocks has been seen.

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 the same age.

The beds were probably deposited in freshwater lakes at the margin of the Basin.

PERMIAN

Permian marine and freshwater sediments are more widespread through the Canning (and Fitzroy) Basins than any other rocks. They form good aquifers and many of the cattle stations depend on them 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 of the sequence exposed in the Fitzroy Basin. The Poole Sandstone has not been identified here; all other formations are represented. 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 was defined by Guppy et al. (1958) as a formation characterized by the large thickness of sandstone, conglomerate, tillite, siltstone, and varves recorded throughout the Fitzroy Basin; it is regarded as Sakmarian in age and overlies rocks as young as Upper Carboniferous.

As the Fitzroy Basin extends into the north-east Canning Basin, the rocks at Mount Bannerman, Mount Mueller, and near Billiluna Station have been referred to the Grant Formation as they occupy a similar stratigraphic position and are of similar lithology to the Grant Formation in the main Fitzroy Basin.

In the north-east Canning, the Grant Formation is predominantly a medium-grained, buff to red, fairly well sorted sandstone, with some clay pellets and containing some rounded or faceted pebbles and cobbles; fragments of fossil wood and wood impressions are common; mica is rarely seen; the sparkling surfaces of the sand grains show that they have regrown and recrystallized. The beds are usually cross-bedded and well jointed, which produces a rough terrain.

The 150-foot section at Mount Mueller (B24) is the most complete in the area and consists of:

(Top)	50 feet	Sandstone, bedded, blocky, medium-grained, with clay pellets, ripple marks; current-bedded and containing wood remains;
	100 feet	Sandstone, massive, friable, clayey, micaceous, with pebbles; foresets of the current beds dip south-south-west; it weathers to give a honeycomb appearance.

Other sections have been measured at

1. M44 (70 feet of section), which dips 1^{o} to the west-north-west;
2. Pyramid Hill, where a conglomerate with faceted cobbles overlies Proterozoic quartzitic sandstone;

3. north of Bulka Hills at M43, M44, and M45 (the last two are on the Mount Ramsay Sheet), where the polymict conglomerate contains wood remains; at M45 it is faulted against the brown and white micaceous sandstone and shale of the Noonkanbah Formation;

4. L39, where mica is conspicuous in coarsely cross-bedded sandstone with foresets dipping north;

5. B23, where worm trails in a clean sandstone crop out.

No major structures have been seen in the formation; dips are low and only small quartz veins cut the sandstone near faults.

Although about 8000 feet of Grant Formation was penetrated in West Australian Petroleum's Grant Range No. 1 Well in the Fitzroy Basin, the formation wedges out against older Palaeozoic rocks north of the Pinnacle Fault. Only 150 feet has been measured in the north-east Canning, but from low dips and photo-interpretation and from several water-bore logs, it is expected that the unit will be found to be at least 500 feet thick in this area.

The formation is a shallow-water shore-line deposit, judging from the predominance of sand, scattered wood, conglomeratic beds, and the widespread current-bedding; the faceted pebbles could suggest that it has, in part an aqueoglacial origin. No varves or tillitic deposits have been found in this area. The source of the sediments is probably the marginal Precambrian rocks and nearby Devonian conglomerates.

The formation is overlain by the Permian Condren Sandstone Member at Mount Bannerman, and unconformably overlies Precambrian rocks on the northern edge of the Basin. It is regarded as being Permian (Sakmarian) in age.

Noonkanbah Formation

The Noonkanbah Formation as defined in the Fitzroy Basin by Guppy et al. (1958) contained soft-weathering fine sandy siltstone and calcareous siltstone, interbedded with shale, calcareous micaceous sandstone, and sandy limestone, of Artinskian age.

In the north-east Canning the formation usually crops out as rubble-covered plains or forms black soil flats near Balgo Mission, around Lakes Jones, Betty, and Lonergan, in the Southesk Tablelands, in the Stansmore Range, and south of Christmas Creek Station.

The lithology is fine sandstone, quartz greywacke, and shale, with beds of coquinites; all are soft-weathering and crop out poorly.

The most complete and thickest section seen is 50 feet in the old Dooma Dora salty well (L4), where fossils were collected in brown, micaceous, medium-grained, soft greywacke-siltstone with dark micaceous shale; some calcareous shale and sandstone were seen in the spoils of the well.

Coquinites rich in Chonetes crop out near Balgo Mission at L38 and L29, and at Thomas Peak (L30) and C42 the silty sandstone is ferruginous and concretionary. The outcrops south of Mount Mueller (B21, B22) are fossiliferous, and the calcareous silty sandstone contains red clay pellets and coquinite interbeds. The outcrops in the Southesk Tablelands are yellow clayey sandstone showing ripple marks and clay pellets. Worm trails in laminated micaceous shale are seen at M8.

The black-soil flats and rubble-covered plains west of Shiddi Creek are underlain either by the Noonkanbah Formation or by the Lightjack Member: the small shale outcrops are overlain, probably with an unconformity, by the Blina Shale at the margins of some flats.

The outcrops are so poor in the Southesk Tablelands and Roberts Range that the Noonkanbah Formation cannot be distinguished from the overlying Balgo Member of the Liveringa Formation, which has beds of similar lithology in the sequence. However, a characteristic air-photograph pattern has enabled the Noonkanbah Formation to be identified in areas obscured by superficial deposits.

No major structure has been seen in the unit, but small faults cut trend-lines which show up clearly on air photographs in claypan areas.

In the Fitzroy Basin the formation has a consistent thickness of 1200-1300 feet, but the poor outcrops in the north-east Canning preclude any measurement; the thickest section exposed is 50 feet in the old Dooma Dora well.

The formation was probably laid down in quiet waters on a gently subsiding shelf, without winnowing by currents, but with bars or stationary strand-lines on or along which beds of coquinite accumulated.

The numerous Chonetes found in coquinites, and the bryozoa, echinoderm plates, gastropods, and ostracods from the Dooma Dora well, suggest a similar fauna to the Noonkanbah Formation in the Fitzroy Basin; the age is Artinskian.

The Noonkanbah Formation apparently rests on the Grant Formation, although no contacts were seen, and seems to grade upwards into the Balgo Member of the Liveringa Formation; the Blina Shale rests with a disconformity on the Noonkanbah in this area.

Liveringa Formation

The Liveringa Formation was mapped and defined by Guppy et al. (1958) in the Fitzroy Basin, where it consists of two marine sequences, the Lightjack and Hardman Members, separated by an unnamed freshwater sandstone. In the north-east Canning Basin the lower marine member and the plant-bearing member are widespread, but the Hardman Member has only been recognised at one locality.

Lightjack Member

Several incomplete sections of the Lightjack Member were found south of Christmas Creek Station - sufficiently close to the Fitzroy Basin to assume identity with the rocks mapped there. The thickest section measured was 70 feet at M56, near Astrofix N 21. Sections were measured at M49, M55, and M56; at each place the rock consisted of shaly siltstone overlying fine-grained quartz greywacke. All these exposures yielded fossils (frequently in concretions) typical of the Lightjack Member (see Guppy et al., 1958, p.52). Similar fossils were found in rubble from a well south of Tonka Spring.

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, well south of the Lightjack Member described above. Although it can be correlated with the Lightjack Member, there are no traceable boundaries between the two, and the southerly outcrops have been given a separate rock-unit name. The unit is named from Balgo Mission (Lat. 20°08'S, Long. 127°48'E), and the type section is at S67, in the Stansmore Range. The Balgo Member crops out near Derbai Creek and in the Stansmore Range, the Southesk Tablelands, Thomas Peak, Point Alphonse, and west of Mount Bannerman.

Outcrop is poor except in folded areas such as the Stansmore Range (Fig. 13). Highly ferruginized shale, fine and coarse-grained sandstone, and quartz greywacke predominate: the lithology is very similar to that of the Noonkanbah Formation (although they are nowhere in contact), except that it lacks calcareous beds; and several outcrops have been mapped as 'Balgo Member or Noonkanbah Formation' because the two could not be distinguished.

The type section, at S67, is as follows (though the measured section is only 66 feet, the completed section, as interpreted from air photographs, is about 800 feet):

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 reddish. Massive, poor bedding, moderately well-sorted and breaks into angular pieces. Contains thin beds of very fine sandstone.
1 foot	Sandstone, coarse-grained light brown, with rounded pebbles up to 3 inches in diameter.
5 feet	Sandstone, fine-grained, micaceous, soft, laminated, silty pink to red and light brown. Ferruginized dark red to brown sandstone bed near middle, 6 inches thick, with concretions and muscovite, and marine fossils: pelecypods, gastropods, and rare brachiopods.

Other exposures from which fossils have been collected are S9, two miles north-west of Warri Peak, S1, near White Hills, S6, and L30 (Thomas Peak). Spoil from well 47 on the Canning Stock Route is reported by drovers to contain fossils 'like the Shell sign' - probably *Aviculopecten*, which is common in the Balgo Member. Slump folds, concretions (many of which are fossiliferous), ripple marks, clay pellets, and worm tracks are common; and at some places (e.g. S6, B14) the concretionary beds contain conglomerate bands with quartzite and other pebbles up to 6 inches across; fossil wood has been seen in some micaceous sandstone beds.

The beds were laid down in a shallow neritic environment, devoid of strong currents which would produce a clean sorted sediment, but in an environment in which many benthonic forms survive and produce thick carbonate skeletons indicative of shallow, warm water.

By analogy with the Lightjack Member, the Balgo Member may be expected to overlie the Noonkanbah Formation conformably: but no contacts have been seen. Conformable contacts with the overlying Condren Sandstone Member have been seen at Pallotine Headland, near Derbai Creek, and at L9.

The contained fossils (see Appendix 1) date the Balgo Member as Artinskian -Kungurian.

Condren Sandstone Member (new name)

The Condren Sandstone Member is the middle, plant-bearing, member of the Liveringa Formation; the type locality is L44, at Condren Pinnacles (Lat. 20^{o} 06'S, Long. 127^{o} 88'E), 12 miles west-north-west of Balgo Mission (Fig. 14). The Member is generally a well sorted micaceous sandstone, light-coloured and porous, with a pronounced joint pattern which produces a rough surface easily recognisable on air photographs. It is probably the most widespread of the three members of the Liveringa Formation, and is well exposed in the Stansmore Range and around Balgo Mission and Christmas Creek. Typically it tops mesas, buttes, or breakaways.

The type section at L44 is:

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

10 feet — Sandstone, white, clayey, weathered and 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 overlying

Balgo Member, ferruginized concretionary sandstone and siltstone.

Many sections were measured, over a wide area, and the Condren Sandstone proved to be remarkably uniform in lithology. About 145 feet was measured at Point Alphonse, 130 feet at Mount Bannerman, 65 feet at Gordon Hills (L11), 140 feet at Mount Erskine (M18, see Fig. 15), 60 feet at M30, and M47, 100 feet at S70, and over 70 feet at C39. The sandstone is mostly well bedded - in places laminated or even rhythmically bedded; mica is a common constituent of the fairly well sorted, medium to fine-grained white, buff, or light brown sandstone. Current bedding is common and ripple marks less so; clay pellets are present, but the sandstone matrix is rarely clayey; worm tracks and concretions are rare; pebbles of quartzite, quartz, or, rarely granite are present in conglomerate bands scattered through the rock.

South-east of Godfreys Tank outcrops are less common.

Plant remains are ubiquitous. From the 900-foot section at Christmas Creek, Guppy et al. (1958) record Bothrodendron sp. ?Gangamopteris sp., and Glossopteris indica (Brong.) ; and White (in Veevers & Wells, 1961) has described the following species from the Condren Sandstone Member: Schizoneura sp., Glossopteris communis Feist., Gangamopteris cyclopteroides Feist., Samaropsis sp., Vertebraria australis McCoy, V. cf. indica Royle, Lycopodiopsis pedroanus Carr., Carpolithus sp., Noeggerathiopsis hislopi (Bunb.), and Phyllotheca cf. australis Brong.

Apart from the section at Christmas Creek, the thickest section estimated was some 500 feet in the Stansmore Range area, where a 150-foot section was measured. This is the thickest section measured in the area.

The Condren Sandstone Member was probably laid down in shallow water, estuarine or lacustrine. It lies apparently conformably on the Balgo Member and at Bababara Rockhole is seen to be overlain, with no apparent unconformity, by sandstone and Isaura-bearing siltstone of the Triassic Blina Shale. At Mount Bannerman it is capped unconformably by 20 feet of pebble conglomerate of unknown age, with a siltstone breccia at its base. That it is Permian can be deduced from its flora.

Hardman Member

Rocks assigned to the Hardman Member of the Liveringa Formation (Guppy et al., 1958, p.51) crop out in a small area around Boundary Hill (M50) in the north-west corner of the Mount Bannerman Sheet, where 60 feet of mottled white, grey, and ferruginous, medium-grained, poorly sorted, micaceous, flaggy sandstone and siltstone are exposed. They have yielded poorly preserved Aulosteges sp. and Conularia sp. (G.A. Thomas, pers. comm.). The Aulosteges is comparable to a species in the Hardman Member of the Fitzroy Basin, and the Conularia is like a species from the top beds of the Port Keats Group, which is of the same age: Upper Permian (Tartarian).

To the south, friable medium-grained sandstone and conglomerate, probably belonging to the Condren Sandstone Member, probably underlie the Hardman sediments conformably: no other relationships with other rocks were seen.

The Hardman Member is absent farther east and south, probably because of non-deposition. No deductions about the environment of deposition can be made from the Boundary Hill exposures.

UNDIFFERENTIATED PALAEOZOIC

Lucas Beds

The Lucas Beds are beds of friable, pale purple, well-sorted, fontainebleau sandstone with some clay pellets and interbedded laminated claystone. They are named from Lake Lucas five miles west of the northern arm of Lake White (Lat. 21°00'S, Long. 129°00'E) where they crop out on the eastern shore and in the floor of the lake. This northern arm was identified by the geological party as the lake named Lake Lucas by Warburton, and the beds were so named because they crop out in its floor; but the Lands and Survey Department of Western Australia ruled that Warburton's 'Lake Lucas' was the claypan five miles west of the lake. Fortunately the Lucas Beds crop out in the floor of Lake Lucas also, so the name did not have to be changed; but the best, and nominate, exposure is in the bed of Lake White.

The age of the Lucas Beds is not known, but they are similar in both photopattern 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.

In the Lake Lucas area, the Lucas Beds have contacts with both probable younger and older formations. At Yam Hill (L48) the following section is exposed:

30 feet	Sandstone, medium and fine grained, partly 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 feet	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 is lithologically similar to the Permian sediments to the west; the overlying sandstone is also regarded as probable Permian. However, it is possible that the Lucas Beds 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 the northern arm of Lake White (Fig. 17), and bedding trends, joints, and small faults are very pronounced on air photographs, but a thin cover of salt and sand precluded an examination. The alternating dark and light thin bands visible on the photographs are probably due to the rhythmically bedded sandstone and claystone. The Permian Noonkanbah Formation in the Fitzroy Valley often shows a similar photopattern.

At Lake White, the beds dip at 3^{o} east and are about 900 feet thick; 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 Lake White, a 23-foot section of interbedded fontainebleau sandstone and laminated claystone, capped by caliche, is exposed. 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 inch. 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 and 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 barytes pebbles occurs; they probably originally formed a thin bed or lens in the Lucas Beds.

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

TRIASSIC

Blina Shale

The Blina Shale was defined by Guppy et al. (1958) as the basal Triassic formation that overlies the Liveringa Formation, probably unconformably, in the Fitzroy Basin. It is characterized by the presence of the conchostracan Isaura (= 'Estheria').

In the north-east Canning Basin the Blina Shale overlies the Liveringa and Noonkanbah Formations and has been encountered in the Bishops Range and Stretch Range and at Bishops Dell and Chilpada Chara. It underlies many of the black soil areas near Lakes Lonergan, Betty, and McLernon. Except in the Bishops Range, outcrops are poor and consist of scattered rubble, or small scarps a few feet high.

The formation consists mostly of micaceous shale and fine sandstone, with some medium-grained sandstone; the rock is pale brown to white when fresh, but reddish brown when weathered. Sections have been measured at C12 (45 feet), C13 (25 feet), C14 (40 feet), C31 (50 feet), M12 (40 feet), M14 (45 feet), and M15 (100 feet). The top of the formation is everywhere eroded, but the total thickness probably does not exceed 150 feet.

Isaura is present in many sections; that at M52 is almost a coquinite, and contains worm trails also (Diplocraterion, A.A. Opik, pers. comm.). Lingula has been found at M13 and M14, and a pelecypod, cf. Pseudomonotis, together with worm tracks and wood remains, at M22.

The Blina Shale was probably laid down in moderately shallow brackish water in a shelf-type environment; the laminae at M52 seem to have been affected by interference ripple marks or small-scale slumping.

The stratigraphical relationships of the Blina Shale in the north-east Canning Basin are obscure; they are discussed by Veevers & Wells (1961, p.115). At Chilpada Chara (C13) and at M29 the Blina Shale overlies Culvida Sandstone (see below), which is of Upper Triassic or even Jurassic age; on the other hand, in the Fitzroy Basin the Blina Shale underlies the Erskine Sandstone (Guppy et al. 1958, p.56), which is equivalent to the Culvida. The most probable explanation is that the terrestrial Erskine and Culvida Sandstones were laid down during a temporary regression of the sea at whose edge the Blina Shale was deposited, and were covered by upper Blina Shale during a renewed transgression. The fossils are neither numerous nor diagnostic enough to confirm this.

Isaura, according to Brunnschweiler (1954), indicates an Upper Triassic age.

Culvida Sandstone (new name)

The Culvida Sandstone is a richly fossiliferous plant-bearing sandstone which overlies either the Blina Shale or the Condren Sandstone Member, and is overlain by the Cretaceous Godfrey Beds.

It crops out mainly in the Minnie Range - Culvida Soak, Well 50 area, Chilpada Chara - and the type locality is at and around Culvida Soak (Lat. 20°13'S, Long. 126°55'E), where the outcrops terminate to the east against a north-south fault.

The type section is half a mile south of Culvida Soak, where the following 60-foot section is exposed:

30 feet Sandstone, 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.

The sandstone exposed at Culvida Soak is probably equivalent to the 10-foot massive sandstone unit in the section, though at Culvida Soak it is current-bedded and contains lenses of claystone and pellet beds; although the surface is brown, the fresh rock is light coloured; muscovite is present but it is not abundant.

The siltstone in the section contains many mudcracks; pieces of the desiccated siltstone have been caught up in the overlying sandstone beds.

Plant fossils occur upstream from Culvida Soak in siltstone which becomes interbedded with the massive sandstone; other plant fossils are found in a 100-foot hill at C63.

The formation seems conformable with the underlying Blina Shale but is probably unconformable on the Condren Sandstone Member.

The maximum section measured was 105 feet in a hill near C63, and it is doubtful if the formation is thicker than 200 feet in any place.

The Culvida Sandstone may be equivalent in age to part of the Erskine Sandstone (Brunnschweiler, 1954) of the Fitzroy Basin. The inter relationships of the Triassic formations of the Canning Basin are discussed by Veevers & Wells (1961, p.115), and plant fossils from the Culvida Sandstone are described by Mary White (in Veevers & Wells, loc. cit., App. 6), who assigns them to the Middle Triassic.

CRETACEOUS

Godfrey Beds

The Godfrey Beds (Elliott, Casey, & Wells, 1958) are named from Godfreys Tank (Lat. 20°12'S, Long. 126°33'E), in the vicinity of which are the only exposures (Figs. 19, 20). They crop out as prominent breakaways, and many peaks in the area named by early explorers are capped with Godfrey Beds. The breakaways are generally capped by 20 feet or so of massive sandstone, under which is softer sandstone in which rockholes readily form at the end of the steep-sided narrow valleys that cut into the hills. Godfreys Tank and Breadens Pool are two such rockholes.

In general the Beds consist of massive quartz sandstone, slightly micaceous, hard and friable, with minor beds of conglomerate, thin-bedded sandstone, and siltstone. The rock is white or pale yellow-brown when fresh and red-brown when weathered. The surfaces are ripple-marked, and burrows of the marine worm Rhizocorallium (Veevers, 1962) are common (Fig. 21).

The type section at C3a (Lat. 20°12'35"S, Long. 126°33'00"E) is as follows:

1 foot	Sandstone, brown, weathering red-brown, poorly thin-bedded, coarse, ill-sorted, conglomeratic with pebbles up to 4 inches long of white and grey quartzite;
13 feet	Sandstone, pale brown and greyish brown, sometimes golden brown, weathering red-brown, fine-grained, thin-bedded, some worm markings, fragments of pelecypods;
121 feet	Sandstone, pale reddish and yellowish brown, weathering red-brown, fine-grained, thin-bedded to laminated, some beds soft, others hard; cross-bedded, numerous worm trails of Rhizocorallium, few thin beds of siltstone, dark brown, thin-bedded;
6 feet	Sandstone, yellow-brown, weathering red-brown, coarse, ill-sorted, poorly bedded, weathers into slabs about four inches thick, a prominent bench marker around the hills.
38 feet	Sandstone, pale yellow-brown, weathering red-brown, fine-grained, soft and crumbly, thin-bedded; near top occasional bed of sandstone, brick red, medium-grained, soft and crumbly.

In other sections measured, the sandstone is more massive, and beds containing clay pellets have been noted near the top of the sequence at Breadens Pool (C57) and Crown Head. At C57 the sequence is 150 feet thick, at Crown Head 300 feet, and at C54 - which is disturbed by faulting - 80 feet.

The beds dip only very slightly, except at C54, where the faulting has tilted them to dip at 17°.

No contacts of positively identified Godfrey Beds with any other formation have been seen. One outcrop near Culvida Soak has been photo-interpreted as Godfrey Beds over Culvida Sandstone, and an exposure at C59 (Fig. 22) of coarse conglomerate over sandstone and shale is probably of Godfrey Beds over Permian.

The widespread presence of the marine worm Rhizocorallium dates the Godfrey Beds as Lower Cretaceous (probably Cenomanian) (see Veevers, 1962), and this is confirmed by the presence of ?Etea sp. (J.M. Dickins, pers. comm.) in the Godfrey Beds at C2a.

Other probable Cretaceous rocks crop out near Brookman Waters, on the Stansmore Sheet (S60 and 61), where a cream siltstone yielded radiolaria cf. Cenosphaera, of probable Albian age (Dr I. Crespin, pers. comm.). These rocks lap against Precambrian. Other outcrops, north of Brookman Waters and in the Murabba Range, have been photo-interpreted as Cretaceous.

Figure 15. Condren Sandstone Member, Mount Erskine

Figure 16. Conical hills of Condren Sandstone caused by erosion along joints, Forebank Hills

Figure 17. Northern arm of Lake White with Lucas Beds in foreground

Figure 18. Lucas Beds on eastern shore of Lake White

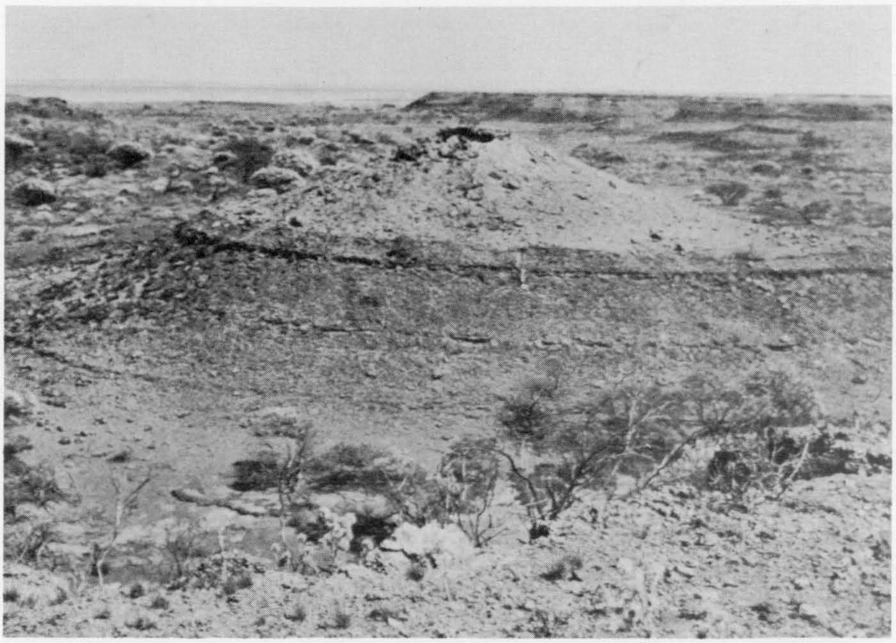
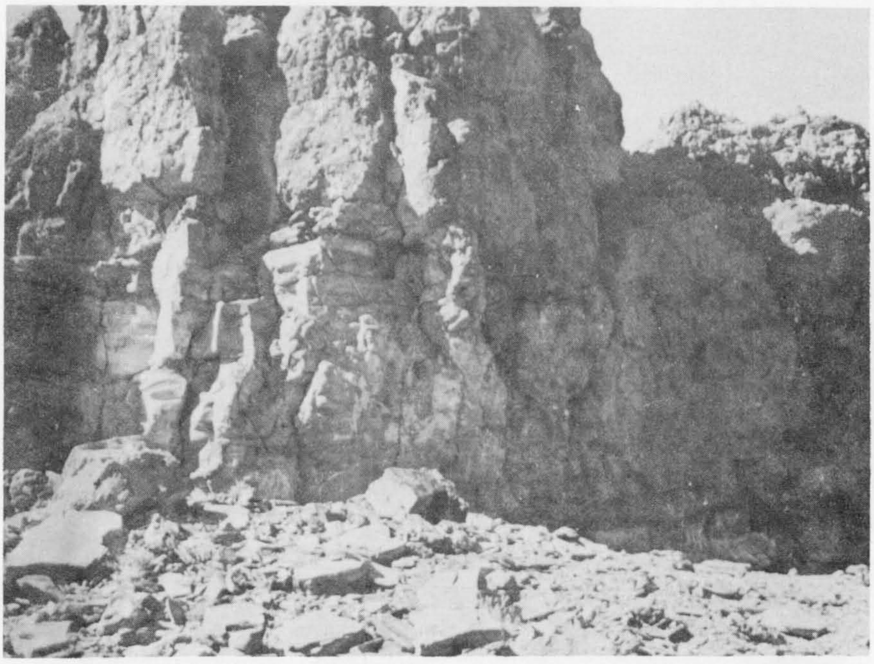


Figure 19. Godfreys Tank

Figure 20. Godfrey Beds near Godfreys Tank

Figure 21. Rhizocorallium in Godfrey Beds, Godfreys Tank

Figure 22. Irregular contact of Condren Sandstone Member with possible Godfrey Beds



TERTIARY

Laterite and Pisolitic Ironstone

Laterite is not widespread and probably never was: it occurs on Lower Proterozoic but not Upper Proterozoic rocks, and pisolitic ironstone caps many of the breakaways in the desert. A better developed profile is found over fine-grained rocks - shale, claystone, and quartz greywacke.

Two isolated occurrences of massive ironstone have a different origin. One, at the north end of the Gardiner Range, about 17 miles south-west of Mount Brophy Spring, may be a detrital laterite. It is dark brown, almost black, vuggy and easily broken, and forms undulating hillocks on the valley floor. It is probably not more than 15 feet thick. The other is a 40-foot thick limonite and limonitic breccia at S54 in the Sydney Margaret Range, and may have been deposited in a lake or from a spring.

Lawford Beds (new name)

The Lawford Beds are massive lacustrine marl and limestone, with a chalcedony capping, which crop out in the Lawford Creek area; some conglomerate and pisolitic ironstone occur at the base.

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, probably lacustrine;
60 feet	Earthy lateritic material, mottled, pisolitic and pallid, some conglomerate possibly derived from the surrounding lateritic material or older conglomerates; in places it is marly and it 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, and thus probably antedates the lake deposits.

The Lawford Beds were deposited in a valley in the dissected laterite crust. The Devonian conglomerate which covers a great deal of this area was probably lateritized and eroded and the surface left covered with pebbles; the surface was then dissected by an ancestral Christmas Creek which formed stream deposits consisting of boulders set in earthy lateritic material. When the creek was dammed, slow evaporation formed the marl and chalcedony deposits of the Lawford Beds, which were later dissected to give the existing mesa and butte topography.

Wolf Gravel (new name)

The Wolf Gravel is the unconsolidated gravel, conglomerate, and sand of unknown thickness along the banks of Wolf Creek. The Wolf Gravel is 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. Its age is unknown.

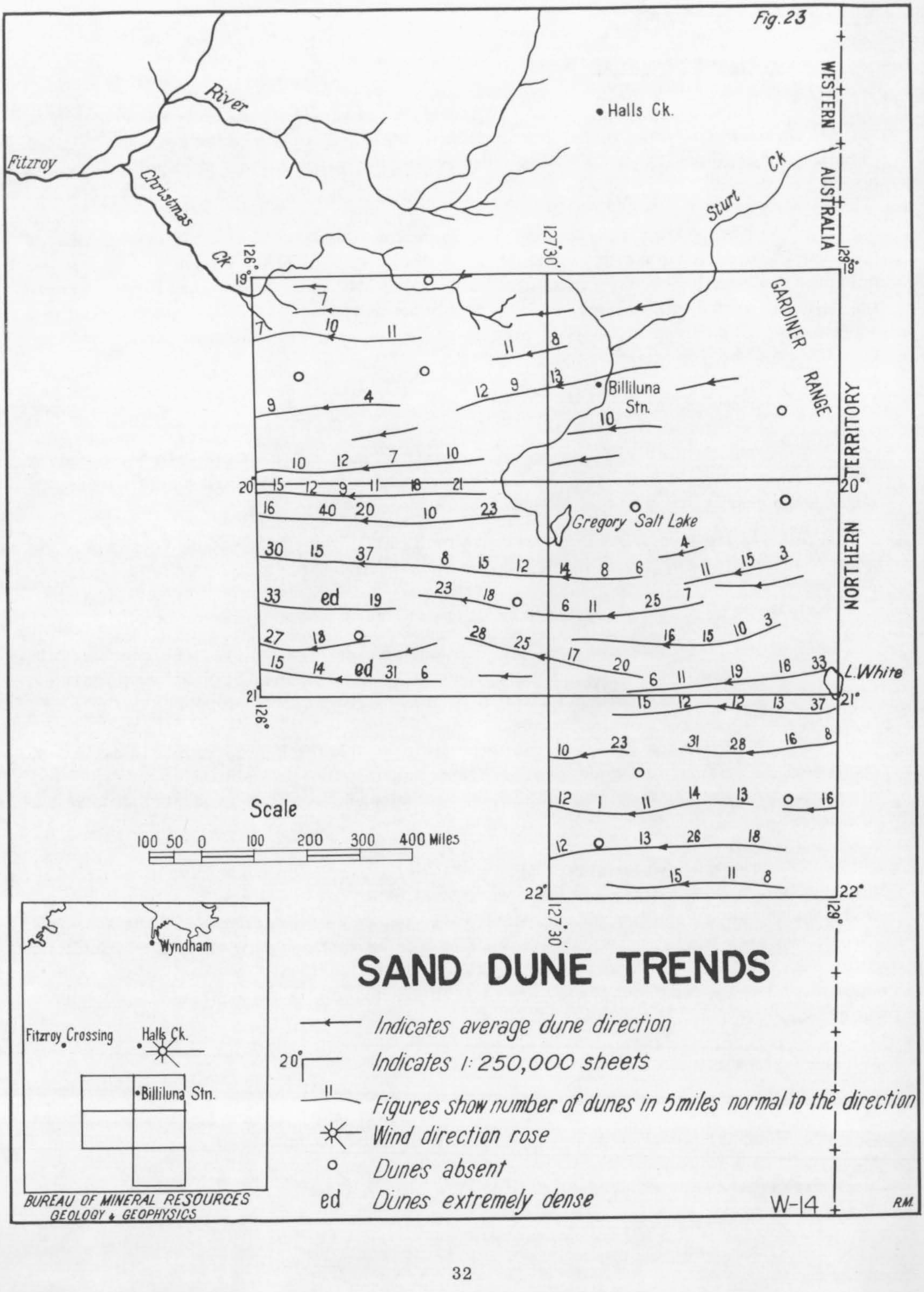


Fig. 23
Halls Ck.
Fitzroy
River
Christmas
Ck
Sturt
Ck
WESTERN AUSTRALIA
NORTHERN TERRITORY
GARDINER RANGE
Billiluna Stn.
Gregory Salt Lake
L. White
Scale
100 50 0 100 200 300 400 Miles
Wyndham
Fitzroy Crossing
Halls Ck.
Billiluna Stn.
SAND DUNE TRENDS
Indicates average dune direction
Indicates 1: 250,000 sheets
Figures show number of dunes in 5 miles normal to the direction
Wind direction rose
Dunes absent
ed Dunes extremely dense
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W-14
R.M.

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

QUATERNARY

Recent

Recent sediments in the area include aeolian sand, travertine and caliche, evaporites, river alluvium, gravel and sand, and alluvial black soil. Aeolian sand covers large tracts of the desert as sand plains or east-west seif dunes (see Fig. 23) which are particularlynumerous in areas occupied by post-Precambrian rocks. The formation of the seifs is discussed in Traves et al. (1956) and Veevers & Wells (1961). Samples of the sand were collected and analysed by G. Brown (1959). Most of the grains are less than 1mm across, but are generally coarser than normal desert sands. Heavy minerals constituted less than 1% of the sample; zircon, tourmaline, hornblende, andalusite, black iron ores, and rutile were the most plentiful. A hematite coating on the grains gives the sand a pronounced red to orange colour.

Travertine and caliche deposits are commonly found in salt lakes; 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 true lake deposit. It is a massive white limestone which weathers to a dull grey colour, and is often interbedded with massive or occasionally laminated, much brecciated, chalcedony. The brecciation may be caused by isolation on a thin laminae of chalcedony, the fragments being later incorporated in 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 are embedded in a thin crust of powdery caliche.

STRUCTURE

The north-east Canning region forms part of the Canning Basin, and it contains the extension of some of the main structural features of the Fitzroy Basin to the north-west: the Pinnacle Fault, the Fitzroy Trough, and the Broome Ridge or Swell. The Precambrian margin in this region includes parts of the Warramunga (Noakes, 1953) and King Leopold (Traves, 1955) Mobile Zones. The major structural lineaments, anticlinal axes, and bouguer anomalies are shown on Plate 2.

The ?Lower Proterozoic rocks (Halls Creek Metamorphics) south of the Gardiner Range are tightly folded, and probably are the western extension of the Warramunga Mobile Zone, which passes through Tanami, Tennant Creek, and the Davenport Ranges; they are intruded by the Lewis Granite and unconformably overlain by Upper Proterozoic arenaceous sediments. The relationship of the Lewis Granite to the granite near Tanami is not known, but petrologically and in hand specimen appearance it is similar to the granite in the Davenport Range, which is dated as about 1440 million years (Walpole & Smith, 1961).

In general, the Upper Proterozoic sediments have low dips (10° or less) in contrast to the Halls Creek Metamorphics, but where Upper Proterozoic sediments have been laid down in Mobile Zones (e.g. Kearney Beds), they have been more strongly folded and faulted than their time equivalents (e.g. Gardiner and Phillipson Beds) laid down on stable blocks such as the Kimberley Block (Gentilli & Fairbridge, 1951) and Stuart Block (Noakes, 1953). The Upper Proterozoic sediments on the stable blocks show broad synclines and anticlines only; and fold axes and faults trend generally east-west in the northern parts of the area (that is, they are parallel to the Mobile Zones), but in the south-east (Lake Hazlett/Red Cliff Pound) they trend north-south and have influenced the shape of the Canning Basin.

The structure in the north-east Canning is based on geological mapping, gravity, and limited aeromagnetic work; no seismic work has been done, although some is programmed by the oil tenement holder.

Gravity surveys carried out recently by the Geophysical Branch of the Bureau of Mineral Resources in the Canning Basin have produced many interesting gravity anomalies which divide the north-east Canning into several tectonic features which can be traced into the Fitzroy Basin. The report on the gravity survey (Flavelle & Goodspeed, 1962) gives the following observations on this area:

'The Hardman Basin [to the north-east of the area] containing Palaeozoic sediments . . . is probably continuous with the Mount Bannerman Gravity Trough. The Trough continues across the Basin boundary without any appreciable change in anomaly magnitude. The gravity minima [Trough] therefore probably represent the effect of a considerable thickness of Proterozoic sediments on both sides of the Basin boundary. Because Lower Palaeozoic sediments are present in the Hardman Basin, it is possible that similar sediments are present at depth [in this area].

'The structure that causes the anomaly "lows" of the Mount Bannerman Gravity Trough branches near Billiluna homestead; a series of "lows" trends south from there, parallel to the Basin edge. This feature has been named the Stansmore Gravity Trough and like the Mount Bannerman Gravity Trough it probably represents a considerable thickness of Proterozoic sediments. In addition, the north-south Trough branches on the Lucas Sheet area where there is a pronounced west-north-west anomaly "low". It is possible therefore that the influence of the Warramunga Mobile Zone extends this far (Traves, 1955).

'The Stansmore Fault is characterised by a steep gradient at its southern end, near the Stansmore Ranges. Towards the north, where its throw is decreased, it crosses the gravity trends obliquely. The main variations in basement depth probably run north from the Stansmore Ranges, following the trend of the Stansmore Gravity Trough.

'Owing to the paucity of outcrop and total lack of subsurface (such as seismic) data it must be assumed that the Gregory Lake Gravity High probably represents shallow basement.'

The extension of the Fitzroy Trough into the north-east Canning seems to be reflected in a series of gravity 'lows' running south-east through the western part of the Mount Bannerman Sheet into Cornish; the Trough seems to be dying out south of Godfreys Tank. The existence of the 'Lonergan Hinge' (Casey & Wells, 1960), which was thought to trend generally south and east from near Balka Hills to the Stansmore Range, is not fully substantiated by the recent gravity results. However, there still remains a series of gravity 'highs' at Lake Betty, north of Godfreys Tank, and west of Gregory Salt Lake, which should be investigated further with seismic surveys for possible petroleum targets.

The Pinnacle Fault is traced into the northern part of Mount Bannerman Sheet, where it seems to be bifurcated by Precambrian at Balka Hills into east-west and south-east trending faults. If this south-east fault still reflects the north-eastern edge of the deep Fitzroy Trough (as the Pinnacle Fault does in the Fitzroy Basin), the gravity anomaly and the surface anticline in the Lake Lonergan/Lake Betty area would be an important area for investigation.

The south-east extension of the Broome Ridge or Swell, which marks the southern edge of the Fitzroy Trough, can be traced by positive gravity anomalies into the Cornish Sheet; according to gravity results the minimum sedimentary section over the ridge is near the north-western corner of Crossland Sheet, which is to the west of Mount Bannerman Sheet (Flavelle & Goodspeed, 1962, p.16).

The Stansmore Fault crops out between the Stansmore Range and the Bishop Range, a distance of 110 miles. It is best expressed in the Stansmore Range (Veevers & Wells, 1961, text-fig. 55), where the Liveringa Formation and probably the Noonkanbah Formation are exposed on the downthrow (western) side. Outcrops on the eastern side are poor, and are mapped as undifferentiated Permian. Rocks immediately west of the fault dip up to 30^{o} westward, and flatten off within 5 miles of the fault, in the Stansmore Range. The Bouguer gravity contours (Flavelle & Goodspeed, 1962) parallel the fault, and the anomaly across the fault, 5 miles south of Warri Creek, ranges from -30 mgals one mile east of the fault to -50 mgals 3 miles west of the fault, indicating a considerable downthrow to the west; this was calculated by Garrett (1956) as about 7800 feet, assuming a density contrast of 0.4 gm/cc. The Stansmore Range is the only area in which the gravity results are obviously connected with surface structure. North-west of the Stansmore Range, the fault runs obliquely to a broad positive anomaly south of the Gregory Salt Lake ('Gregory Lake Gravity High' of Flavelle & Goodspeed, 1962). In the Stretch Range, the Liveringa Formation and the Blina Shale crop out on both sides of the fault. We believe that the gravity and aeromagnetic data do not indicate the surface of the Precambrian rocks for the following reasons:

(1) An elongate negative anomaly ('Stansmore Gravity Trough' of Flavelle & Goodspeed, 1962) trends north of Waterlander Breakaway across the Stansmore Fault in the Stretch Range, and through Balgo Hills, and branches at Knobby Hills; one branch continues northward through the Wolf Creek Meteorite Crater, another trends westward to Mount Erskine, and a third trends east of the Stretch Range to Lake Lucas. No change is registered over the Precambrian sedimentary rocks at the basin margin near the Meteorite Crater, and this suggests that the anomaly is related, at least in part, to the underlying, probably thick Precambrian (probably Upper Proterozoic) sedimentary rocks. A rise in the negative anomaly west of the crystalline Precambrian rocks near the Kearney Range probably reflects thin Precambrian and younger sedimentary rocks over the crystalline rocks. The gravity trough between the Stretch Range and Lake Lucas probably indicates thick Precambrian sediments or Lucas Beds or both.

(2) An aeromagnetic traverse (Spence, traverse 14) passed without anomaly from the Canning Basin near Mount Bannerman northward to the Precambrian quartzite of the Cummins Range, showing that the Precambrian sedimentary rocks of this area are indistinguishable magnetically from the Phanerozoic rocks.

The area of the negative Bouguer anomaly is covered either by younger Precambrian sedimentary rocks or Phanerozoic rocks alone. The gravity and aeromagnetic evidence supports the idea that Precambrian sedimentary rocks extend from the margin into the Basin, and perhaps are thickest in the Basin. The basinward limit of the postulated Precambrian sedimentary rocks is possibly marked by the west and south parts of the negative Bouguer anomaly.

The Stansmore Fault, except its southernmost part, and almost all other faults in the north-east Canning Basin strike obliquely to the Bouguer contours; the displacement on the Stansmore Fault is considerable (5000 feet or more) in its southernmost part, and probably negligible elsewhere. The numerous faults that trend south-south-eastward in a belt south-east of the Fitzroy Trough have small displacements. Structural domes and basins are known in various places in the north-east Canning Basin (Veevers & Wells, 1961, text-figs. 55, 66, and plate 2).

The broad Bouguer anomalies with low gradients, and the smooth aeromagnetic anomalies, indicate, by comparison with these features in the Fitzroy Trough, that the depth of the crystalline basement is deep. Two aeromagnetic anomalies, one 20 miles north-east of the Dummer Range, the other 10 miles north-west of Chilpada Chara, may be interpreted as indicating the sides of the Fitzroy Trough.

The south-east extension of the Broome Ridge or Swell, which marks the southern edge of the Fitzroy Trough, can be traced by positive gravity anomalies into the Cornish Sheet; according to gravity results the minimum sedimentary section over the ridge is near the north-western corner of the Crossland Sheet, which is to the west of the Mount Bannerman Sheet (Flavelle & Goodspeed, 1962, p. 16).

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 in 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 the surface dips 3^{o} to the east.

All the Upper Proterozoic sediments were deposited in a similar environment, and Traves et al. (1956) suggested that their source was uplifted areas of the granite and metamorphics which now form 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 plains of sand underlain by Lower Proterozoic rocks.

The Canning Basin began to form in the Ordovician, with coarse-grained sandstone and conglomerate deposited on a shallow marine shelf. The Silurian and Lower Devonian was apparently a period of non-deposition.

The Middle and Upper Devonian and Lower Carboniferous are well represented in the Fitzroy Basin; but the only outcrops of this age in the north-east Canning Basin are the small areas of limestone and freshwater sandstone on the Mount Bannerman and Billiluna Sheets. Biohermal and biostromal limestones may have developed along hinge and positive gravity areas in the Mount Bannerman and Cornish Sheets, but they are not exposed. No Upper Carboniferous rocks are exposed in the area, but the Mount Anderson Formation of the Fitzroy Trough, which is only known from drill holes, may be present below the surface in the south-easterly continuation of the trough into the north-east Canning Basin.

Permian sedimentation began with aqueoglacial sediments of the Grant Formation, followed by alternating marine and brackish-water sediments; the richly fossiliferous Noonkanbah Formation follows the Grant Formation with a minor break 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, after which a minor transgression laid down the Hardman Member over a small area. The Condren and Balgo Members are widespread; both are certainly in contact with the Grant Formation and may have overlapped the Noonkanbah Formation.

The Permian sediments were eroded and gently folded before the Triassic Blina Shale was deposited in brackish or estuarine water, and the plant-bearing Culvida Sandstone, perhaps contemporaneously, farther to the east. 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. 22).

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 structure and topography of the Precambrian basement no doubt influenced the shape of the Canning Basin and the trend of folds and faults.

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.

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.

The deposits on the bed of Gregory Salt Lake consist of fine white silt and powdery caliche with minor amounts of salt. The proportion of salt rises in certain parts of the lake bed, particularly at the 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 the Hidden Basin and Weston Basin (Terry, 1934) near the Northern Territory Border, are covered with a white salt crust. Samples of the top three inches of salt crust were collected from the bed of Lake White. White, powdery, calcareous material constitutes the top half inch and is underlain by a layer of salt crystals about two inches thick. The salt crystals are underlain by soft brine-saturated sand and silt of unknown depth. Lumps of white, porous, homogeneous, calcareous travertine, up to six inches in diameter, are scattered on the soft caliche layer at the surface. 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 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.

A sample from Lake Mackay reported by Terry (1934) contained 20.08% $CaSO_4$, 4.17% NaCl, and 0.93% KCl.

On the margin of Lake Lucas near L18 a small deposit of pink barytes is found. It occurs as a small line of boulders in weathered sandstone and shale of the Lucas Beds, and was probably deposited as a small lens.

Metallic Deposits

No metallic deposits are being worked commercially within the area examined. Near the Gardiner Range, traces of gold were reported (Davidson, 1905) from quartz veins cutting the Lower Proterozoic Halls Creek Metamorphics. The metamorphics show few signs of hydrothermal action; a few very narrow quartz veins occur. However, the area south-west and south of Larranganni Bluff and east of the Lewis Range is worth further prospecting. In both areas quartz veins are more numerous and considerable areas of granite occur; some crystalline hematite is associated with the quartz veins. Radiometric tests of the Halls Creek Metamorphics in several areas, and of Upper Proterozoic shales at the south end of the Gardiner Range, gave negative results.

Gold has been worked spasmodically since 1880 at the Ruby Queen mine, 20 miles south of the Halls Creek township. Numerous quartz reefs cut interbedded schists and quartzites and the lode varies from a few inches to 15 feet wide, and yielded an average of 12 to 15 dwt per ton; the depth of the workings is 200 feet. Total production has been 6250 oz.

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

Petroleum Prospects

As the Fitzroy Basin extends at least into part of the north-east Canning, the petroleum possibilities of the north-east Canning must not be underestimated, even though less than 3000 feet of Palaeozoic and Mesozoic sediments are exposed.

Any continuation of Ordovician rocks south-east from the Fitzroy Basin could form the best source rocks for petroleum; Ordovician calcareous beds containing traces of oil crop out at Prices Creek (Guppy et al., 1958), 20 miles north-north-west of the north-west corner of the area. Ordovician sandstone and conglomerate crop out in the Cummins Range and west of Wolf Creek, and could have deeper water and calcareous equivalents to the south-west. The Devonian sediments, although thin and sandy, could also have suitable source rocks as their deeper water equivalents. In the Noonkanbah and Balgo units only the shale beds could be regarded as having any source possibility.

Reservoir rocks (carbonate, including reefs, and sandstone) are known in the Ordovician, Devonian, and Permian sequences elsewhere in the Fitzroy Basin and these probably extend into the north-east Canning.

Cap rocks of shale and dense limestone may also persist at depth into this area.

Until more is known about the origin of some 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.

Water

The low rainfall and high evaporation mean that full use must be made of underground as well as surface water supplies. Surface waters in the area are very few, and consist chiefly of the semi-permanent pools (Ima Ima, etc.) in Sturt Creek in the Billiluna Sheet area; this lack of good water has naturally restricted pastoral development. 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, another large rock-hole near Breadens Pool, is inaccessible to stock). The rock-holes in the Godfrey area have been formed by the deep dissection and scouring of the softer sandstone and shale which underlie the more massive sandstone. 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 sometimes over 3 miles long and half a mile wide. Lake Stretch is a similar but smaller pool 10 miles south of Billiluna Homestead.

Numerous springs occur in the Permian sediments south of Christmas Creek (e.g. McDonald Spring); they seem to be controlled by small faults. The spring water 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 the production of 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	24 1/2	1500	" "
48	65 1/2	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 feet. Grave of Jack Smith, died 1939.

Well No.	Depth (feet)	Supply gals./hr	Remarks
50	62	500	Excellent water.
51	22	900	Poor quality water; gypsum and travertine nearby. Water level 15 feet but fallen in; called Weriadoo.

Well No. 1 on the stock route from Christmas Creek to Well 49 has a water level of 46 feet and excellent water. The surface rock is pisolitic ironstone with spoils of fine to medium friable sugary sandstone, micaceous and 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 marsh next to the salt lake.

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

Billiluna Station is well supplied with sub-surface water. The bore at the homestead, 120 feet deep, produces good fresh water from the Grant Formation and overlying sands. 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. 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 salt bores (less than 15 feet) 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 where shale, presumably in the Gardiner Beds, has been encountered, bores are dry or salty. Sturt Creek 26-mile bore is 160 feet deep and has a good supply, but Sturt Creek Dud No. 8, 12 miles south-south-east of the homestead (near B13), struck salt water; the spoil is 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-foot bore, 7 miles from the homestead on the direct road to Flora Valley, struck salt water at 60 feet. Another salt-water failure, 300-400 feet deep, is on a black soil plain north of Bindi. An unsuccessful bore, about 40 miles from the homestead on the middle road to Flora Valley, reached 300 feet in 'blue rock' - probably basalt. The semi-permanent pools in Sturt Creek help to alleviate the water shortage resulting from the unsuccessful drilling.

ACKNOWLEDGEMENTS

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

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APPENDIX 1

PERMIAN FOSSILS FROM THE CANNING BASIN

by

J.M. Dickins

The fossils were collected by Bureau field parties in 1955 (J.N. Casey and A.T. Wells) and 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

M44 (Lat. 18°58'S, Long. 126°27'E).

Unidentifiable shell fragments.

Noonkanbah Formation

B21 (Lat. 19°55'S, Long. 127°50' E).

Brachiopods: 'Chonetes' sp. (sulcate form)

Gastropods: Bellerophon sp.

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

B22 (Lat. 19°55'S, Long. 127°51'E).

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 that these beds are equivalent in age to the top part of the Noonkanbah Formation.

L4 (Lat. 20°12'S, Long. 127°56'E).

Gastropods: Bellerophon sp. ind.

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

L29 (Lat. 20°8'S, Long. 127°54'E 2 1/4 miles ENE of Balgo Mission).

Brachiopods: 'Chonetes' sp. ind.

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

Strebtopteria? sp. nov. has been found to be an important marker fossil for distinguishing the Noonkanbah Formation from the 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

C47 (Lat. 20°57'S, Long. 127°13'E).

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 & 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

M49 (Lat. 19°17'S, Long. 126°11'E).

Unidentifiable shell fragments.

M56 (Lat. 19°02'S, Long. 126°04'E).

Pelecypods: Stutchburia muderongensis Dickins, 1956.

Poorly preserved pelecypods and gastropods.

Doubtful Lightjack Member

M55 (Lat. 19°16', Long. 126°5').

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

S4 (Lat. 21°15'S, Long. 127°45'E).

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 its occurrence together with A. fletcheri indicates that these beds can be correlated with the Lightjack Member.

S6 (Lat. 21°30'S, Long. 128°10'E).

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 S9).

Aviculopecten? hardmani Etheridge, 1907.

Indeterminate gastropods and a brachiopod.

Large animal trails or castings.

For reasons stated above, the beds at S6 can be correlated with the Lightjack Member.

S9 (Lat 21°28'S, Long. 128°06'E).

Pelecypods: 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: Ptychomphalina cf. P. sp. nov. from S67.

Warthia sp.

Brachiopods: 'Martiniopsis' sp.

Plants: Gangamopteris sp.

The beds at S9 can be correlated with those at S4 and S6 and in turn all can be correlated with the Lightjack Member.

S12 (Lat. 21°16'S, Long. 128°04'E).

Animal tracks or burrows.

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

S67 (Lat. 21°49'S, Long. 127°58'E).

Pelecypods: Stutchburia muderongensis Dickins, 1956.

Pseudomonotis? sp. ind.

Pectinid gen., sp. nov. (as in S6 and S9).

Streblopteria sp.

Gastropods: Ptychomphalina sp. nov. (whorl section more rounded than P. maitlandi Etheridge, 1902).

Brachiopods: 'Martiniopsis' sp.

Large animal trails or castings.

S68 (Lat 21°50'S, Long. 127°57'E)

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

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

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

S77 (Lat. 21°49'S, Long. 127°58'30"E).

Pelecypods: Stutchburia muderongensis Dickins, 1956.

Pseudomonotis? sp. ind.

Pectinid gen., sp. nov.? (shows hinge of right valve with a ligament pit).

Gastropods: Ptychomphalina sp. nov.?

S4, S6, S9, S67, S68, and S77 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 and is regarded as a marker fossil for the Lower Liveringa. In addition, Stutchburia muderongensis, Astartila fletcheri, and Aviculopecten? hardmani 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 a 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 & Dickins, 1954).

Doubtful Balgo Member

L5 (Lat. 20°13'S, Long. 127°57'E).

Pelecypods: Aviculopectinidae gen. et sp. ind.

Indeterminate gastropods.

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

L6 (Lat. 20°13'S, Long, 127°56'E).

Gastropods: Ptychomphalina? sp. ind.

Bellerophontidae gen. et sp. ind.

The fossils are of little use for correlation.

L28 (Lat 20°11'S, 127°57'E).

Pelecypods: Atomodesma sp. ind.

Pectinid gen. ind.

Aviculopecten sp. (A. subquinquelineatus line, ribbing not as complexly developed as for A. sp. nov. from S9, but may be an immature specimen).

Brachiopods: Strophalosia sp. ind.

'Chonetes' sp. ind.

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

L30A (Lat. 20°55'S, Long. 128°04'E, 3 miles NNW of Thomas Peak).

Pelecypods: Atomodesma sp. ind.

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

L44 (Lat. 20°07'S, Long. 127°41'E).

Pelecypods: Nucula? sp.

Stutchburia sp. ind.

The fossils present are of little value for correlation.

Doubtful Condren Sandstone Member

C39 (Lat. 30°38'S, Long. 126°41'E).

Fragments of indeterminate pectinid shells.

L37 (Lat. 20°16'S, Long. 127°50'E).

Pelecypods: Stutchburia? sp. ind.

Gastropod gen. et sp. ind.

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

Hardman Member

M50 (Lat. 19°22'S, Long. 126°12'E).

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

C38 (Lat. 20°37'S, Long. 126°37'E).

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.

C49 (Lat. 20°58'S, Long. 127°27'E).

Indet. invertebrate exoskeleton remains.

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THE PERMIAN FORMATIONS OF THE NORTH-EAST CANNING BASIN

AND THEIR CORRELATION

(Appendix 1)

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 — Condren Sandstone
Kungurian ?	Coolkilya Greywacke Baker Formation	Lightjack Member	Lightjack & Balgo Members
	Norton Greywacke Wandagee Formation Quinnanie Shale Cundlego Formation Bulgadoo Shale Mallens Greywacke	Noonkanbah Formation	Noonkanbah Formation
Artinskian (Approx)	Coyrie Formation Moogooloo Sandstone (= 'Wooramel Sandstone') Callytharra Formation	Poole Sandstone — Nura Nura Member	No definite outcrop of Poole Sandstone recognised.
Sakmarian ?	Lyons Group	Grant Formation	Grant Formation

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

APPENDIX 2

PETROGRAPHIC DESCRIPTIONS OF SELECTED ROCK SPECIMENS

by

J. Kerry Lovering

LOWER PROTEROZOIC - HALLS CREEK METAMORPHICS AND LEWIS GRANITE

B32 (Larranganni Bluff): Quartz Greywacke

The hand specimen is pale pinkish grey, and consists of fine grains of quartz cemented by a fine matrix. The rock 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 (Larranganni Bluff): Crushed Greywacke

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 (Six miles south of Bulka Hills): Quartzite

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 (10 miles south of Bulka Hills): Quartzite

The hand specimen is a hard, medium-grained rock which consists 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 recrystallization of the grains has occurred.

M36 (8 miles south of Christmas Creek): Sandstone

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 (Christmas Creek): Quartz Greywacke

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.

L25 (Lewis Range): Muscovite Granodiorite

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 (Kearney Range): Chert

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 (Pyramid Hill): Silicified quartz sandstone

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 the rock is silicified.

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. The colour banding seen in hand specimen is due to 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 more silicified portion from the rest of the rock.

B10 (Near Tent Hill): Silicified quartz sandstone

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 owing 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) (18 miles NE of Mount Brophy): Sandstone

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) (18 miles NE of Mount Brophy): Silicified quartz sandstone.

The hand specimen is a quartz-rich rock.

The thin section reveals that the original 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., and their original outline is preserved by dust particles. A few quartzite grains contain some tourmaline. The rock as a whole has been subjected to stress; uneven extinction is seen in most of the quartz.

B31 (Fort Hill): Quartz-tourmaline hornfels

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 subparallel arrangement of large elongate grains. Some of the quartz grains have been recrystallized, 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 recrystallized), 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. Metasomatism has produced a rock approaching a quartz-tourmaline hornfels. The specimen is a pebble taken from the basal conglomerate of the Gardiner Beds.

B36 (Gardiner Range): Sandstone

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) (Gardiner Range): Sandstone

The hand specimen, which greatly resembles B40(b), 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, and zircon and tourmaline grains.

B40(b) (Gardiner Range): Silicified quartz sandstone

The 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) (Gardiner Range): Silicified quartz sandstone

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 (Gardiner Range): Magnetite-quartz rock

The hand specimen appears to be extensively replaced by an iron-rich band about 1 1/2 inches thick. It varies from a dark reddish to a yellow colour. The rock is porous, but is nevertheless heavy.

The thin section reveals rounded quartz grains about 0.5 mm. in diameter, set in a matrix of yellowish chalcedony. Some of the original clean recrystallized quartz has a crystalloblastic texture. Magnetite oxidized to hematite on its borders is associated with the chalcedony; it appears that the iron and the chalcedony crystallized at about the same time and replaced the original matrix in which the rounded quartz grains are set.

B42 (Gardiner Range): Quartz sandstone

The chrome yellow hand specimen is a fine-grained sandstone. In parts, the yellow coloration 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) (Wolf Creek - west branch): Silicified quartz sandstone

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 emphasized by films of hematite. Other grains present are magnetite and quartzite.

B43(b) (Wolf Creek - west branch): Silicified quartz sandstone

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 feldspar are scattered at random.

B43(c) (Wolf Creek - west branch): Quartz sandstone

The hand specimen is a fine-grained yellow sandstone.

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

B44 (5 miles west of Astro W.H., Wolf Creek): Silicified quartz sandstone.

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 authigenic outgrowths of the original sand grains. Limonitic particles give the orange colour to the rock.

Besides the effects of compaction and cementation, this rock shows those of compression.

L16 (Phillipson Range): Sandstone

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 (North of Lake Lucas): Silicified quartz sandstone

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 quartz 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 (Christmas Creek): Siltstone

The hand specimen is an extremely fine-grained laminated rock with a subconchoidal 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 (20 miles east of Stansmore Range): Silicified quartz sandstone

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 recrystallization 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 grain-size, 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 (Lake Lucas): Calcareous sandstone

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 grain-size is very uniform. The longest dimension of the irregularly shaped quartz grains is about 0.5 mm., and they are uniformly distributed about 0.5 mm. apart. Other similarly shaped grains consist of quartzite and hematized fragments. The groundmass consists of irregularly shaped grains of calcite. Many of these are coated with a film of hematite.

DEVONIAN

M38 (Christmas Creek): Limestone

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 (Knobby Hills): Silicified quartz greywacke

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

The thin section reveals that angular grains, from 0.5 to 1.5 mm. in length, 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 (Knobby Hills): Sandstone

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 (Kearney Range): Laminated sandstone

This salmon-coloured rock is laminated; the laminae, 2 to 4 mm. thick, are alternatively very fine-grained and medium-grained. The base of each lamina 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. One lamina, which is yellow, consists of medium-sized quartz grains in a matrix of limonite.

PERMIAN - GRANT FORMATION

B24 (Mount Mueller): Sandstone

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 (4 miles west of Mount Bannerman): Sandstone

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.

PERMIAN - UNDIFFERENTIATED

C15 (Bishop Range): Siltstone

The rock is extremely fine-grained, reddish brown with some wavy bands of yellow colour, 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 oxidized to limonite.

QUATERNARY - TRAVERTINE ETC.

B20 (8 miles south of Mount Mueller): Opal

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 (French Hills): Porcellanite

The pores of this white hand specimen are rimmed with reddish-brown material. The rock consists of fine granular chalcedony which appears to have been precipitated during the drying up of a lake. Clay material rims every pore and must have come into the deposit when the supply of chalcedony was almost exhausted.

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

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 an 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 which 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 diminishes towards the surface of the deposit.

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

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 ooliths 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. l.

L21 (6 miles north of Lake Lucas): Porcellanite

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 composed of chlorite chamosite, and calcite pseudomorphs in a groundmass of fine-grained clay and granular calcite. These fragments, blebs, and flakes of clay, so arranged as 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) (6 miles north of Lake Lucas): Porcellanite

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 very little clay. Finally the clay disappears entirely.

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

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. They curve around the large grains, which are about 4 mm. in diameter and 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) (11 miles SE of White Hills): Argillaceous limestone

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

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.

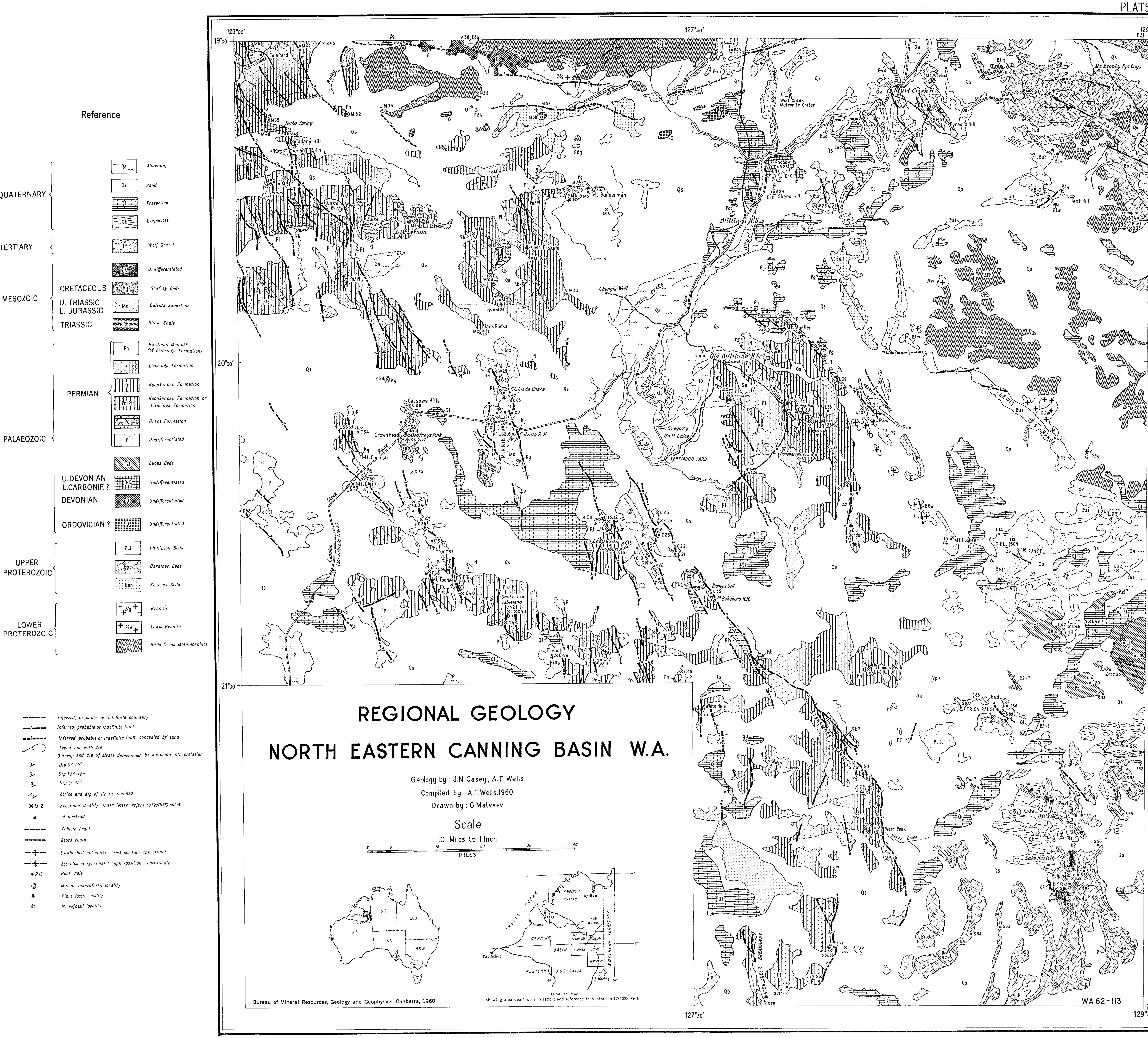
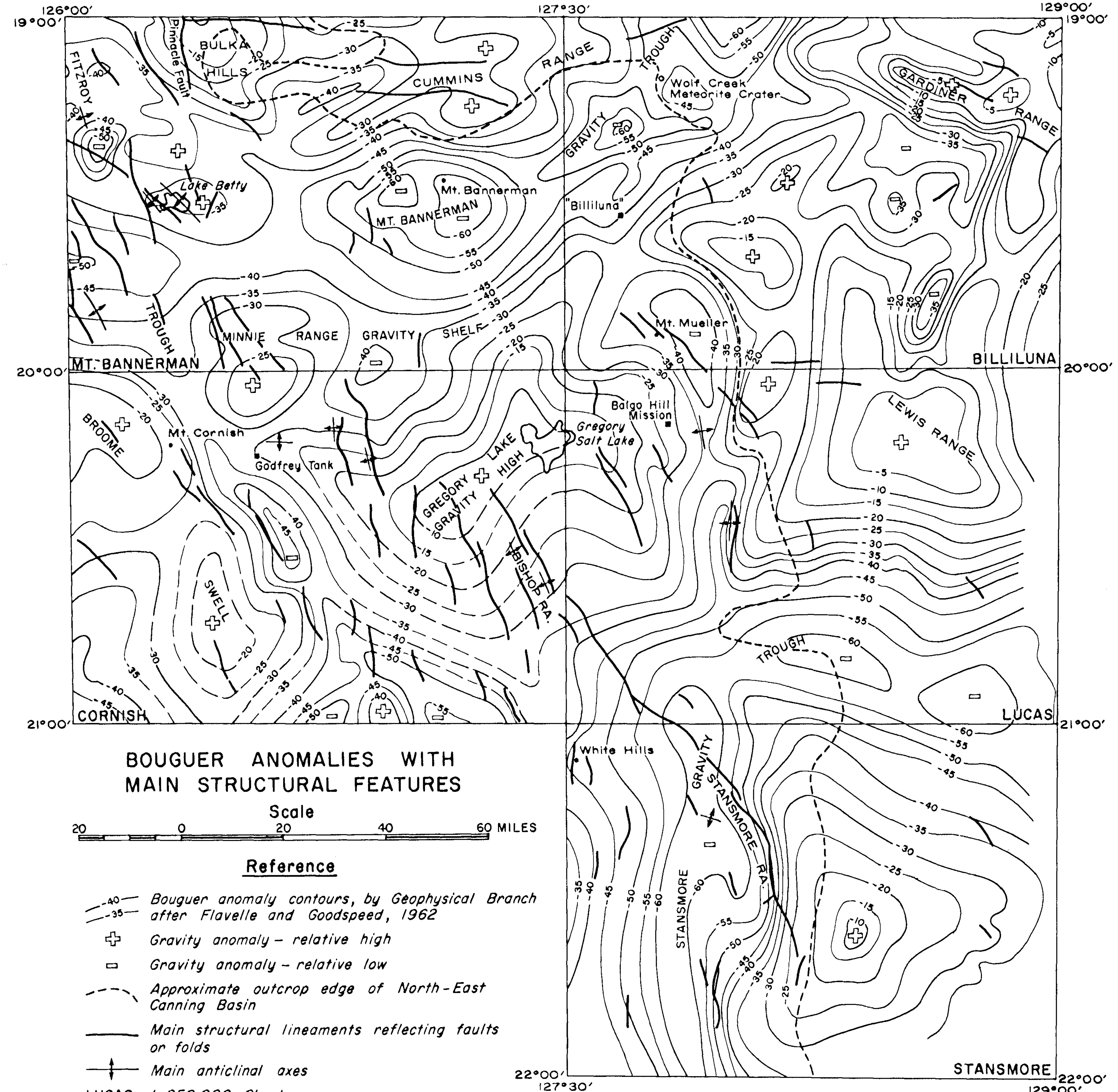

REGIONAL GEOLOGY
NORTH EASTERN CANNING BASIN W.A.
Geology by : J.N. Casey, A.T. Wells
Compiled by : A.T. Wells.1960
Drawn by : G.Matveev
Scale
10 Miles to 1 Inch
MILES
Bureau of Mineral Resources, Geology and Geophysics, Canberra, 1960
WA 62-113
Reference
QUATERNARY
Alluvium
Sand
Travertine
Evaporites
TERTIARY
Wolf Gravel
MESOZOIC
Undifferentiated
CRETACEOUS
Godfrey Beds
U. TRIASSIC L. JURASSIC
Culvida Sandstone
TRIASSIC
Blina Shale
PALAEOZOIC
PERMIAN
Hardman Member (of Liveringa Formation)
Liveringa Formation
Noonkanbah Formation
Noonkanbah Formation or Liveringa Formation
Grant Formation
Undifferentiated
Lucas Beds
U.DEVONIAN L.CARBONIF. ?
Undifferentiated
DEVONIAN
Undifferentiated
ORDOVICIAN ?
Undifferentiated
UPPER PROTEROZOIC
Phillipson Beds
Gardiner Beds
Kearney Beds
LOWER PROTEROZOIC
Granite
Lewis Granite
Halls Creek Metamorphics
Inferred, probable or indefinite boundary
Inferred, probable or indefinite fault
Inferred, probable or indefinite fault concealed by sand
Trend line with dip
Outcrop and dip of strata determined by air-photo interpretation
Dip 0°-15°
Dip 15°-45°
Dip > 45°
Strike and dip of strata-inclined
Specimen locality - index letter refers to 1:250,000 sheet
Homestead
Vehicle Track
Stock route
Established anticlinal crest-position approximate
Established synclinal trough -position approximate
Rock hole
Marine macrofossil locality
Plant fossil locality
Microfossil locality
LOCALITY MAP
showing area dealt with in report and reference to Australian 1:250,000 Series

PLATE 2



BOUGUER ANOMALIES WITH MAIN STRUCTURAL FEATURES

Scale

20 0 20 40 60 MILES

Reference

-40- -35- *Bouguer anomaly contours, by Geophysical Branch after Flavelle and Goodspeed, 1962*

Gravity anomaly – relative high

Gravity anomaly – relative low

Approximate outcrop edge of North-East Canning Basin

Main structural lineaments reflecting faults or folds

Main anticlinal axes

LUCAS *1:250,000 Sheet*

Bureau of Mineral Resources, Geology and Geophysics. September, 1963. *To accompany Report No. 49* F.J.R. W-15