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UPPER DEVONIAN AND CARBONIFEROUS GEOLOGY OF THE BONAPARTE GULF BASIN, WESTERN AUSTRALIA AND NORTHERN TERRITORY.

by

J.J. Veevers and J.Roberts

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ILLUSTRATIONS

INTRODUCTION

This report deals with the Upper Devonian and Lower Carboniferous sequence of the southern, landward part of the Bonaparte Gulf Basin. This part of the basin is only a small, but not insignificant, part of the original depositional basin. For brevity, and following established custom, we refer to this area of Palaeozoic sedimentary rocks as the Bonaparte Gulf Basin, bearing in mind that this is merely the southern landward part of the entire basin.

History of current investigation

This report deals with the Upper Devonian and Lower Carboniferous sequence, which, because it is the thickest and best-exposed in the basin, received most of our attention. The underlying Cambrian-Ordovician sequence was studied in 1963 (Kaulback & Veevers, 1967) and the Permian, Triassic, and Cretaceous sequence in 1965 (Dickins, Veevers, & Roberts, 1968).

This work is the first published revision of Traves' (1955) work in the southern Bonaparte Gulf Basin. Since Traves' report appeared, much unpublished geological and geophysical work and the first deep drilling (Spirit Hill No.1, Bonaparte Nos 1 and 2) have been done, and where appropriate references to this work are incorporated in this report. A comprehensive account of geological work carried out up to 1962 is given by Drummond (1963).

The field work in the Upper Devonian and Lower Carboniferous sequence was done by Veevers and Roberts during 1963 and 1965. P.J.Jones and E.C.Druce spent short periods in the field collecting micropalaeontological samples. The sequence is abundantly fossiliferous, and the principal groups of fossils are being studied by the following:

Brachiopods -	Roberts
Ostracods and, in the initial stages, conodonts -	Jones
Conodonts -	Druce
Foraminifers, with the later collaboration of M.Mamet	- D.J.Belford
Algae, trace fossils -	Veevers
Plants (Appendix 2) -	Mary E.White
Pollen and spores -	G.Playford
Fish -	Joyce G.Tomlinson
Pelecypods -	J.M.Dickins

Veevers is studying the sedimentology of the sequence, and F.C.Loughnan has examined the clay mineralogy of selected bores (Appendix 1). All this specialized work, most of it still in progress, has been freely drawn on in this report. The results will be published separately.

During this investigation, we have co-operated closely and exchanged information with interested oil prospecting companies, in particular Australian Aquitaine Petroleum Ltd.

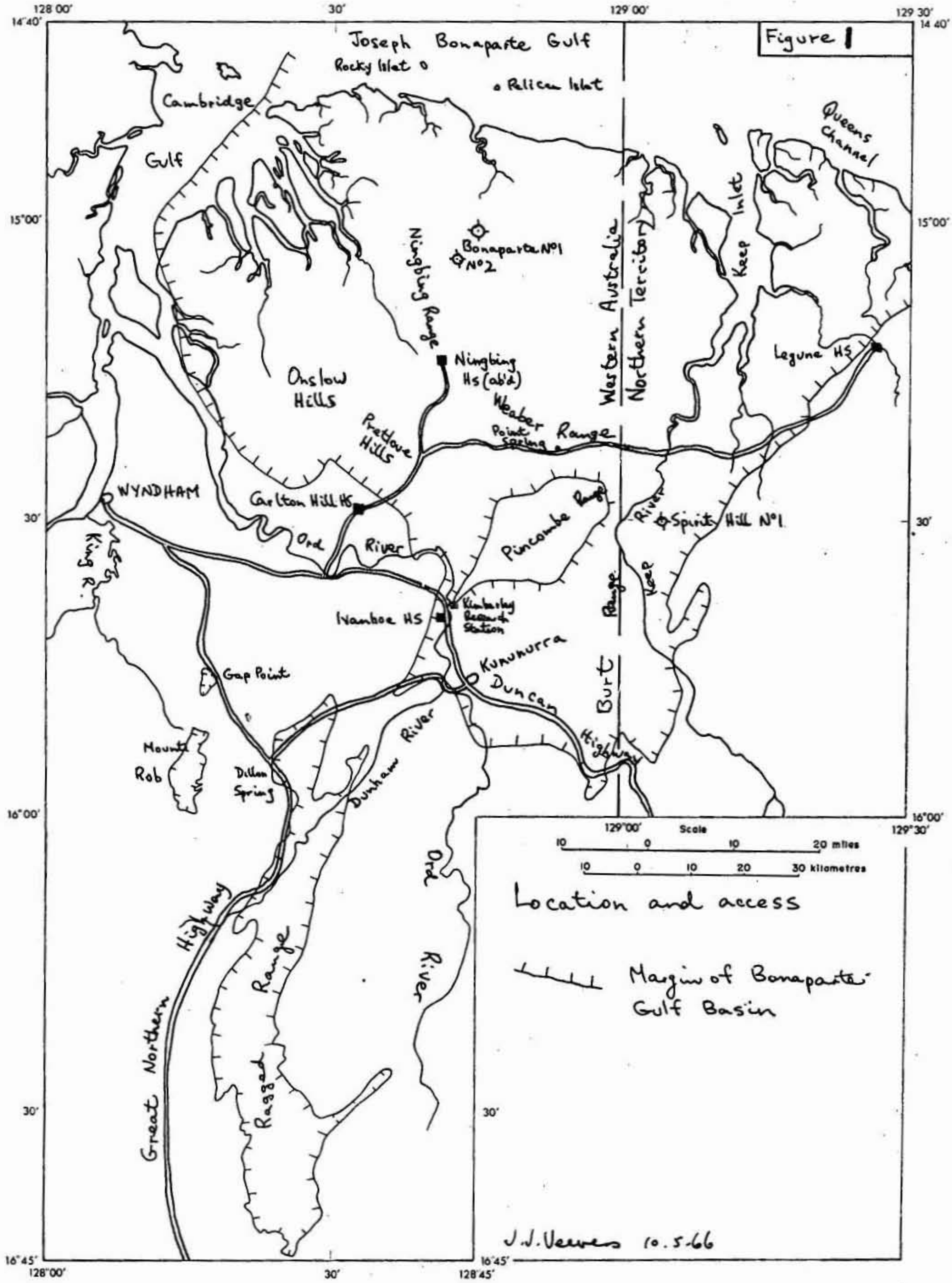
Figure 1
Joseph Bonaparte Gulf
Rocky Islet
Pelican Islet
Cambridge
Gulf
Queens Channel
Keep Inlet
Bonaparte No1
No2
Ningbing Range
Western Australia
Northern Territory
Ningbing Hs (ab'd)
Legune HS
Onslow Hills
Pretlove Hills
Weaber Range
Point Spring
WYNDHAM
Carlton Hill HS
Ord River
Pincombe Range
Spirit Hill No1
Keep River
King R.
Ivanhoe HS
Kimberley Research Station
Kununurra
Duncan Highway
Burt Range
Gap Point
Mount Rob
Dillon Spring
Dunham River
Ord River
Great Northern Highway
Ragged Range
Scale
20 miles
30 kilometres
Location and access
Margin of Bonaparte Gulf Basin
J.J. Veevers 10.5.66
128°00'
129°00'
129°30'
14°40'
15°00'
16°00'
16°45'
128°45'

Published preliminary results that have already appeared are Veevers et al.(1964), Playford et al.(1966), and Jones & Druce (1966).

Following a brief visit during 1965, J.Hays prepared an outline of the geomorphology which is included in this report.

Previous work

Previous work is referred to in the appropriate places in the text. A compilation of work carried out up to December 1962 was made by Drummond (1963). E.P.Uttings' unpublished work was particularly useful to us.

Location and access (Fig.1)

The area described in this report lies on either side ofthe Western Australia/Northern Territory border, behind the southern shore of the Bonaparte Gulf. The north-western edge of the area is marked by Cambridge Gulf, and the north-eastern edge by Queens Channel. In terms of 1:250,000 Sheets, the area is covered by parts of Medusa Banks, Cambridge Gulf, Lissadell, Auvergne, and Port Keats. The area contains two towns : the port of Wyndham, which is a centre for the cattle-raising industry; and Kununurra, the centre of the Ord River Irrigation Scheme. Both towns are linked to Perth and Darwin by regular air services, and Wyndham by regular shipping services. The Great Northern Highway and the Duncan Highway cross the area, and numerous tracks serve the cattle stations. The irrigated farming area north of Kununurra has a close network of roads.

Climate

The area has a warm monsoonal climate with a short rainy season in summer and a long dry season or drought in winter. The annual rainfall is about 30 inches and, compared with areas farther inland, is reliable. Temperature and humidity are high throughout theyear. Wyndham has the highest recorded mean temperature (or the meanest temperature) in Australia of 84°F. Further details are provided by Traves (1955).

Topography

Except for the Burt Range, the whole area lies within the Cambridge Gulf Lowlands (Traves, 1955, Fig.6). The elevation ranges from sea-level to 1,012 feet in the Burt Range. The area is drained by the lower reaches of the Ord and Keep Rivers.

Air Photographs

The area is covered by 1:50,000 vertical air photographs taken by the RAAF in 1948. Part of the area is covered by trimetrogon air photographs taken in 1944. The area of the Ord River Scheme and neighbouring areas (Spirit Hill, part of the Weaber Range) are covered by 1:16,000 vertical air photographs taken in 1961. Before field work started, air-photo geological maps were prepared by R.Ruker, R.Richard and W.J.Perry. Richard also briefly visited us in the field.

Field methods

In addition to the air-photo geological maps, Ruker, Richard, and Perry supplied air-photo overlays showing their interpretations. These overlays and the accompanying photographs provided the base for mapping. When added to and modified by field observations, they were later reduced and compiled as the maps accompanying this report.

The thickness of well-exposed sections was measured rapidly and directly with an Abney level attached at right-angles to a five-foot Jacob staff (Robinson, 1959). This method avoids over-estimating the thickness as is done when it is measured with the geologist's eye-height as scale. This error is negligible (1.5% for a 10° dip) in low-dipping strata but rapidly increases (10% for a 25° dip) with increasing dip.

In 1965, field sections were plotted directly on to a strip log, using a device described by Veevers & Jackson (1966).

Numerous stratigraphical sections (aggregating 50,000 feet) were measured and described, and many of these are presented in graphic form in this report. An explanation of the symbols and abbreviations used in these sections appears in Figure 2. These sections are descriptive only. For example, only those breaks (unconformities, disconformities) which are visible as such in the sections are shown.

Figure 3 is a key diagram of detailed maps.

PRE-UPPER DEVONIAN

The Upper Devonian - Lower Carboniferous sequence unconformably overlies Precambrian rocks, mainly sediments, Lower Cambrian volcanics (Antrim Plateau Volcanics), and Middle and Upper Cambrian and Lower Ordovician sediments. The Cambrian and Ordovician sediments (Fig.4) which are not found east of a line joining Point Spring and the Ragged Range, are quartz sandstone, some glauconitic and hematitic, and minor dolomite and shale. The original description of these sediments by Traves (1955) has been recently amplified by Kaulback & Veevers (1967). The Antrim Plateau Volcanics (Fig.5) are widespread in the Bonaparte Gulf Basin and its outliers, and in the region to the east and south-east (Traves, 1955). In the Bonaparte Gulf Basin, the Volcanics are represented almost exclusively by amygdaloidal basalt with vugs of calcite and silica, and are probably nowhere thicker than several hundred feet. The Precambrian sequence in the Western Australian part of the region is currently being studied by geologists of the Bureau and WA Geological Survey. The following notes, supplied by K.A.Plumb, are intended to serve as a sketch of the Precambrian geology of the area bordering the Bonaparte Gulf Basin.

Widespread outcrops of Precambrian rocks enclose the Palaeozoic Bonaparte Gulf Basin on the eastern, southern, and western sides (Fig.6) and form the basement for the Basin. They can be divided into two main groups : (1) an ancient complex of plutonic igneous and metamorphic rocks unconformably overlain by (2) a younger succession of sedimentary rocks, generally gently tilted.

The plutonic rocks crop out in the Halls Creek Mobile Zone, a linear belt about 30 miles wide which extends in a north-north-easterly direction from Halls Creek in the south to near the Ord River Damsite and continues into the Northern Territory, roughly along the eastern margin of the Bonaparte Gulf Basin. The rocks consist of a suite of metasediments and volcanics with metamorphic grades ranging from greenschist to granulite facies, and associated granite-gneisses, gabbros, ultrabasics and massive granites. A wide range of mineral assemblages are represented.

Figure 2

4.5.66 21.6.66 Fig. 2 — Abbreviations and symbols used in columnar sections.

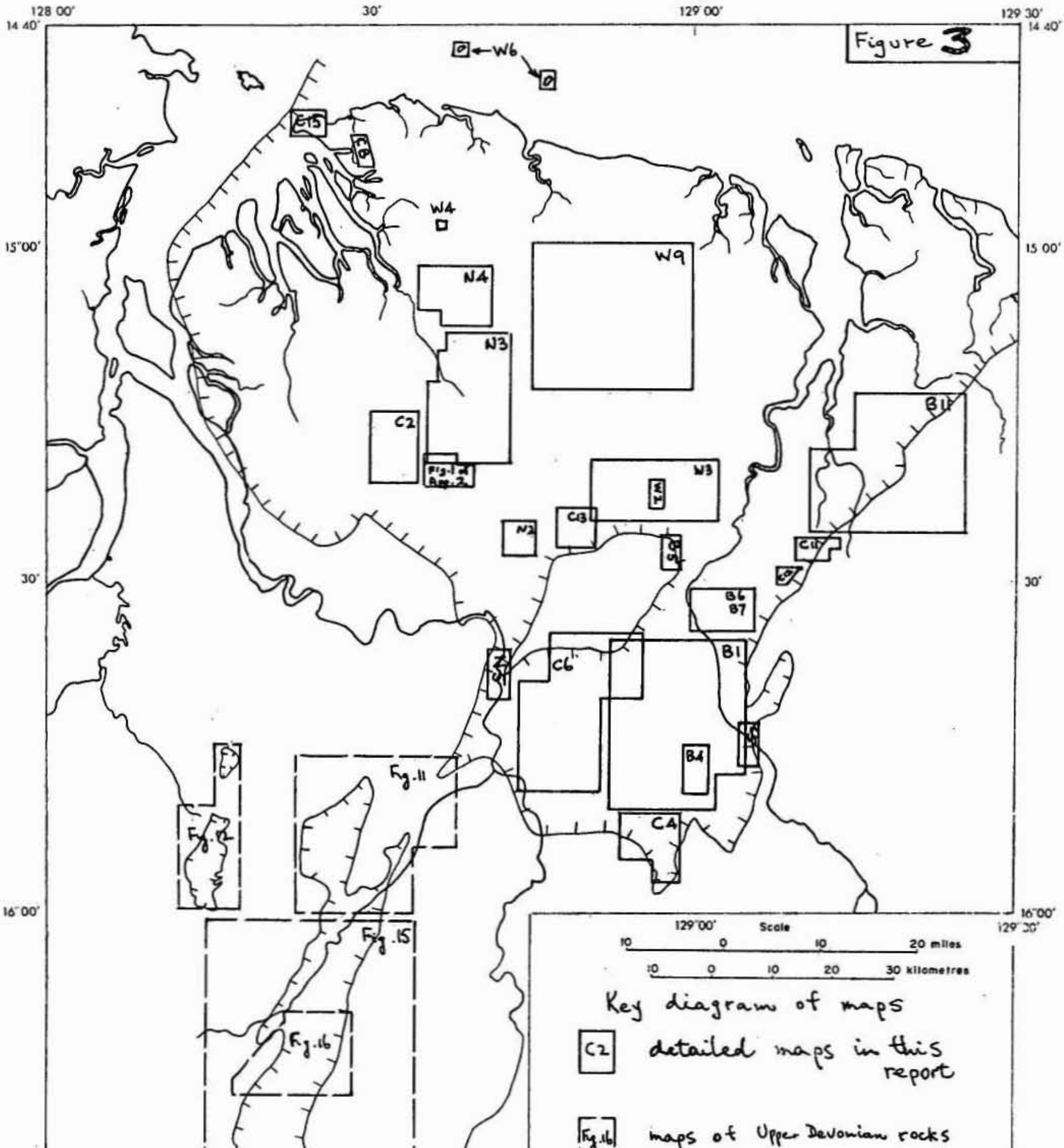
Figure 3
128°00'
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W6
W4
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N4
N3
C2
C13
N2
C6
C4
B1
B4
B6
B7
B11
Fig.11
Fig.12
Fig.15
Fig.16
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Key diagram of maps
C2 detailed maps in this report
Fig.16 maps of Upper Devonian rocks in Kaulback & Veevers (1967)
J.J. Veevers 10.5.66

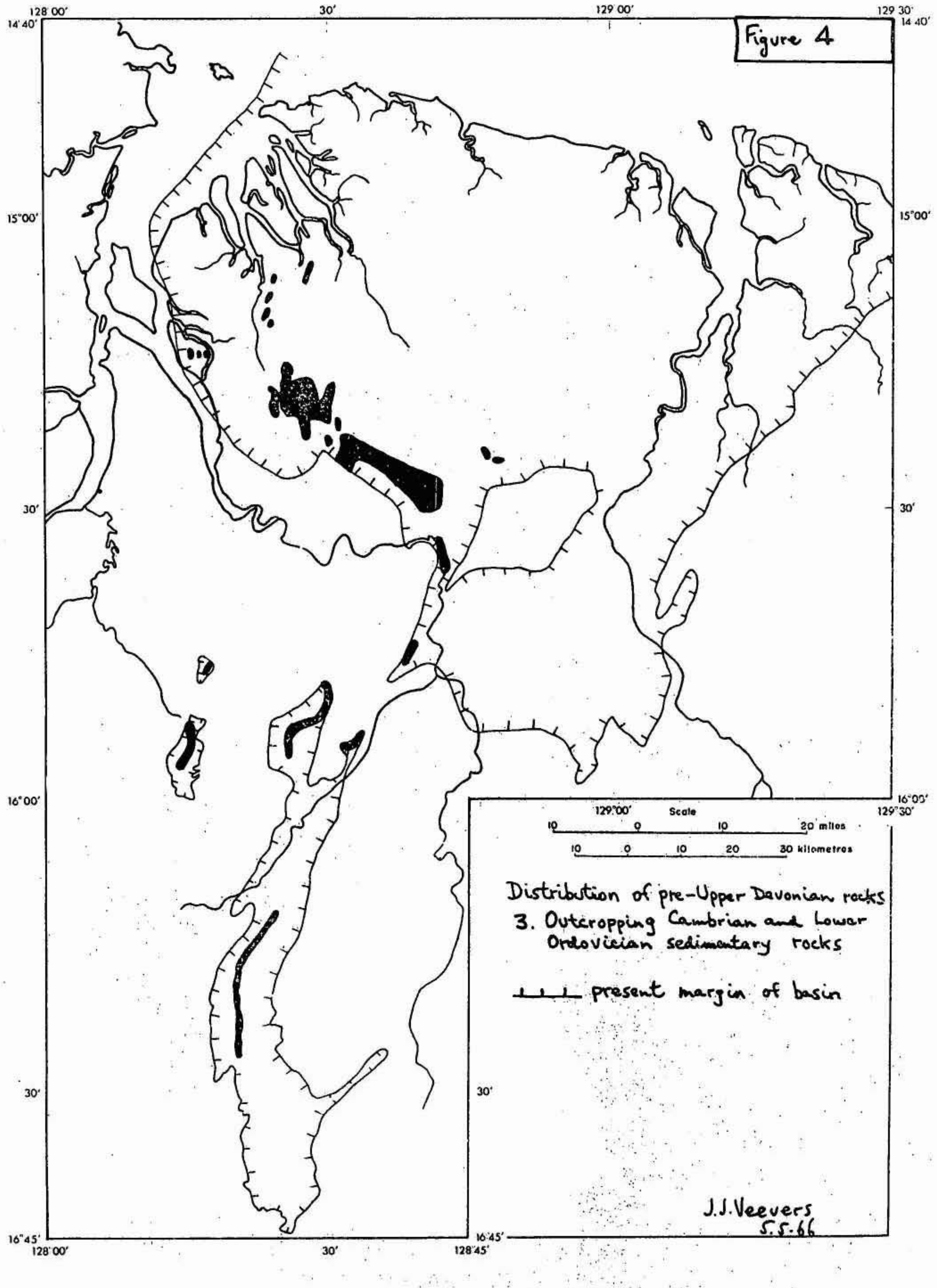

Figure 4
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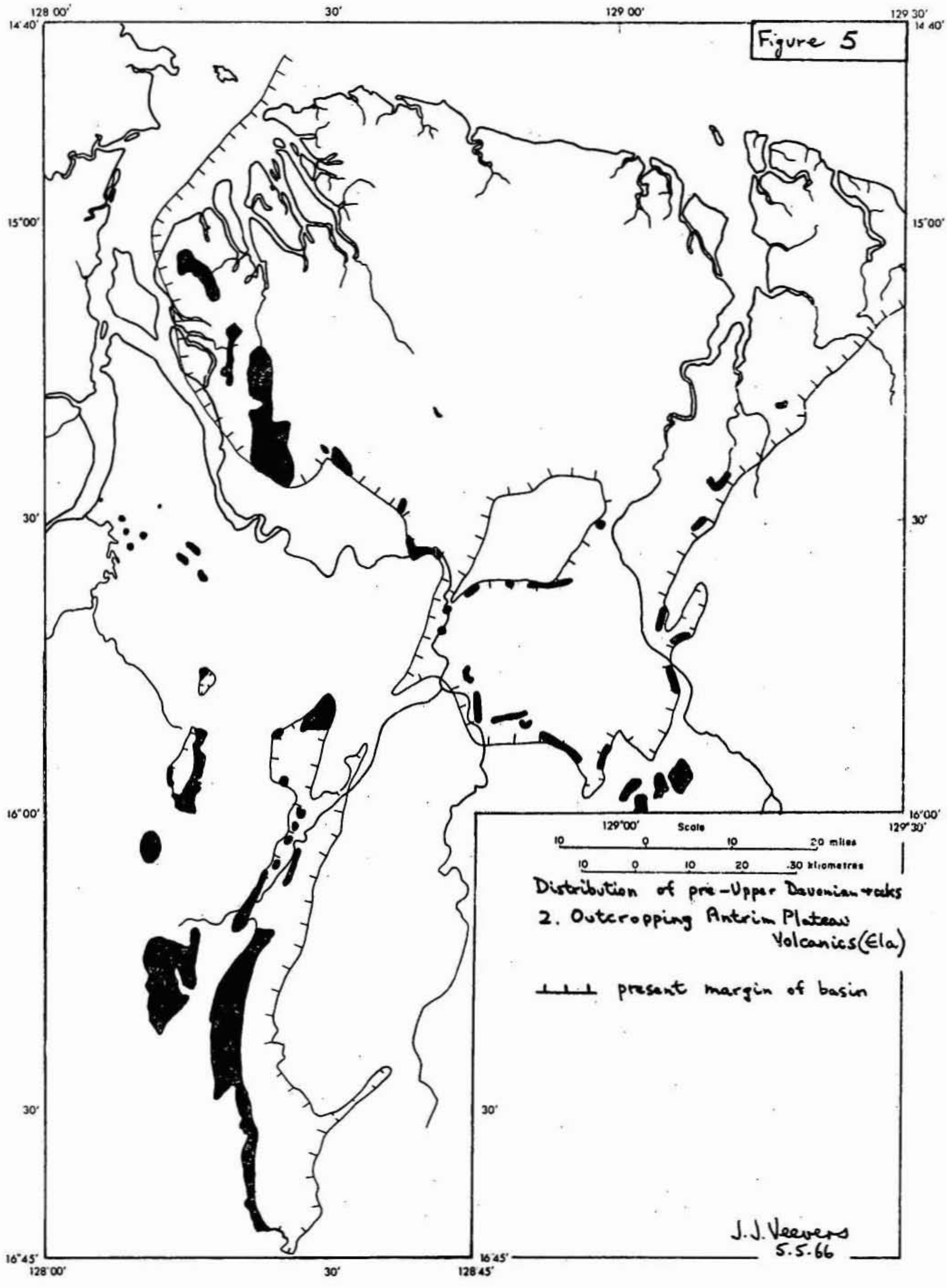
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Distribution of pre-Upper Devonian rocks
3. Outcropping Cambrian and Lower Ordovician sedimentary rocks
present margin of basin
J.J. Veevers
5.5.66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16°45'
128°00'
128 45'
16 45'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Distribution of pre-Upper Devonian rocks
2. Outcropping Antrim Plateau Volcanics (Ela)
present margin of basin
J.J. Veevers
5.5.66

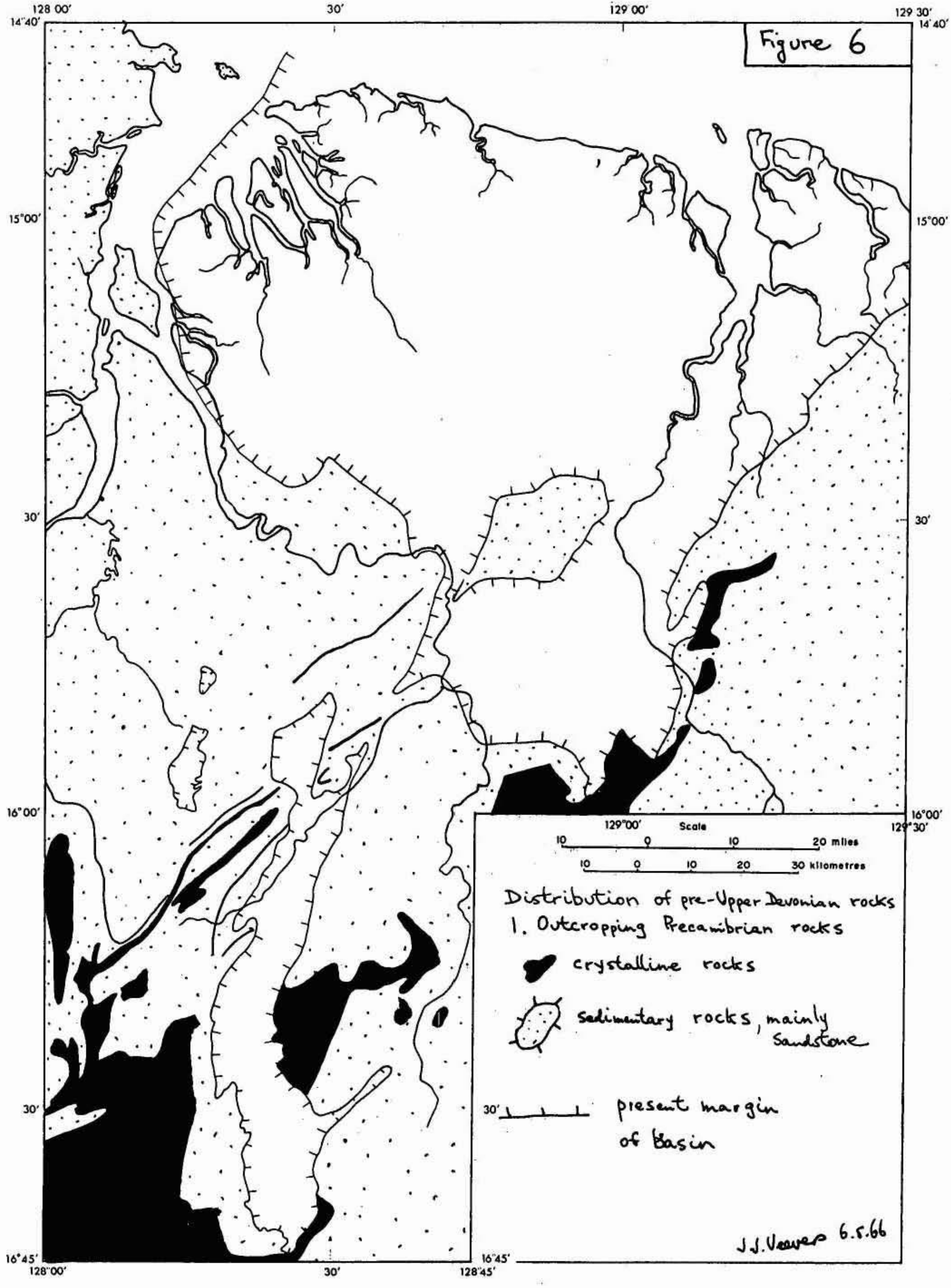
Figure 6
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128°45'
129°00'
129°30'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Distribution of pre-Upper Devonian rocks
1. Outcropping Precambrian rocks
crystalline rocks
sedimentary rocks, mainly Sandstone
present margin of Basin
J.J. Veevers 6.5.66

By far the greatest area of outcrop of Precambrian rocks consists of the gently tilted sediments which were deposited in the Kimberley Basin to the west and Victoria River Basin to the east. Smaller outliers also crop out in the Carr Boyd Ranges, south of Kununurra, and in the Osmond and Albert Edward Ranges farther south towards Halls Creek. The bulk of the rocks in these successions are clean well-sorted quartz sandstones with lesser amounts of siltstone and shale and minor acid and basic volcanics and carbonates. Widespread basic intrusives occur in the west.

The sandstones tend to form the strongest topographic relief of all the Precambrian rocks and therefore would have the strongest run-off and subsequent mechanical erosion. This fact, combined with their widespread outcrop, makes it highly likely that the sandstones provided the bulk of the source material for the Bonaparte Gulf Basin.

COCKATOO FORMATION

Introduction

The Frasnian Cockatoo Formation consists of about 5,000 feet of quartz sandstone, conglomerate, limestone, and dolomite that crop out over large areas in the Bonaparte Gulf Basin and in its outliers. The Cockatoo Formation unconformably overlies the Precambrian and the Cambrian-Ordovician sequences, and is conformably overlain, above transition beds, by the Ningbing Limestone or the Buttons Beds. The Cockatoo Formation is a variable unit, with both vertical and horizontal variation in its content of conglomerate, quartz sandstone, and limestone or dolomite. This variation, ~~not hitherto~~ described, is expressed here in the revision of the name from 'Sandstone' to 'Formation'. The following summary of the depositional history of the Cockatoo Formation is intended to serve as a guide through the many pages of description that follow.

The Cockatoo Formation was deposited during the Frasnian in two provinces (Fig.7) largely determined by the regional geological setting. In the marginal province, between the eastern edge of the basin locally marked by a system of major normal faults and an intrabasinal ridge (Pincombe Inlier) were deposited a sequence (Ragged Range Conglomerate Member) of almost pure quartzose rocks, including thick coarse conglomerate of boulders, cobbles and pebbles of meta-quartzite and vein quartz in a matrix of coarse lithic quartz sandstone. The conglomerate was deposited as a wedge, at least 700 feet thick and possibly as much as several thousands of feet thick, along the faulted eastern edge, and as a thin wedge, less than 150 feet thick, near the Pincombe Inlier. A short distance from the eastern edge of the basin, the conglomerate interfingers with two thick tabular bodies of cross-bedded pure quartz sandstone, conglomeratic near the eastern edge. The lower sandstone (Kellys Knob Member) is about 1,000 feet thick, and the upper one (Cecil Member) exceeds 2,000 feet. Sandwiched between these sandstones is a sequence (Kununurra and Abney Members), about 500 feet thick, of fine-grained glauconitic locally calcareous quartz sandstone and siltstone, whose carbonate content increases away from the eastern edge. The top of theCockatoo Formation is a sequence (Jeremiah Member) of interbedded quartz sandstone and carbonate rocks, possibly as much as 1,000 feet thick, which pass transitionally into the overlying Ningbing Limestone and the Buttons Beds.

The middle province lies between the Pincombe Inlier and an inferred hinge-line. The two thick bodies of quartz sandstone (Kellys Knob and Cecil Members) extend into this province but they lack pebbles and boulders, and the sequence between these bodies (Hargreaves and Westwood Members) contains increased amounts of carbonate rocks which become incipient reef at their north-westernmost point.

A third, outer province in the Frasnian is as yet conjectural. Probably during part of the Famennian and during parts of the Lower Carboniferous, dark siltstone (Bonaparte Beds) was deposited in the Bonaparte No.1 Well area at the same time as sandstone and limestone were deposited on the margins. By a simple downward extrapolation of this kind into the Frasnian, as indicated by the deposition of the Cockatoo Formation in the marginal and middle provinces, we may speculate that the dark siltstone was also deposited in the outer province in the Frasnian. No more can be said about this until the sequence beneath the Famennian in the outer province is penetrated by the drill.

Previous work

The first published reference to outcrops of the Cockatoo Formation was by Wade (1924, p.33). He noted the conspicuous false bedding of the CockatooFormation, and the ease with which it crumbles to sand in the Cockatoo Spring area, and pointed out its similarity to other outcrops at Mount Glass and Mount Buchanan in the Hardman Basin. These outcrops were mapped as sandstones, probably old dune deposits, of unknown age. The conglomerate north of Cockatoo Springs was also noted.

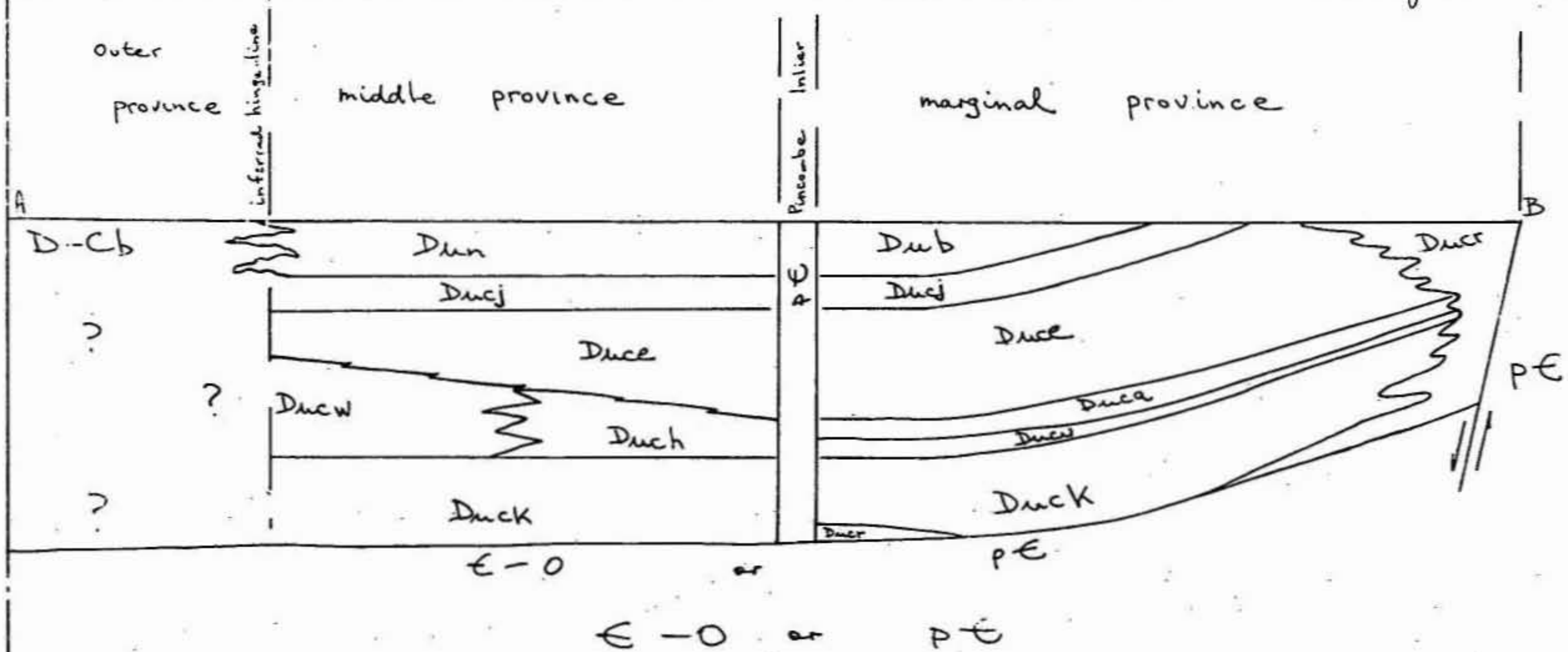
Matheson & Teichert (1948, p.82), introduced the name 'CockatooSeries', showed its distribution in the area between Cockatoo Spring and Martin Bluff, and near Buttons Crossing, gave its minimum thickness as 4,000 feet in the Cockatoo Spring area, found plant fossils, and dated it as Upper Devonian.

Reeves (1951) reduced the thickness of the 'Cockatoo Series' to 3,000 feet, because, as he explained in an earlier unpublished report, he regarded the core of Mount Cecil as Precambrian. Incidentally, it was in this paper that the name Bonaparte Gulf Basin was introduced.

Noakes et al. (1962, p.94, 95) revised the name to 'Cockatoo Sandstone', and introduced the nomen nudum 'Onslow Beds' for the Upper Devonian sandstone and limestone in the Onslow Hills approximately equivalent to the Cockatoo Sandstone.

Traves (1955) extended the known distribution of the Cockatoo Sandstone to the area west and north-west of Ningbing and discovered the Dillon Spring outlier. He recorded numerous fossils, mainly pelecypods, from several localities. Rocks now recognised as Cockatoo Formation in the Pretlove Hills and along the eastern edge of the basin were mapped as Cambrian and Permian respectively, and the Ragged Range Conglomerate was also dated as Cambrian. Traves followed Reeves in regarding the core of Mount Cecil as Precambrian, despite the fossils he found nearby.

Fig. 7



Bonaparte Gulf Basin

Relationships of Upper Devonian stratigraphical units

D-Cb	Bonaparte Beds	: dark siltstone and shale, minor sandstone
Dun	Ningbing Limestone	: carbonate reef complex
Dub	Buttons Beds	: silty limestone, minor shale, sandstone
Duc	Cockatoo Formation	
j	Jeremiah Member	: interbedded sandstone, siltstone, and carbonates
e	Cecil Sandstone Member	: quartz sandstone, x-bedded
w	Westwood Member	: sandy carbonate, including incipient reef, sandstone
h	Hargreaves Member	: sandy carbonate, sandstone, marl
a	Abney Sandstone Member	red thin-bedded sandstone
u	Kununurra Member	sandy carbonate, sandstone
k	Kellys Knob Sandstone Member	quartz sandstone, x-bedded
r	Ragged Range Conglomerate Member	conglomerate, pebbly sandstone
Є-O	Cambrian-Ordovician	
pЄ	Precambrian	

Note: diagram not to scale

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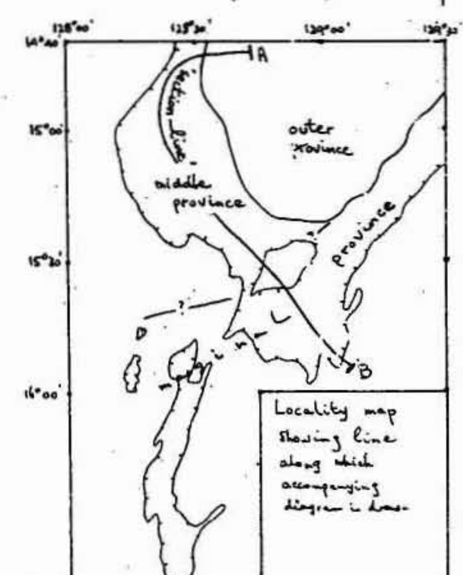


Fig. 7

E.P.Utting's (pers.comm.) main discovery in theCockatoo Formation was the richly fossiliferous exposure at Westwood Creek.

No new information was published until Veevers et al. (1964) summarized the results of mapping in 1963. Many of the new observations reported in this paper were independently made by the field party of Australian Aquitaine Petroleum (Guillaume, 1966). The new information about the Cockatoo Formation concerned the Upper Devonian age of the Ragged Range Conglomerate, of the sandstone and dolomite of the Pretlove Hills, and of the outcrops in the Nigli Gap area, and the thick fossiliferous interbedded limestone and sandstone at Westwood Creek. Jones & Druce (1966) listed the conodonts from Westwood Creek, which indicate a Frasnian (to I) age.

DESCRIPTION

The chief lithological variations in the Cockatoo Formation have been mapped as eight members, seven of them new. In what follows, we describe the Cockatoo Formation by province, or vertically, rather than by member, or horizontally. This avoids repeating the description of the field relations of each area that contains outcrops of two or more members. To compensate for the loss of horizontal continuity, summary descriptions of the members and a key diagram of their relationships precede the description of the provinces.

Summary description of the members, and their relationships

The relationships between the members are shown diagrammatically in Figure 7.

The Ragged Range Conglomerate Member is a basal wedge of boulder conglomerate and red-brown lithic quartz sandstone, at least 1,000 feet thick, that was deposited in the marginal province along the eastern edge of the basin, and in front of the southern part of Pincombe Ridge.

The Kellys Knob Sandstone Member is a tabular body of cross-bedded quartz sandstone, at least 1,000 feet thick, that extends over the marginal and middle provinces. In the marginal province it is commonly pebbly, and is conglomeratic near the eastern margin itself.

The Kununurra Member is a sheet of fossiliferous fine-grained glauconitic quartz sandstone and dolomite 300 feet thick, known from the marginal province only. Its dolomite content increases with its distance from the eastern edge of the basin.

The Abney Sandstone Member is a sheet of thin-bedded red-brown quartz sandstone 330 feet thick, also known from the marginal province only. It is pebbly near the edge of the basin.

The Hargreaves Member is a tabular body, probably 2,000 feet thick, of sandstone, dolomite, and marl in the south-western part of the middle province. Part or all of it is laterally equivalent to the Kununurra and Abney Members, and to the Westwood Member.

The Westwood Member is a tabular body of quartz sandstone and limestone, probably as much as 2,000 feet thick, known only in the north-west part of the middle province. Like the Ragged Range Member, the Westwood Member is an extreme phase of the Cockatoo Formation, this time the extreme of carbonate rock deposition, culminating in incipient reefs. It is equivalent to the Kununurra, Abney and Hargreaves Members, and probably to the lower part of the Cecil Member.

The Cecil Sandstone Member is a tabular body of cross-bedded quartz sandstone, at least 2,000 feet thick, that extends over the marginal and middle provinces. Except its stratigraphical position and its greater thickness, it is identical with the Kellys Knob Member.

The Jeremiah Member is a sheet of sandy dolomite, at least 360 feet thick, that extends over both marginal and middle provinces. It links the rest of the Cockatoo Formation with the overlying Ningbing Limestone and Buttons Beds.

Finally, the Bonaparte Beds (not included in the Cockatoo Formation but possibly equivalent to part of it) are thick dark siltstone with minor sandstone and shale known in the subsurface of the outer province only. The age of the lowermost part of the beds penetrated by the drill is not precisely known - it is probably Famennian or older -, and is possibly equivalent to part of the Cockatoo Formation.

Some of these ideas are summarized in Figure 7.

Detailed description of the members and their field relations

1. Marginal province

A. Martin Bluff/Kununurra area (Fig.8)

This area is described first because it contains the type localities of four members. The outcrops in this area are the westernmost part of the Burt Range syncline (or monocline), on which the secondary structures of the Mount Cecil dome and Martin Bluff monocline are superimposed.

Ragged Range Conglomerate Member

The type Ragged Range Conglomerate Member in the Ragged Range is discussed on p. 19 . In the Martin Bluff area theRagged Range Member is a poorly exposed lens of pebble to boulder conglomerate and red-brown sandstone that unconformably overlies the Cambrian Antrim Plateau Volcanics and is conformably overlain by the Kellys Knob Member. As shown in Figure 8, to the east and south the Ragged Range Member wedges out and the Kellys Knob Member rests on the Antrim Plateau Volcanics.

The Ragged Range Member varies markedly in thickness and in the proportions of conglomerate and sandstone (Figs.8, 9). In section 412, which is incomplete, the Ragged Range Member consists of an estimated 330 feet of thin bedded cross-bedded medium to coarse sandstone and 15 feet of boulder conglomerate, first described by Matheson & Teichert (1948 p.83). Most fragments in the conglomerate are rounded boulders of metaquartzite, and the biggest are blocks, up to 3 feet across, of basalt; a few fragments, mainly pebbles, of other igneous rocks were also found. Two miles eastward, the Ragged Range Member is slightly thinner than in section 412, and, as seen in washaways in the western flank of Martin Bluff (locality 86/1), consists of roughly equal amounts of basalt wash

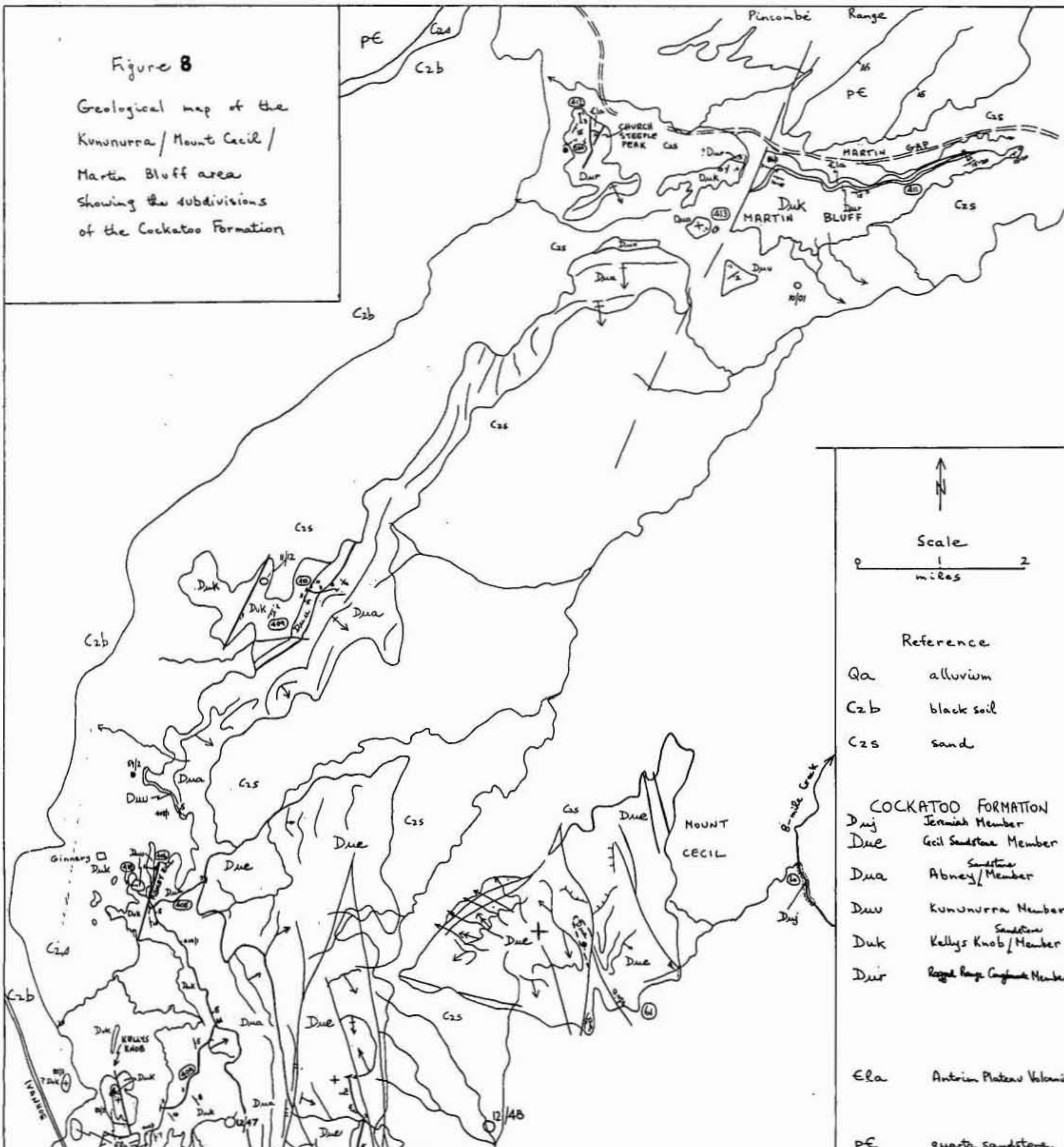
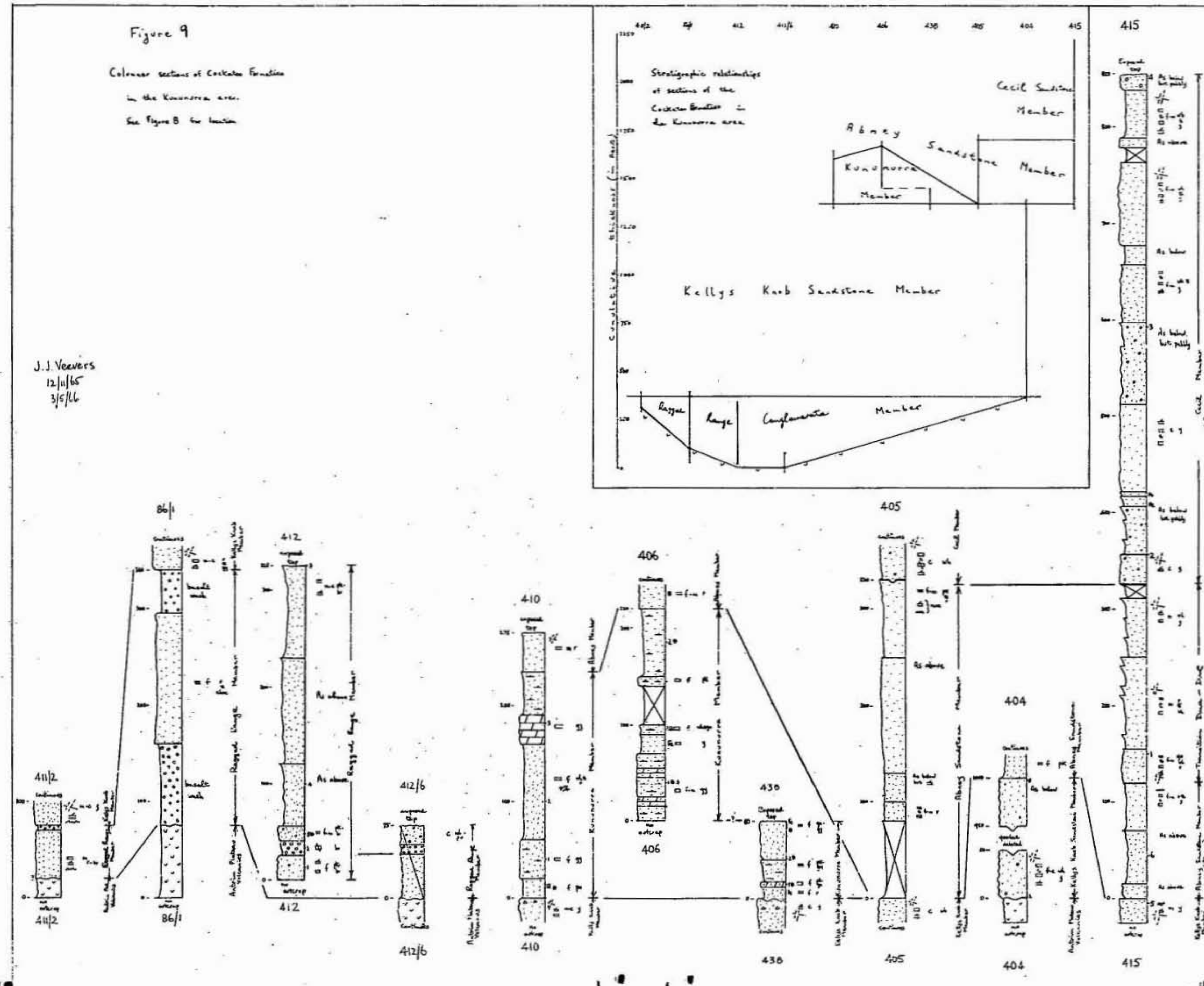


Figure 8
Geological map of the Kununurra / Mount Cecil / Martin Bluff area showing the subdivisions of the Cockatoo Formation
Pincombe Range
CHURCH STEEPLE PEAK
MARTIN GAP
MARTIN BLUFF
MOUNT CECIL
KELLYS KNOB
KUNUNURRA
Ginnery
DUNCAN HIGHWAY
Qa
N
Scale
0 1 2
miles
Reference
Qa alluvium
Czb black soil
Czs sand
COCKATOO FORMATION
Duj Jeremiah Member
Duc Cecil Sandstone Member
Dua Abney Sandstone Member
Duu Kununurra Member
Duk Kellys Knob Sandstone Member
Dur Ragged Range Conglomerate Member
Ela Antrim Plateau Volcanics
p€ quartz sandstone, siltstone
general locality
sample reference
fault
Parts of the map are derived from air-photograph interpretation by R. Richard (IFP) and R. Rukter.
J. Veevers 12/4/65

Fig. 8

Figure 9

Columnar sections of Cockatoo Formation in the Kununurra area.
See Figure 8 for location



(basalt detritus up to the size of boulders, with rare pebbles of metaquartzite and vein quartz) and laminated red to chocolate fine sandstone. Kaulback & Veevers (1967) misidentified this sequence as Cambrian Tarrara Formation. A little over 2 miles farther eastward, at locality 411/2, the Ragged Range Member is only 55 feet thick, and consists predominantly of cross-bedded red-brown medium sandstone, with only 5 feet of conglomerate. Probably within a short distance eastward of this locality, the Ragged Range Member wedges out altogether, as it does within the area between Church Steeple Peak and Kellys Knob.

Besides this and the type area, outcrops of the Ragged Range Member are known only along the eastern edge of the Basin (Fig.10) and these occurrences will be described as part of the description of the Cockatoo Formation in this area.

The distinctive characters of the Ragged Range Member are its cobble and boulder conglomerate, and the red colour of its sandstone.

Kellys Knob Sandstone Member (new name)

The Kellys Knob Sandstone Member is defined as the tabular body of yellow to white quartz sandstone that lies between the Antrim Plateau Volcanics or Ragged Range Conglomerate Member and the Kununurra or Abney Members in the Kununurra/Martin Bluff area. The type section is section 404, east of Kellys Knob. The geographical co-ordinates are Lat.15°46'S, Long. 128°45'E. In the type section, the Kellys Knob Member unconformably overlies the Antrim Plateau Volcanics, and is paraconformably overlain by the Abney Sandstone Member. In Martin Bluff, the Kellys Knob Member overlies the Ragged Range Member, and between Abney Hill and Martin Bluff is conformably overlain by the Kununurra Member. Except for increasing amounts of pebbles and boulders near the very edge of the basin, where it seems to pass laterally into the Ragged Range Member, the Kellys Knob Member is a remarkably uniform yellow to white quartz sandstone.

In the type section (Fig.9), the Kellys Knob Member consists of 1,000 feet of uniform deeply jointed medium- to thick-bedded cross-bedded fine- to coarse-grained white to yellow friable quartz sandstone, with rare pebbles. The Kellys Knob Member is readily identified in the airphotographs by its rough pattern of regular close vertical joints and light tone. The sandstone is weakly cemented by overgrowths round the quartz grains, and when the thin weathered skin is broken with a hammer, the sandstone disintegrates into sand. Thus, access to the outcrop is impeded by loose sandy elluvium and, within the outcrop, by deep incision along joints. Minor joints cut the beds into 'bricks', which, together with the deep joints, give the outcrops a castellated appearance. Another characteristic of the Kellys Knob Member is its almost ubiquitous cross-bedding, typical examples of which are illustrated by Matheson & Teichert (1948, Fig.9) and Traves (1955, Fig.25). Ripple-marks and contorted stratification are less common. An exceptional feature in sections 438 and 410 (Fig.9) is the occurrence at the top of the Kellys Knob Member of intraformational breccia, with angular fragments of thin-bedded sandstone embedded in identical sandstone. These and other sedimentary structures will be described in forthcoming publications.

The only fossil found in the Kellys Knob Member in the type locality is Leptophloeum about 200 feet above the base at Kellys Knob (J.N.Casey, pers.comm.). Indeterminate pelecypods were found in this member in the Alpha Hill and Matheson Ridge areas.

The Kellys Knob Member is widely distributed and its description in other areas will be dealt with later. Its age will be discussed in the summary at the end of the chapter.

Its uniform quartz sandstone lithology, jointing, and cross-bedding distinguish the Kellys Knob Member from all other members of the Cockatoo Formation, except the Cecil Sandstone Member, from which it can be distinguished only by reference to stratigraphic position.

Kununurra Member (new name)

The Kununurra Member is defined as the lenticular body of varicoloured fine micaceous quartz sandstone, dolomitic sandstone, and dolomite that lies between the Kellys Knob and Abney Members in the area between Abney Hill and Martin Bluff. Section 410 is designated type, and it is 235 feet thick. The co-ordinates of the base are Lat.15°41'S, Long.128°46'E. In the air photographs, the Kununurra Member is a uniform grey with only a few traces of bedding, and is indistinguishable from the overlying Abney Member.

South of Abney Hill, the Kununurra Member wedges out and the Abney Member rests on the Kellys Knob Member. This is a rapid change, as shown by section 438-406, 220 feet thick, which wedges out entirely a ¼-mile southward near a fault. This is probably a scissor fault; the Kununurra Member was probably deposited on the downthrown block, while the upthrown block, surfaced with Kellys Knob Member, was an area of non-deposition.

In the marginal province, the Kununurra Member is the oldest member that is abundantly fossiliferous, and in the type area conodonts, pelecypods, brachiopods, crinoid ossicles, trace fossils, and plants (Leptophloeum) have been found.

Lying between white and red sandstone, the Kununurra Member is distinguished by its finer grain, grey or green colour, beds of dolomite, and fossils.

Abney Sandstone Member (new name)

The Abney Sandstone Member is defined as the tabular body of red thin-bedded fine- to medium-grained quartz sandstone that lies above the Kellys Knob Member and below the Cecil Sandstone Member south of Abney Hill. In Abney Hill itself, the Abney Member rests on the Kununurra Member. As mentioned above, the Kununurra Member wedges out south of Abney Hill, and the boundary between the Kellys Knob Member and the Abney Member is accordingly a paraconformity or disconformity.

Section 405 is the type section of the Abney Member, and it is 330 feet thick. The co-ordinates of the base of the section are Lat.15°44'S, Long.128°45'E. In the air photographs, the Abney Member is uniformly grey with poorly expressed bedding, and is indistinguishable from the underlying Kununurra Member. In section 415, measured in the area 2½ miles east-south-east of Kununurra, the Abney Member passes upward into the Cecil Member through 200 feet of transitional beds. In contrast, the boundary between these units in section 405 is an erosional surface, with trough

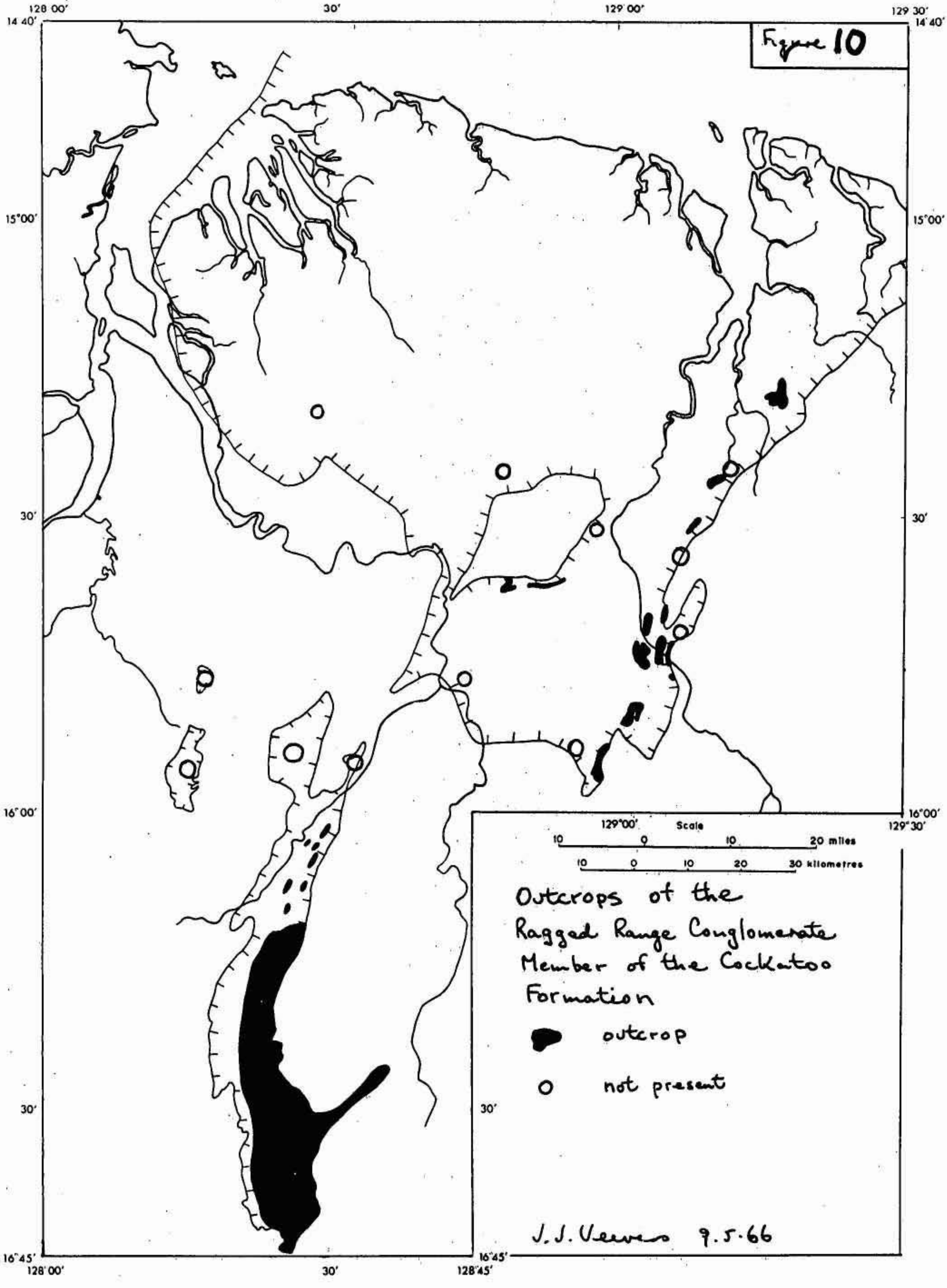


Figure 10
128°00'
30'
129°00'
129°30'
14°40'
15°00'
30'
16°00'
16°45'
128°45'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Outcrops of the Ragged Range Conglomerate Member of the Cockatoo Formation
outcrop
not present
J. J. Veevers 9.5.66

cross-beds in the Cecil Member cutting two feet down into the top of the Abney Member.

An exposure of the Abney Member in the core of the Mount Cecil dome contains pelecypods, first discovered by Traves (1955, loc.12). Brachiopods at the top of section 406 are the only other fossils known from the Abney Member.

The diagnostic features of the Abney Member are its red colour and uniform thin- to medium-bedding.

Cecil Sandstone Member (new name)

The Cecil Sandstone Member is defined as the tabular body of white to yellow quartz sandstone that rests on the Abney Member in the Kununurra/ Mount Cecil area. The type section, which is incomplete, is section 415, 2¾ miles east of Kununurra. The co-ordinates of the base of the type section are Lat.15°47'S, Long.128°47'E. In the type locality, parts of the Cecil Member are pebbly, and the pebble content increases eastward toward the edge of the basin. Elsewhere, the Cecil Member, like the Kellys Knob Member, is a uniform quartz sandstone without pebbles. Except for being thicker (exceeding 1,800 feet in the type section of the Cockatoo Formation), the Cecil Member is a copy of the Kellys Knob Member.

In Mount Cecil, the Cecil Member is silicified, probably as the result of intense faulting, and has an exceptional air-photo pattern. Elsewhere, the Cecil Member and the Kellys Knob Members are indistinguishable by air-photo interpretation, and their identification depends entirely on stratigraphical position.

The only fossils known from the type locality are plants (Leptophloeum) from Mount Cecil, discovered by Matheson & Teichert (1948). In other areas, fish plates have also been found.

The top of the Cecil Member is not exposed here or elsewhere so that its detailed relationship with the overlying Jeremiah Member is not known. The Jeremiah Member is itself poorly exposed in this area, and the little that is known of it here will be included below in the formal description of this member.

B. Matheson Ridge area (Fig.11)

Matheson Ridge includes the type locality of the Cockatoo Formation, and is situated on the western limb of a north-pitching syncline.

Type section of the Cockatoo Formation

By original designation (Matheson & Teichert, 1948, p.82), the area north-west of Cockatoo Spring is the type, and, within this area, we designate section 28-29-30-58 (Fig.12) across Matheson Ridge as the type. In this section, the Cockatoo Formation unconformably overlies the Antrim Plateau Volcanics, and its top is exposed. The section, about 3,500 feet thick, differs from that exposed in the Kununurra/Martin Bluff area in lacking the Ragged Range Member, in being thicker, both in aggregate and in each member except the Kununurra Member, and, with the exception again of the Kununurra Member, in containing more pebbles and cobbles, locally concentrated in the Kellys Knob Member in beds of conglomerate. Another exceptional feature of the Kellys Knob Member in this section is the red colour of its uppermost 200 feet, which is probably an interdigitation of the Ragged Range Member.

The Kununurra Member generally resembles the type but is only half as thick and contains only one thin bed of dolomite. Pelecypods, brachiopods, and trace fossils are common. The Abney and Cecil Members here also correspond to the types except for being thicker and containing abundant pebbles and cobbles. The Cecil Member is incomplete but its measured thickness of 1820 feet is the thickest known exposure of the Member. The air-photo characteristics of each member are the same as in the Kununurra area except for a visible difference between the Kununurra and Abney Members.

In the Cockatoo Spring area (Fig.11), the Ragged Range Member unconformably overlies the Antrim Plateau Volcanics and Precambrian sheared metaquartzite on the western side of the Cockatoo Fault, and Precambrian metamorphics on the eastern side. At locality 81/1 on the eastern side (Matheson & Teichert, 1948, p.82; Traves, 1955, p.72), the Ragged Range Member is exposed in a prominent cliffed hill, 650 feet high, and consists of rounded pebbles and boulders 2 feet across of metaquartzite and rare weathered igneous fragments in a sparse sandstone matrix; within the conglomerate are lenses 6 inches thick of friable brown lithic quartz sandstone with angular pebbles of slate. The conglomerate is thick bedded and deeply jointed, and the estimated minimum thickness is 1,000 feet. This section is virtually identical with the type section of the Ragged Range Member at Conglomerate Hill, as noted also by Matheson & Teichert (1948, p.85).

On the other side of the fault, the Ragged Range Member dips up to 40 degrees in a dome cut by the Cockatoo Fault (Matheson & Teichert, 1948, Fig.1). In the air photographs, the Ragged Range Member has an even dark-grey tone. At locality 81/7, $\frac{3}{4}$ mile north of Cockatoo Spring, a well-exposed outcrop consists of steep-dipping close-jointed Precambrian metaquartzite unconformably overlain by a basal breccia of angular fragments of the underlying metaquartzite and siliceous siltstone set in a lithic quartz sandstone matrix, and lenses of pink quartz sandstone. The nearest boulders of the conglomerate lie on the surface a few paces westward. Whether the basal breccia is the base of the Ragged Range Member at this locality or merely a later superficial deposit cannot be determined on the available evidence. Because no consolidated superficial deposits of this kind are known in the area, and because the pink quartz sandstone interbedded with the breccia resembles the sandstone interbedded with the conglomerate, we regard the breccia as the local base of the Ragged Range Member.

The Ragged Range Member west of the Cockatoo Fault consists almost entirely of conglomerate with cobbles and boulders of metaquartzite and rare interbedded sandstone; the estimated minimum thickness is 700 feet. Four miles north-north-east of Cockatoo Spring, the Ragged Range Member is overlain, apparently conformably, by a jointed cross-bedded white sandstone identified as the Kellys Knob Member. Three miles westward, in Matheson Ridge, the Kellys Knob Member rests direct on the Antrim Plateau Volcanics, showing the rapid thinning of the Ragged Range Member away from the edge of the basin.

Fig. 11

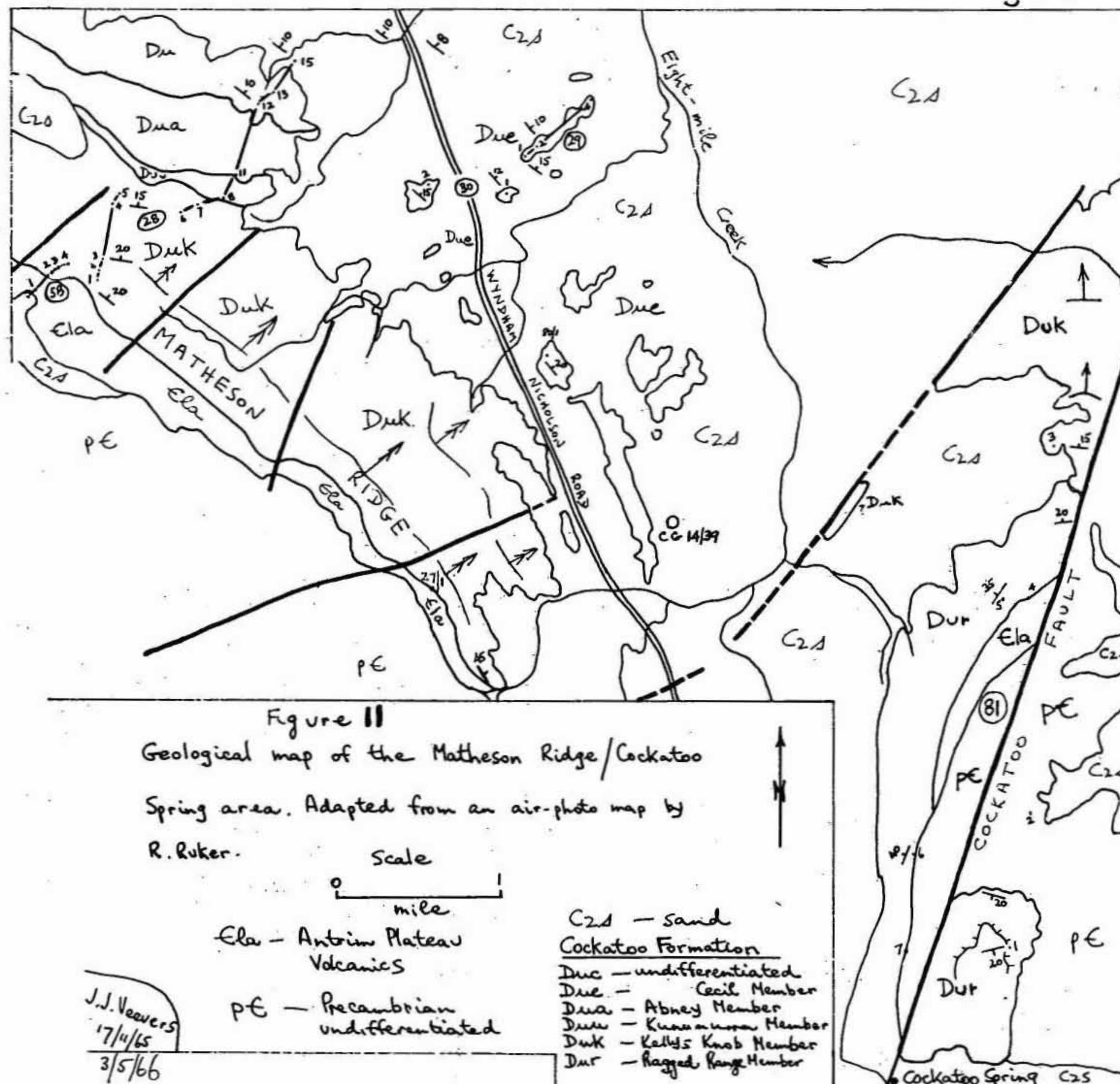


Figure 11
Geological map of the Matheson Ridge/Cockatoo Spring area. Adapted from an air-photo map by R. Ruker.

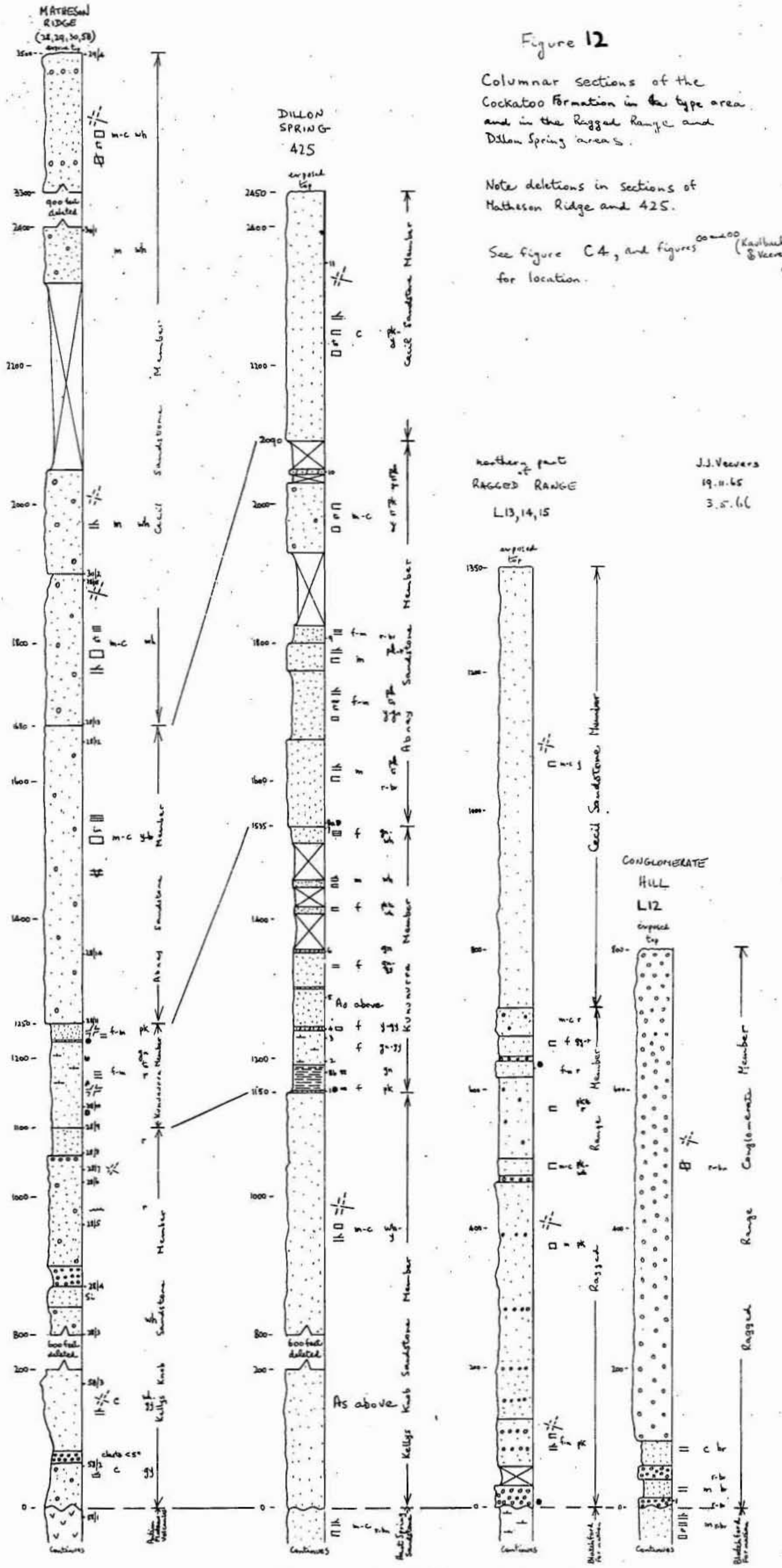


Figure 12

Columnar sections of the Cockatoo Formation in the type area and in the Ragged Range and Dillon Spring areas.

Note deletions in sections of Matheson Ridge and 425.

See figure C4, and figures 00 and 00 (Kaulback & Veevers, 1967) for location.

Fig. 12

C. Ragged Range, Dillon Spring, and Mount Rob areas - the outliers

The same lateral change in the Cockatoo Formation from the Cockatoo Spring area through Matheson Ridge to Kununurra is found in the Formation from Ragged Range to Dillon Spring and Mount Rob.

Ragged Range Conglomerate Member

The Ragged Range Conglomerate (Traves, 1955, pp.46, 47), a formation first regarded as Cambrian and later found to be Devonian (Veevers et al., 1964; Kaulback & Veevers, 1967), is revised here and assigned a member of the Cockatoo Formation. Two columnar sections of the Ragged Range Member are shown in Figure 12, and the field relations are described in Kaulback & Veevers (1967).

The extreme development of the Ragged Range Member is found in the type section (designated here) at Conglomerate Hill (Fig.12, section L12), which consists of 800 feet of deeply jointed very thick-bedded red-brown cobble to boulder conglomerate with minor brown quartz sandstone. In the northern part of the Ragged Range (sections L13-15), the section is divisible into two parts: pink to red-brown conglomerate and conglomeratic sandstone in the lower half, and jointed yellow quartz sandstone in the upper half. Kaulback & Veevers (1967) identified the entire section as Ragged Range Conglomerate; detailed analysis of the CockatooFormation elsewhere now shows that only the lower half of the section is the Ragged Range Member, and that the upper half is better identified as Cecil Member, because it lacks the conglomerate and red sandstone characteristic of the Ragged Range Member. The Ragged Range Member in this section has many points in common with the Kellys Knob Member of the Matheson Ridge Section, but its dominantly pink to red colour indicates that it belongs to the Ragged Range Member. Fossils are known from two places: indeterminate pelecypods and gastropods in conglomerate at the base, and pelecypods from red sandstone near the top. The only other fossils known from the Ragged Range Member are indeterminate pelecypods immediately above the conglomerate bed at Church Steeple Peak (section 412), and Leptophloeum at the Ochre Mine.

Since Kaulback & Veevers (1967) described the Cockatoo Formation of the Dillon Spring outlier, another section (425) has been measured, and this section and its relations with the Matheson Ridge section are shown in Figure 12. The lower 1150 feet of this section are jointed white to yellow cross-bedded quartz sandstone indistinguishable from the type section of the Kellys Knob Member. A sequence of varicoloured, dominantly grey to green sandstone, sandy dolomite, and siltstone, identified as Kununurra Member, occupies the interval from 1150 to 1535 feet, and contains brachiopods, pelecypods, and conodonts at its base. The next unit, from 1535 to 2090 feet, identified as Abney Member, is a dominantly red sandstone, part of it pebbly; pelecypods, discovered by Traves (1955, pp.60,61) are found near the base. The uppermost unit, from 2090 feet to the exposed top at 2450 feet, is jointed yellow to pink cross-bedded sandstone, readily identified as Cecil Member.

No further comment on the poorly exposed probable Cockatoo Formation of the Mount Rob outlier (Kaulback & Veevers, 1967) is made except that the glauconitic sandy dolomite with trace fossils near the exposed top is possibly part of the Kununurra Member.

D. Eastern edge of the basin, from south of the Amphitheatre to the Ochre Mine

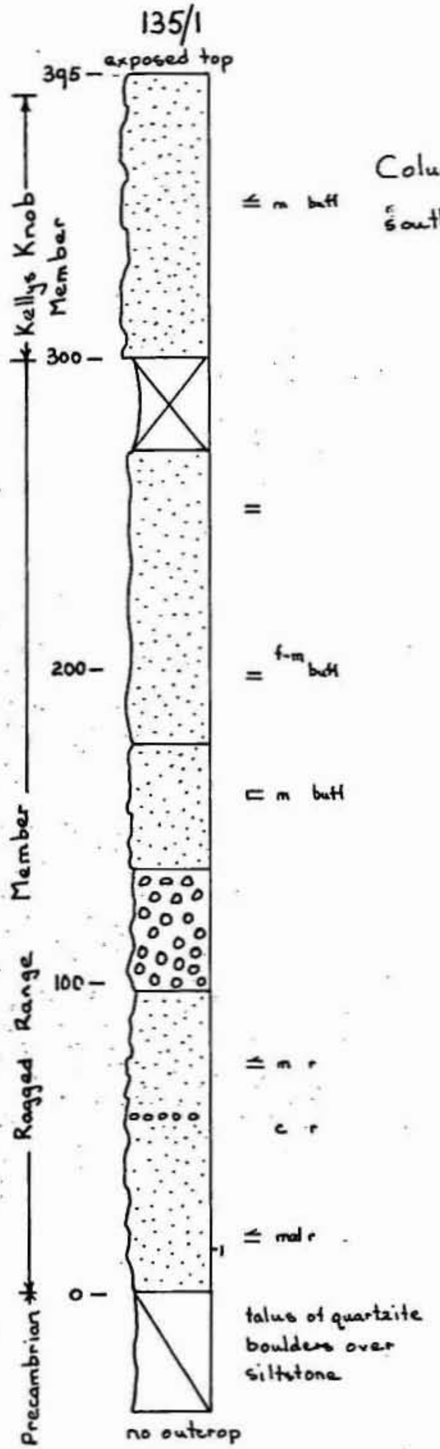
A few miles south of the Amphitheatre (Fig.31), rocks tentatively identified as Ragged Range Member lie beneath, and possibly interfinger with, the Kellys Knob Member in the core of an anticline. Traves (1955, p.73, figs.23,30) identified these rocks as Precambrian metamorphics but the indication in the air photographs that part of these rocks interfingers with the Kellys Knob Member and the lack of lineation inclines us to regard them tentatively as Ragged Range Member. Matheson & Teichert (1948, p.85) described these rocks as unstratified conglomerate.

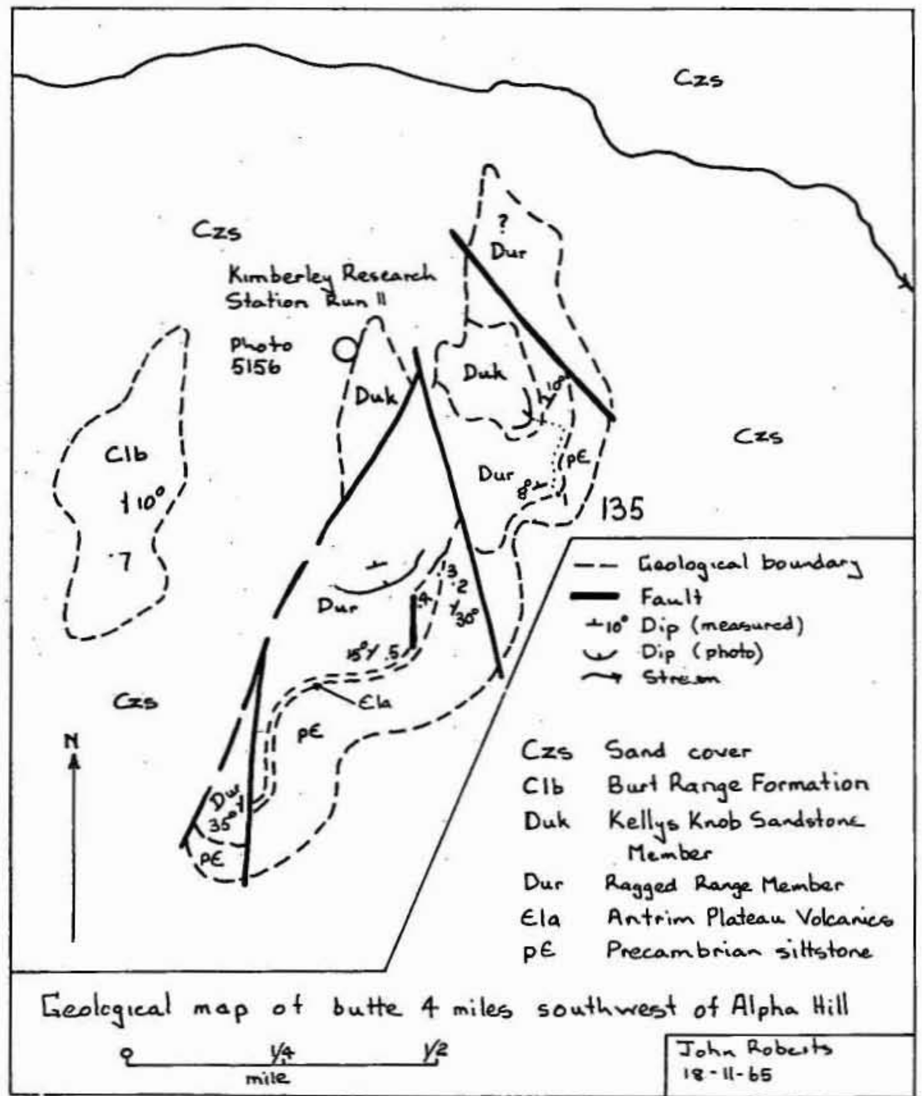
A group of outcrops of Ragged Range Member stretch on either side of the Keep River north-west from Nigli Gap. One mile south-east of Nigli Gap (Fig.15), the Ragged Range Member is 445 feet thick, and consists of a basal conglomerate of metaquartzite cobbles and boulders overlain by red-brown cross-bedded hematitic pebbly quartz sandstone. The Ragged Range Member unconformably overlies amygdaloidal basalt of the Antrim Plateau Volcanics, and is conformably overlain by the Kellys Knob Member. The only previously published reference tothis area is Traves (1955, p.74, plate 1), who proposed the name Nigli Gap Sandstone for the sandstone that crops out in Nigli Gap. On the basis of plant stems (Equisetales) and ice-rafted pebbles in this sandstone, Traves dated it as Permian. We disagree with this determination. In the Nigli Gap area, the sequence of volcanics overlain by white to yellow pebbly quartz sandstone, in turn overlain by white to yellow pebbly quartz sandstone can be matched with identical sequences in nearby areas, each consisting of Antrim Plateau Volcanics, Ragged Range Member, and Kellys Knob Member, and these identities are, at least to us, convincing evidence that it is these units that are found in the Nigli Gap area. The kind of plant stems (Equisetales) recorded from Nigli Gap range from Devonian to Permian, and do not affect the argument, and Traves' assertion that the pebbles in the Nigli Gap Sandstone were derived from glaciers rafted by ice during the Permian glaciation is unfounded. Furthermore, Traves' idea that the volcanic rocks at the eastern end of Nigli Gap are part of a volcanic vent that issued through the Nigli Gap Sandstone along a fault is unlikely to be true. The volcanics consist of amygdaloidal trachyte or alkaline basalt - a more precise determination is hampered by the severe alteration - types common in volcanic flows. The trachyte or basalt is underlain by closely jointed mylonitized acid igneous rock, identical with outcrops of Halls Creek Metamorphics 1 mile north-north-eastward (Fig.15, locality 74).

North-west of Nigli Gap, the Ragged Range Member is identified in the air photographs by its uniform soft dark-grey tone which contrasts with the light tone and fine pattern of close joints in the overlying Kellys Knob Member. Locality 417/1 contains 45 feet of exposed Ragged Range Member, including at the top 15 feet of conglomerate, notable for containing cobbles

Fig. 13

Columnar section at butte 4 miles southwest of Alpha Hill.





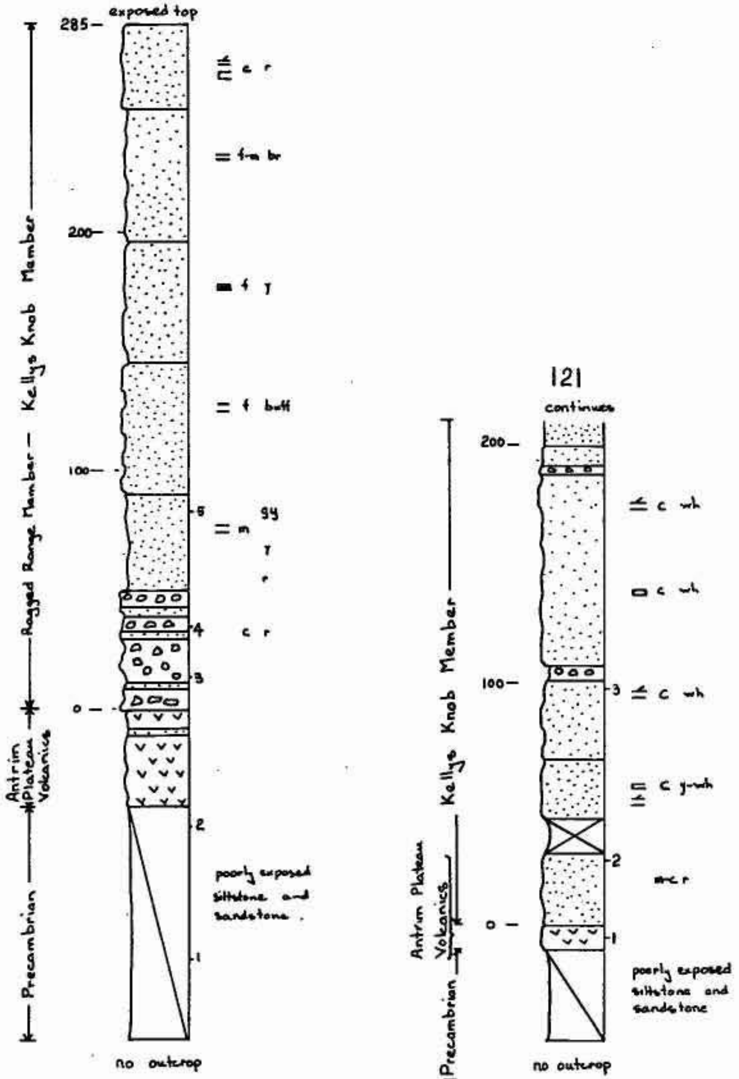
Geological map of butte 4 miles southwest of Alpha Hill

29.3.66

Fig. 13'

Fig. 14

Columnar Sections at Alpha Hill



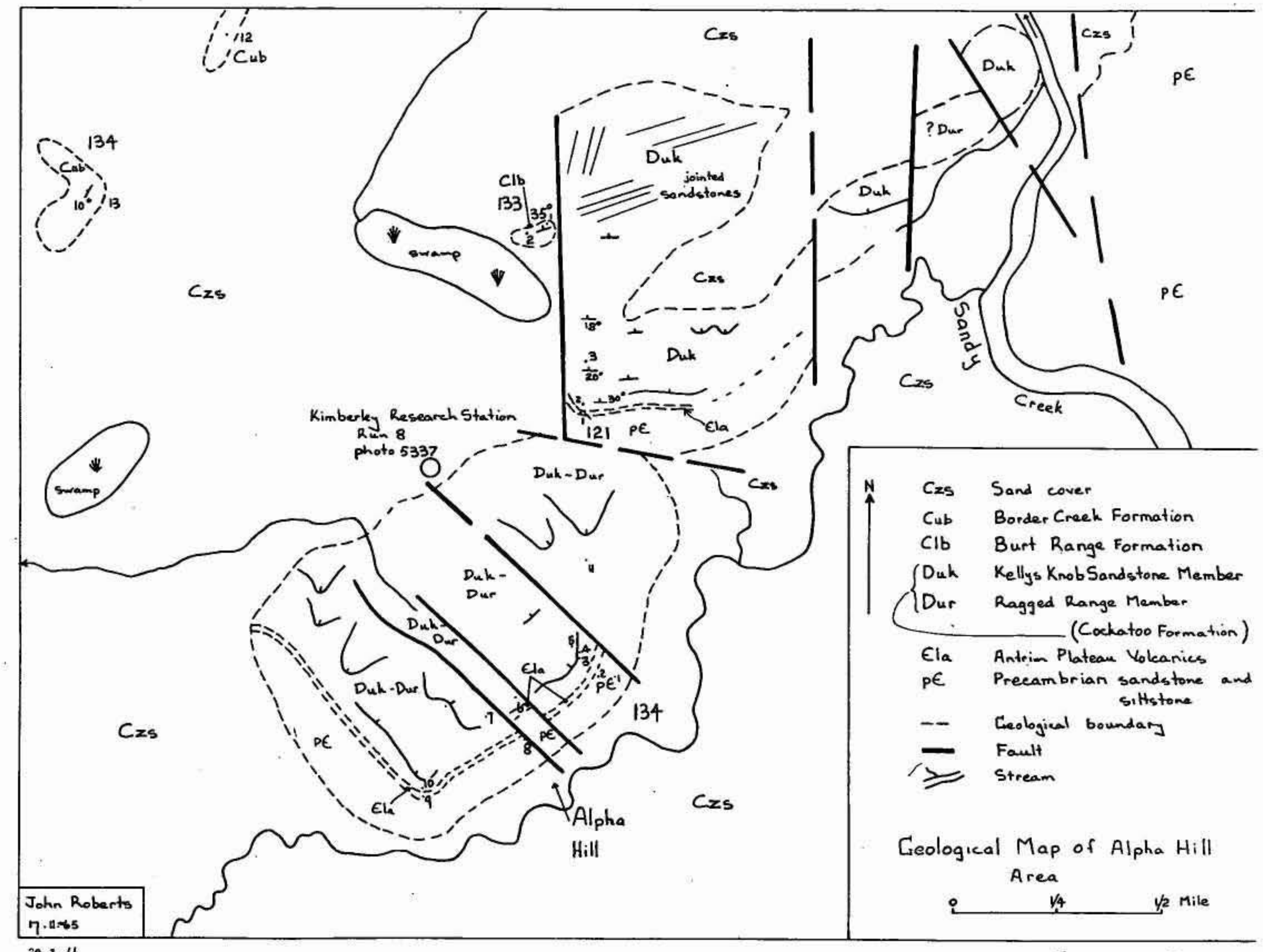
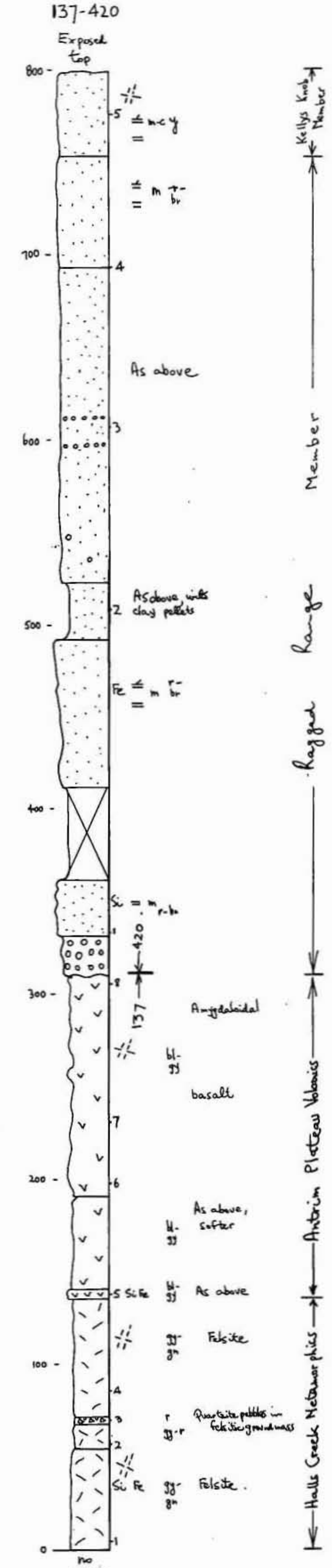


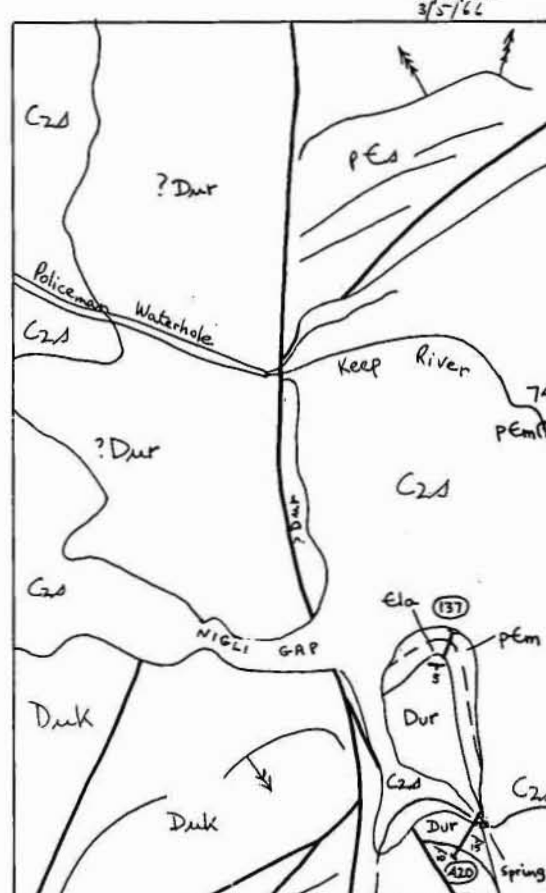
Fig. 14

Figure **15**

Columnar section of the Halls Creek Metamorphics Antrim Plateau Volcanics and the Ragged Range Conglomerate Member in the Nigli Gap area

J. J. Veevers
19/11/65
5/2/66
3/5/66





Geological map of the Nigli Gap area

Scale

0 1 mile

N

Czs – sand

Cockatoo Formation

Duk – Kellys Knob Sandstone Member

Dur – Ragged Range Member

Єla – Antrim Plateau Volcanics

pЄs – Sandstone, quartzite

pЄm – Halls Creek Metamorphics

Fig. 15

of basalt and Precambrian siltstone besides the common fragments of metaquartzite. Outcrops of the Ragged Range Member are not found west of the Amphitheatre Fault until the Martin Bluff area is reached.

The only other member of the Cockatoo Formation in the area between Cockatoo Spring and Spirit Hill is the Kellys Knob Member, whose outcrop is almost continuous. Besides containing variable amounts of pebbles and cobbles, the Kellys Knob Member is unexceptional. It conformably overlies the Ragged Range Member, its top is eroded, and it is bounded on the east by faults. As noted already, this outcrop of the Kellys Knob Member corresponds to Traves' Nigli Gap Sandstone.

Several outcrops near Spirit Hill merit attention. At locality 266, in the south-eastern part of the Spirit Hill area (Fig.40), pebbly quartz sandstone contains abundant Leptophloeum australe (M'Coy) and pelecypods which are the same as those from locality 146/4 (Fig.31) near Eight-Mile Creek. Half a mile northwards, the lower part of section 114 consists of barren, white quartz sandstone overlain, probably unconformably, by the Burt Range Formation.

One mile east of Spirit Hill, sandstone, identified as the Cockatoo Formation, crops out on either side of the Cockatoo Fault, and on the eastern side overlies the Precambrian. The Cockatoo Formation is a cross-bedded, medium to coarse-grained, white quartz sandstone, conglomeratic at the base, and the Precambrian is a white quartzite.

Four miles north-east of Spirit Hill (Fig.13), a butte one mile long consists of Precambrian siltstone overlain by Antrim Plateau Volcanics and the Ragged Range and Kellys Knob Members of the Cockatoo Formation.

Traves (1955, p.74) mapped a similar sequence at his localities 27 and 28 as Permian Weaber Group. Glover (1955, Appendix A in Traves) gave petrographic descriptions of the volcanics from this butte and from Alpha Hill, 5 miles to the northeast (localities 24, 25, 26, 35 and 36 of Traves) and identified them as flows of amygdaloidal sanadine trachyte. We have mapped these lavas as Antrim Plateau Volcanics because they rest between the Precambrian and fossiliferous Upper Devonian along the eastern margin of the basin. All of the volcanics along this margin area, however, more alkaline than the basalts typical of the Antrim Plateau Volcanics. Traves' fossil localities 18, west of the butte, and 19, 2 miles to the southwest, are identified as Burt Range Formation.

In the northern part of the butte at locality 135/1 (Fig.13), the Precambrian siltstone is unconformably overlain by red and buff sandstone and conglomerate of the Ragged Range Member. The red sandstone is a coarse to medium-grained, locally pebbly, quartz sandstone which is cross bedded and has current lineation on some of the bedding planes. The conglomerate disconformably overlies the sandstone and contains rounded quartzite boulders up to 2 feet in diameter and small angular fragments of Precambrian siltstone set in a matrix of feldspathic quartz sandstone. Overlying the conglomerate is a medium-grained, buff quartz sandstone containing occasional trace fossils. The Ragged Range Member is in turn overlain by cliff-forming, cross-bedded, buff feldspathic quartz sandstone of the Kellys Knob Member. In the fault block west of this section the Antrim Plateau Volcanics lie between the Precambrian siltstone and the Ragged Range Member. The Antrim Plateau Volcanics consist of copper-stained tuff and trachyte and overlie, with angular discordance, thin-bedded purple Precambrian siltstone. The trachyte and siltstone were faulted before being overlain by red sandstone and conglomerate of the Ragged Range Member (Fig.13).

In the westernmost fault block the Antrim Plateau Volcanics are again missing; they are missing in the westernmost and easternmost fault blocks probably because these blocks were faulted up and their cover of volcanics removed before the Ragged Range Member was deposited.

Similar sequences were found 5 miles north-west in the Alpha Hill area (Fig.14). At Alpha Hill itself (section 134) the Precambrian and Antrim Plateau Volcanics are unconformably overlain by 50 feet of red conglomerate, in turn overlain by 235 feet of grey, buff, yellow and red sandstone which we identify as interfingering Ragged Range Member and Kellys Knob Member. The Antrim Plateau Volcanics contain silicified interbeds of sandstone, boulders of which constitute a large part of the overlying conglomerate. The boulders are angular to sub-rounded, reach a maximum diameter of 3 feet, and are set in a matrix of basalt fragments and coarse sandstone stained by red ochre. The conglomerate is overlain, apparently conformably, by cliff-forming sandstone.

Half a mile northwards at locality 121 the Antrim Plateau Volcanics are overlain by a thick sequence of white quartz sandstone and conglomerate identified as Kellys Knob Member; either the Ragged Range
stripped off, because the block north of Alpha Hill was faulted up before the Kellys Knob Member was..
Member was/deposited, or the Ragged Range Member accumulated in depressions, and the overlying Kellys Knob Member locally overlapped these deposits. The Kellys Knob Member is silicified at the base and is a medium to coarse-grained quartz sandstone containing lenses of conglomerate. Poorly preserved pelecypods were collected from locality 121/2.

A sequence similar to that at Alpha Hill crops out at the Ochre Mine (Fig.37), 8 miles west of Alligator Springs. Poorly exposed white Precambrian siltstone is overlain by haematitized and silicified Antrim Plateau Volcanics which, in turn, are overlain by the Ragged Range Member. The basal conglomerate of the Ragged Range Member is 20 feet thick and contains slabs of siltstone, boulders of quartzite, interbeds of shaley siltstone having clay pellets, and pebbly quartz sandstone. The conglomerate is overlain by a fine siltstone composed mainly of red ochre followed by a fine to medium-grained, red quartz sandstone containing the plant <u>Leptophloeum australe</u> (M'Coy). The ochre mine itself has been described by Traves (1955, pp.105, 106).

Sandstone identified as Kellys Knob Member crops out alongside the Carlton Hill - Legune track near Sandy Creek, and appears to rest directly on Precambrian siltstone.

Further cross-bedded, white quartz sandstone identified as Kellys Knob Member, and also apparently overlying the Precambrian, crops out in hills 5 miles west of Alligator Springs. The absence of the Ragged Range Member at both of these localities is due either to the erosion of up-faulted blocks before the deposition of the Kellys Knob Member, or to the Kellys Knob Member overlapping Ragged Range Member that was deposited in depressions.

The northernmost outcrops of Cockatoo Formation are two isolated turrets of fawn to white quartz sandstone, identified as Kellys Knob Member, at locality 124/2 near Legune Station (Fig.37).

Two hillocks two miles south of Sorby Hills (Plate 1) contain the only known outcrops of Antrim Plateau Volcanics and Cockatoo Formation along the eastern edge of the Pincombe Range. The larger hillock is conical, consists of 10 feet of basalt, identified as Antrim Plateau Volcanics, overlain by about 140 feet of blocky silicified micaceous quartz sandstone, feldspathic quartz sandstone and laminated quartz

Figure 16

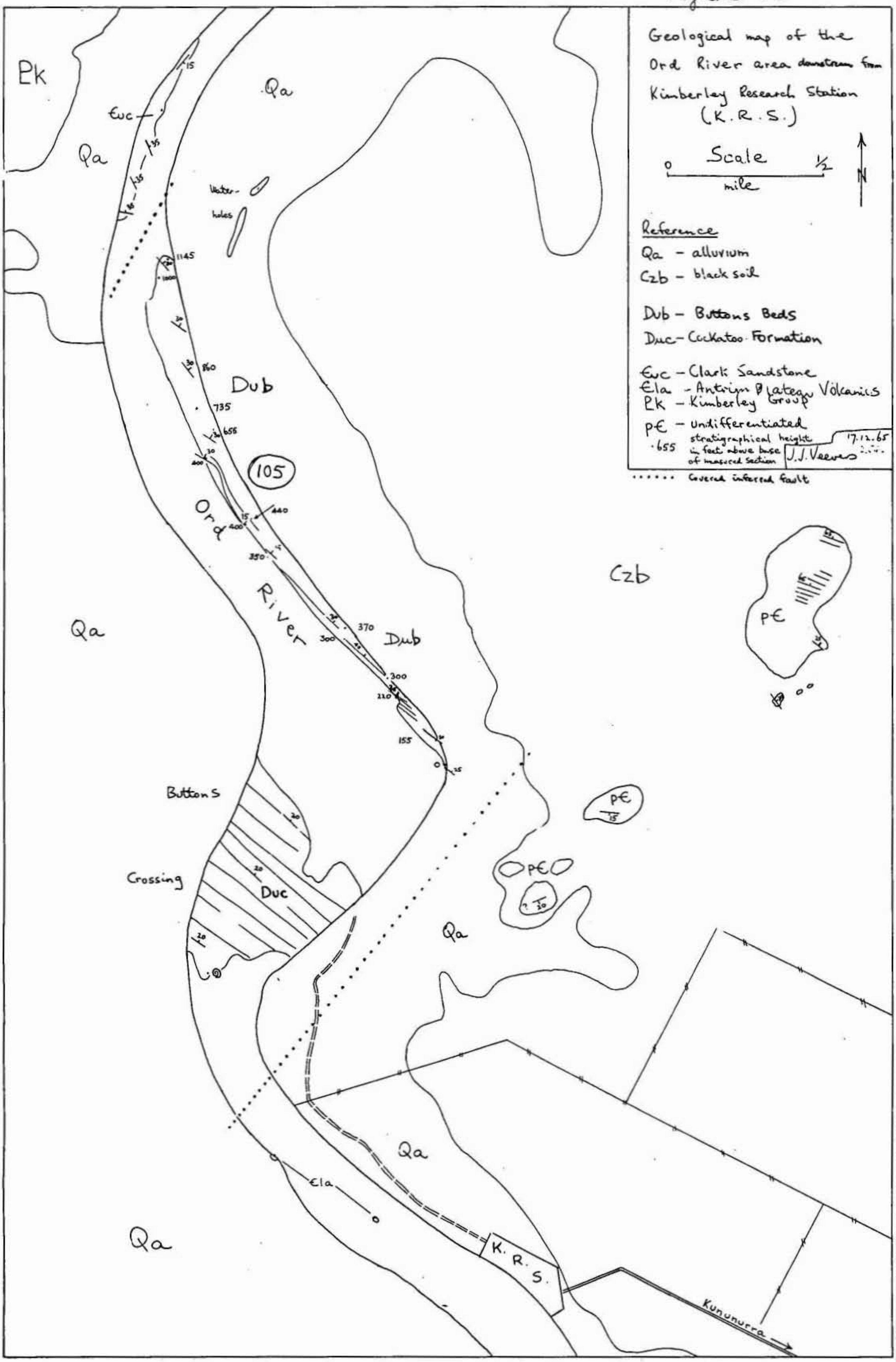


Fig. 16

sandstone with clay galls, identified as Cockatoo Formation, tentatively as the Kellys Knob Member. Most of the exposed sandstone is in loose blocks, but the few blocks in situ indicate that the bedding is horizontal. (The conical form of horizontal silicified sandstone of the Cockatoo Formation is also found at Church Steeple Peak, which consists of fault-bounded Antrim Plateau Volcanics overlain by loose blocks of silicified sandstone of the Ragged Range Member, and at Cone Hill, whose sandstone blocks are probably Cecil Member overlying the Westwood Member). The importance of these two outcrops on the eastern edge of the Pincombe Range is out of all proportion to their size, because they show that the Antrim Plateau Volcanics and the Cockatoo Formation extend from the eastern edge of the basin across to the Pincombe Range, and that consequently the general structure of this part of the basin is a graben, or syncline, or both. Another point is that the Buttons Beds unconformably overlie the Precambrian siltstone in the Sorby Hills and are only locally transgressive deposits which stretch a short distance beyond the regional graben or syncline.

This concludes the description of the Cockatoo Formation that lies strictly within the marginal province. One other outcrop, however, which lies on the western flank of the Pincombe Range inlier and hence geographically in the middle province, is described here because it contains pebbles and cobbles indicative of the marginal province. This is the isolated outcrop of sandstone at Buttons Crossing (Fig.16), on the Ord River, previously described by Matheson & Teichert (1948, p.84). About 1,000 feet of jointed cross-bedded quartz sandstone, with minor beds of pebbly and cobbly sandstone, dip 20 degrees north-eastward. Some beds have a weak calcareous cement. Indeterminate pelecypods were found near the exposed base. In view of the complex and largely obscured structure of the area, extrapolations from the Buttons Crossing outcrop are speculative. Outcrops of Antrim Plateau Volcanics a little over ½-mile upstream are probably separated from the sandstone by the covered inferred fault shown in Figure 16. In the other direction, the outcrops of Buttons Beds ½-mile downstream are apparently concordant structurally with the sandstone. However, this is not certain, as Matheson & Teichert (1948, p.84) believed, because in this area faults with large displacements leave little or no visible trace, exemplified by the inferred fault with an estimated throw of 6,000 feet that separates the Buttons Beds and the Cambrian Clark Sandstone (Fig.16). If the Buttons Beds and Cockatoo Sandstone were conformable in this area, as they are thought to be elsewhere in the basin, the outcropping sandstone would be identified as the Cecil Member, and the covered interval between the outcrops would probably be underlain by the Teichert Member.

2. Middle province

A. Southern part

The area lying between the Pincombe Range and the northern part of the Hargreaves Hills contains dipping strata crossed by numerous prominent strike faults of large throw, so that pains must be taken to avoid overlooking less prominent faults in measured sections. Furthermore, the repetitious lithologies in parts of the sequence rule out indisputable connections between fault blocks. In view of these problems, in the Hargreaves Hills we measured sections which appeared to us to contain the structurally least disturbed sequences in the area. In choosing these sections, we were guided by the detailed work in this area by the Australian Aquitaine Petroleum geological party.

The quartz sandstone exposed on either side of the fault that marks the western edge of the Hargreaves Hills (Fig.17) is identified as Kellys Knob Member on the tenuous ground of its general properties and not by reference to its stratigraphical position, which, because of faults, is not known. The only exceptional feature of this sandstone, if indeed it belongs to this member, is its thick cross-bedding, seen at localities 239A-C, and 217/2. The thickness of the sets of cross-strata exceeds 20 feet, suggesting that these beds are aeolian. This is not certain though, because this thickness also lies within the size range of aqueous cross-beds.

Hargreaves Member (new name)

The Hargreaves Member is defined as the tabular body of varicoloured fine-grained quartz sandstone, dolomitic quartz sandstone, sandy dolomite, and marl that conformably underlies the Cecil Member in the Hargreaves Hills (Fig.17). The interval from 0 to 720 feet of section 431 (Fig.18) is designated type; sections 427, 428, 429, and 430 are supplementary. The geographical co-ordinates of the base of the type section are Lat.15°20'S, Long.128°35'E. The base of the type section is marked by a fault, and the top is conformably overlain by the Cecil Member. The type section consists of 720 feet of laminated to medium-bedded fine-grained yellow, green, and white quartz sandstone, with minor beds of dolomite and dolomitic sandstone. Pelecypods, brachiopods, conodonts, fish plates, and trace fossils were found at two localities. Part of section 431 was chosen as type because it is the only one of our measured sections in the Hargreaves Hills whose stratigraphical relations with another member are clear. The relations of section 431 with the other measured sections in the Hargreaves Hills, as shown in Figure 18B, are conjectural, there being no suitable marker to provide a link between fault blocks. The connections between sections 427, 428, and 429 are based on the recognition of markers or sequences of markers in different fault blocks. We are aware of the shortcomings of this method, and offer the scheme shown in Figure 18B merely as the best informed guess.

With these reservations, the Hargreaves Member is thought to consist of more than 2,000 feet of generally thin- to medium-bedded, fine-grained quartz sandstone, with minor dolomitic sandstone, sandy dolomite, and marl. The quartz sandstone of the Hargreaves Member is readily distinguished from that of the Cecil Member because it is fine grained and well sorted, and most samples studied contain rare glauconite. The sandstone is friable, with a weak cement of secondary quartz overgrowths. Most of the sandy dolomite and dolomitic sandstone consists of varying amounts of well-sorted fine quartz sand in a matrix of mosaic dolomite.

Outcrops of the Hargreaves Member are etched into numerous sharp strike ridges and valleys which contrast with the bluffs of probable Kellys Knob Member at the western edge of the Hargreaves Hills and of Cecil Member at the eastern edge.

Fig. 17

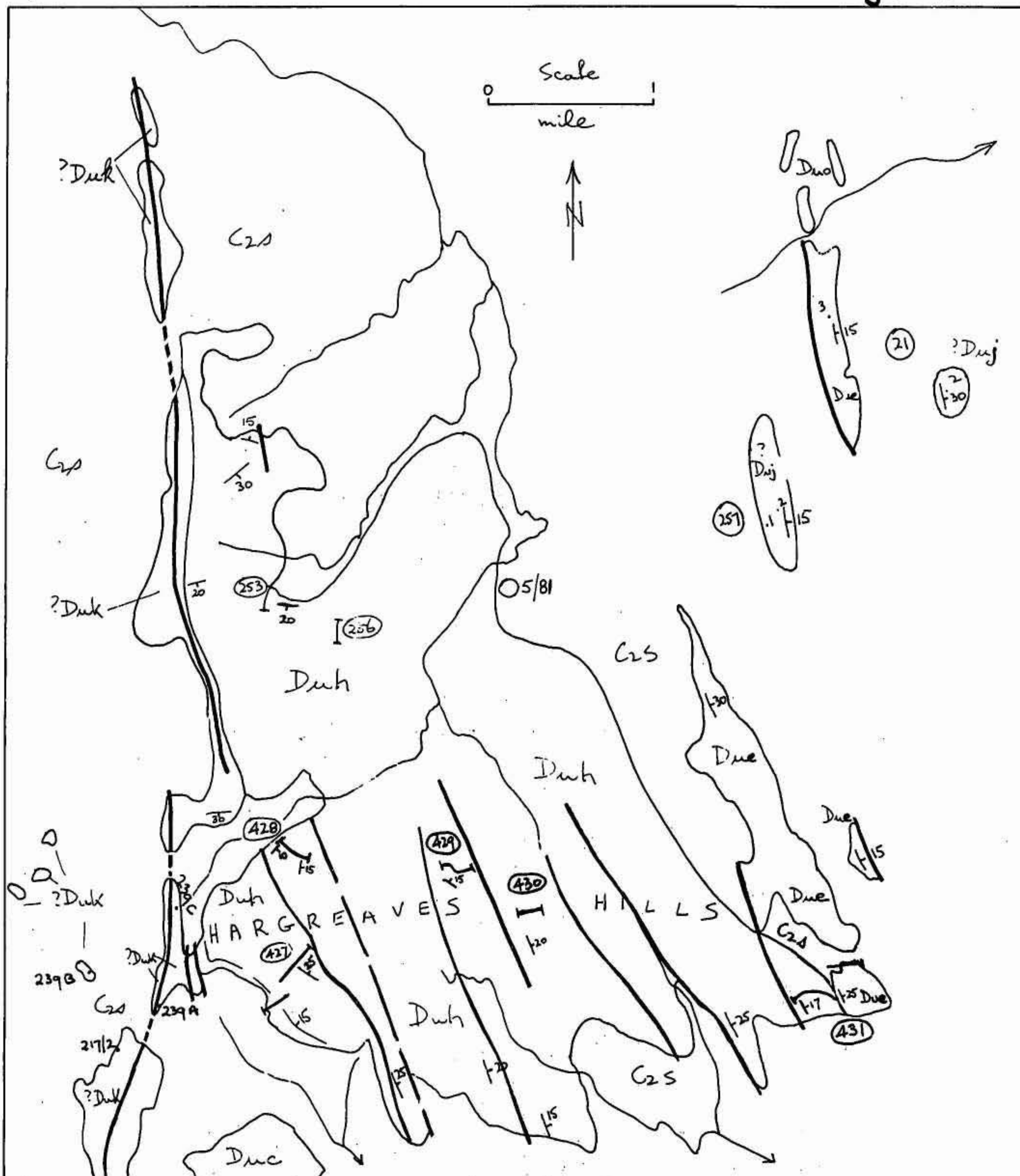


Figure **17** Geological map of the Hargreaves Hills area, showing members of Cockatoo Formation

Cockatoo Formation
- Duj — Jeremiah Member
- Due — Cecil Sandstone Member
- Duh — Hargreaves Member
- Duk — Kellys Knob Sandstone Member
- Duc — Undifferentiated

J. J. Veevers
25/11/65 3/5/66
10/2/66

Poorly preserved fossils were found at 12 different horizons, and include pelecypods, brachiopods, trace fossils, and fish plates.

A composite section (Fig.17, 253, 256) through part of the Hargreaves Member was measured in the area 1½ miles north of locality 428. The measured thickness of 400 feet consists of roughly equal parts of interbedded quartz sandstone and sandy dolomite, and a single bed with pelecypods was found. What part of the Hargreaves Member is represented by the section is not known.

The Hargreaves Member was recognised in various parts of the Pretlove Hills, but, owing to the intense strike-faulting of this area, could not be mapped without a disproportionate investment of time. A small fault block of dolomite and fossiliferous marl 2 miles east of Cark Jumpup, was described by Traves (1955, p.61, fig.22). In another paper (1967) we argue that the Hargreaves Member in the Pretlove Hills was the chief source of the blocks of dolomite in the Visean Waggon Creek Breccia.

Other Members

The jointed cross-bedded sandstone marking the western edge of the Hargreaves Hills, tentatively identified as Kellys Knob Member, is traced southward and south-eastward along a major fault into the Pretlove Hills, where it is juxtaposed against outcropping Cambrian sedimentary rocks (Kaulback & Veevers, 1967, figs.3, 5, 6).

About 500 feet of friable quartz sandstone are exposed in the cliff face of a large fault block in the Onslow Hills, 2½ miles east of Hart Spring (Kaulback & Veevers, 1967, fig.6, locality 222). This sandstone is cross-bedded in thick sets, and is probably part of the Kellys Knob Member.

The final outcrop of probable Kellys Knob Member to be mentioned in this area lies between Point Spring and Teichert Hills (Fig.19). At locality 423/5, barren fine-grained silicified yellow quartz sandstone, probably the Kellys Knob Member, unconformably overlies fossiliferous red and white quartz sandstone, some of it glauconitic, identified as Cambrian Clark Sandstone. Localities 423/4,6 and 7 all contain trilobites. This is the only locality known to us where an unfaulted contact between the Cockatoo Formation and Cambrian sedimentary rocks is visible. Closely faulted sandstone at locality 423/8 is also probably Kellys Knob Member. The other outcrpps in this area are Ningbing Limestone, which will be described later.

The Cecil Member probably occupies a large part of the northern Pretlove Hills, as shown for example, by the outcrop of dipping sandstone (?Cecil Member) at the Carlton/Legune road crossing of Redbank Creek.

As noted earlier, the Cecil Member on the eastern edge of the Hargreaves Hills conformably overlies the Hargreaves Member, and about 400 feet of it are exposed in the area (Fig.18, section 431). As elsewhere, so here the Cecil Member is deeply jointed and strongly cross-bedded. The only fossil found in the section was a fish plate.

Poor outcrop and structural dislocation by faults in the area east of Hargreaves Hills rule out all attempts at estimating the total thickness of the Cecil Member in this area. To the east, the first group of outcrops of a recognisably younger unit are those found west of Siggins Spring in the headwaters of Mistake Creek, (section 21, Fig.26; Fig.20). These scattered outcrops consist of glauconitic quartz sandstone, sandy limestone, and dolomite (including oolite) and are overlain, apparently conformably, by the Ningbing Limestone. Pelecypods were found at locality 21/12. The estimated stratigraphical thickness of 1,240 feet between the oldest exposure in the core of the anticline and the base of the Ningbing Limestone may of course include beds repeated by concealed faults. These beds are identified as part of the Jeremiah Member, which is described below. Carbonate rocks and sandstone at localities 257 and 21/2 (Fig.17) are tentatively identified as Jeremiah Member.

Jeremiah Member (new name)

The Jeremiah Member is defined as the sequence of sandy limestone and dolomite, with minor interbedded sandstone that conformably lies beneath the Ningbing Limestone in the Jeremiah Hills (Fig.21). The interval from 0 to 360 feet in section 442 (Fig.20) is designated type. The geographical co-ordinates of the base of the type section are Lat.15° 12'S, Long.128° 44½'E. The base of the type section is marked by a fault, and the top is conformably overlain by the Ningbing Limestone. The type section consists of brown, red, and yellow-grey sandy dolomitic limestone, thin to very thick bedded, with minor interbeds of dolomitic quartz sandstone. Brachiopods, conodonts, and crinoid ossicles were found at four localities. The regular bedding and subdued morphology of the Teichert Member serve to distinguish it in the air photographs from the crags of overlying Ningbing Limestone. Outcrops of the Jeremiah Member were found beneath the Ningbing Limestone in the southern half of the Jeremiah Hills, and a measured section (444) from the eastern edge of the Jeremiah Hills is also shown in Figure 20. Section 444 contains more sand at its base compared with the equivalent part of section 442.

The interval 0 to 1240 feet in section 21 (Fig.20) has been mentioned already. The only other known outcrops of the Jeremiah Member are in the marginal province, but for completeness will be described here.

Isolated outcrops (Fig.8, locality 60) are found in the bed of 8-mile Creek, 1½ miles east of Mount Cecil, and consist of varicoloured sandy colomite, dolomitic sandstone, and marl. The section is too poorly exposed to be measured. The geologists of Australian Aquitaine Petroleum (pers.comm.) found plant fossils (?Leptophloeum) at this locality.

Poorly preserved fossils were found at 12 different horizons, and include pelecypods, brachiopods, trace fossils, and fish plates.

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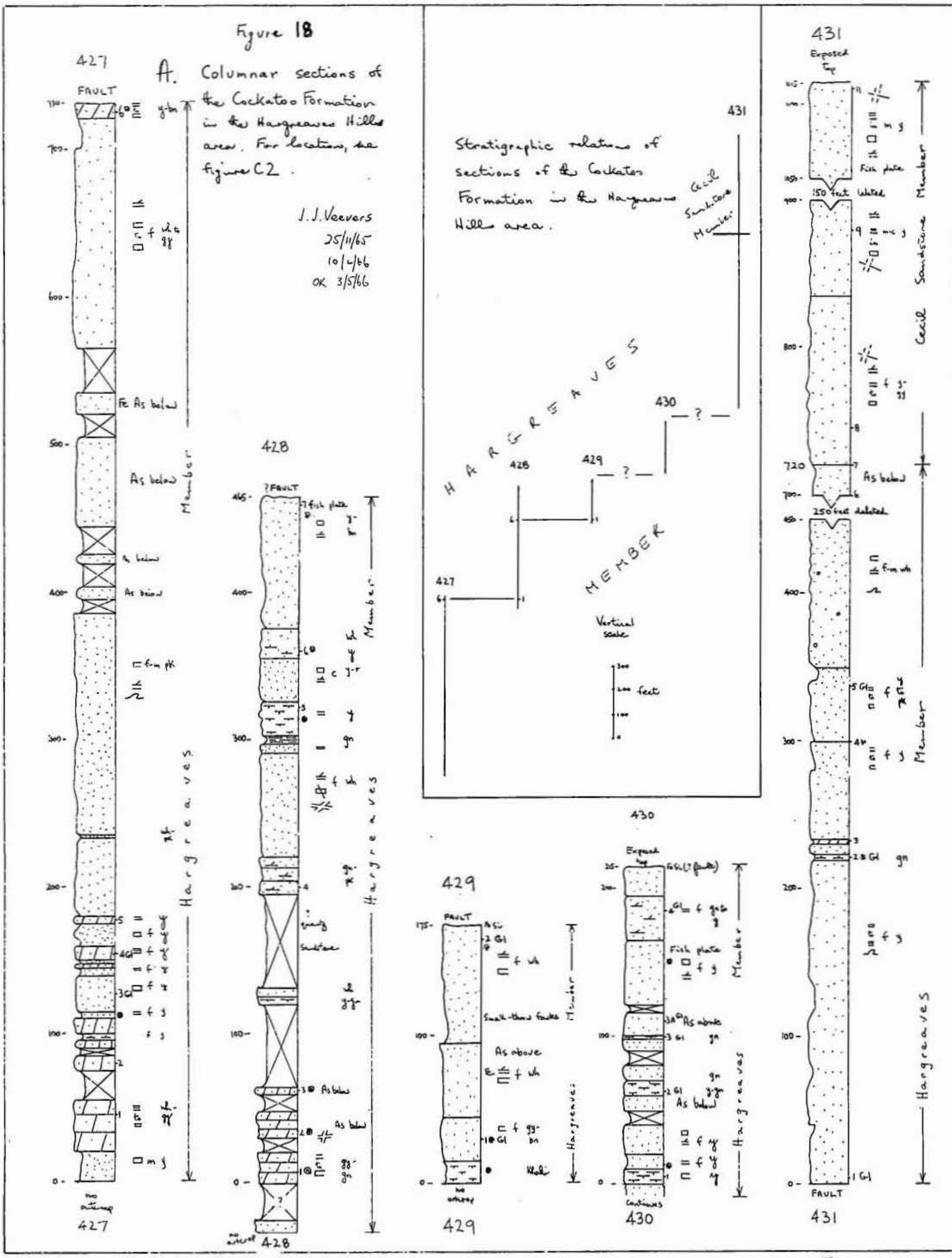

Figure 18

A. Columnar sections of the Cockatoo Formation in the Hargreaves Hills area. For location, see figure C2.

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Fig. 18

Fig. 19

Geological map of the area 5 miles West-south-west of Point Spring

N

0 — 1 mile

C2b — black soil

C2s — sand

Dun — Ningbing Limestone

Duc — Cockatoo Formation

Єuc — Clark Sandstone

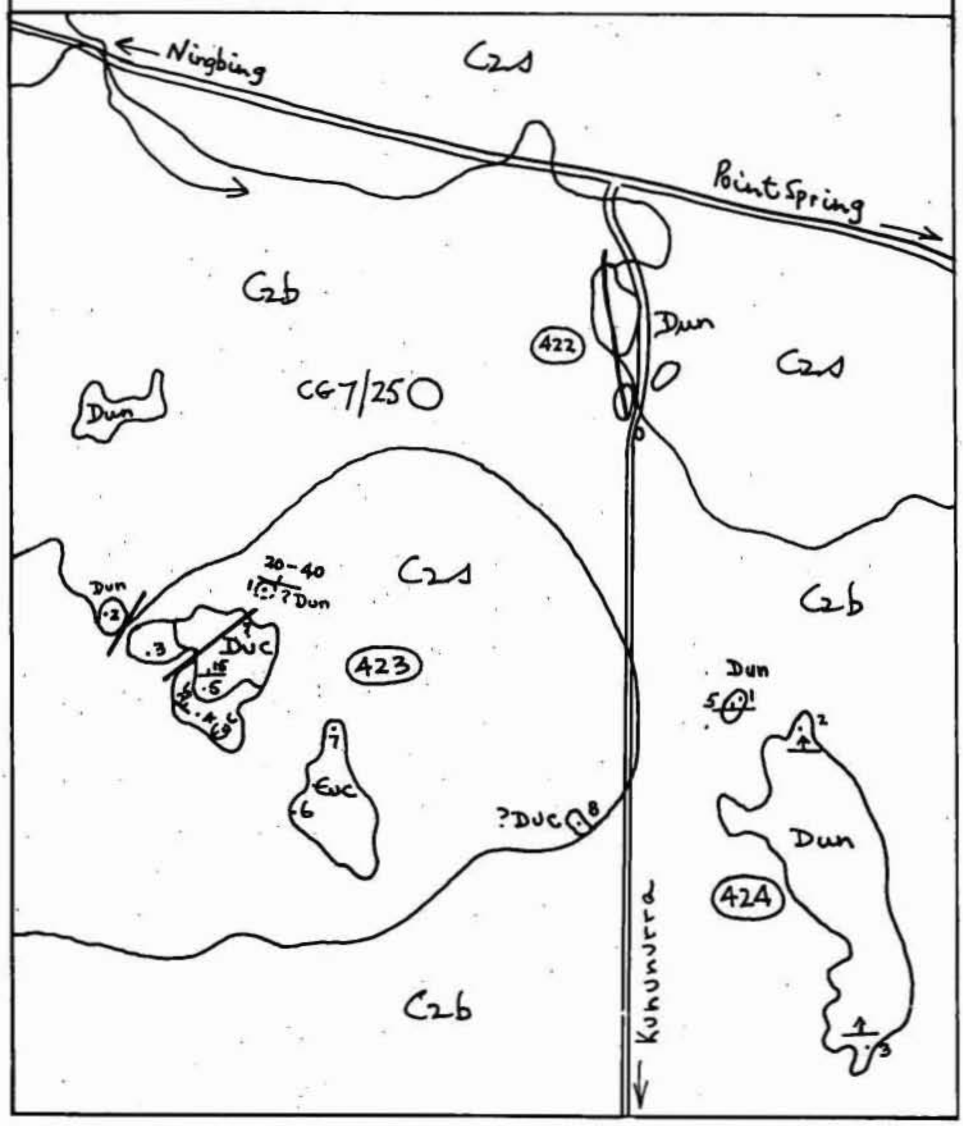

Fig. 19 3.5.66

Figure 20

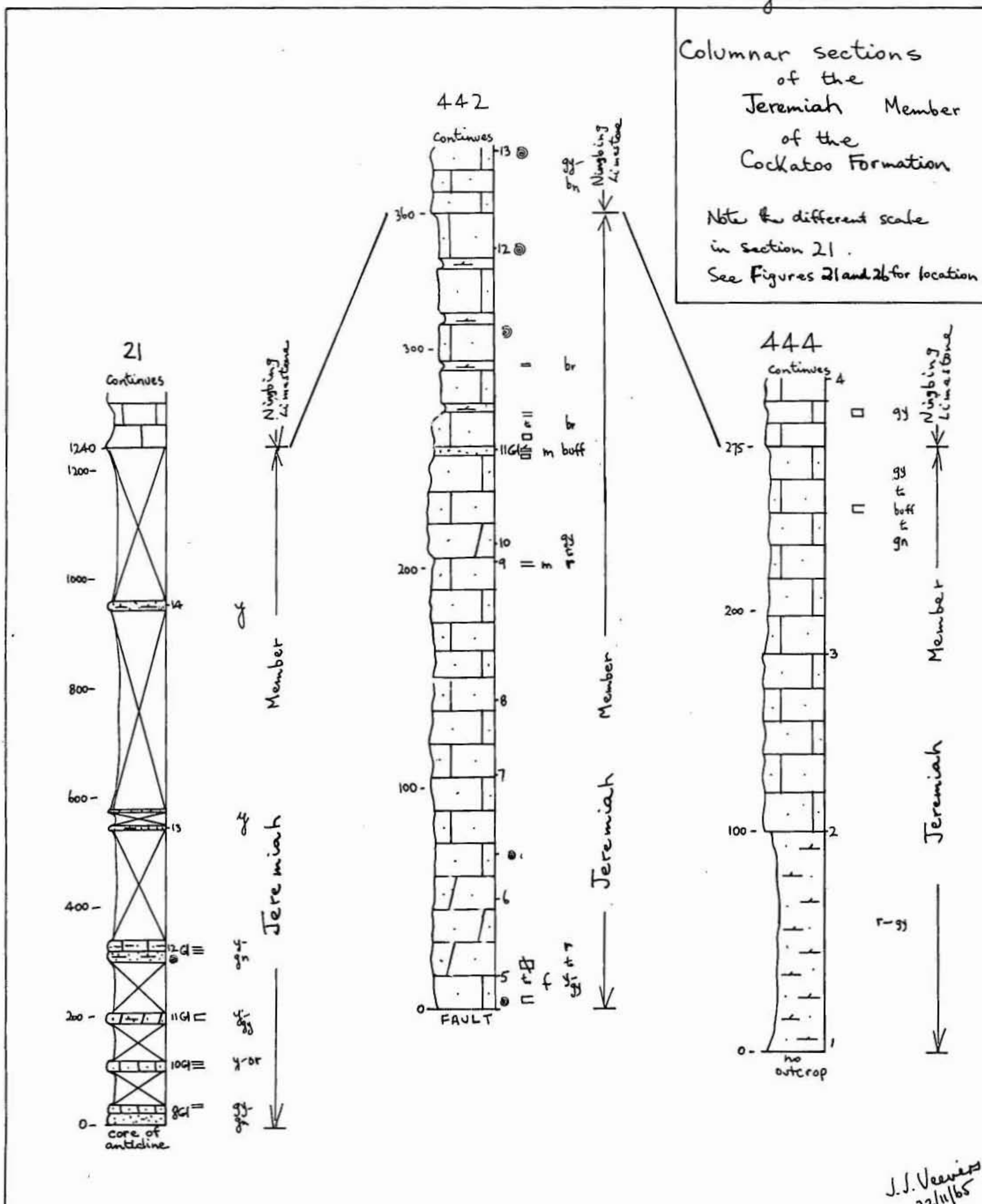

Fig. 20

11.2.66
3.5.66

Fig. 21

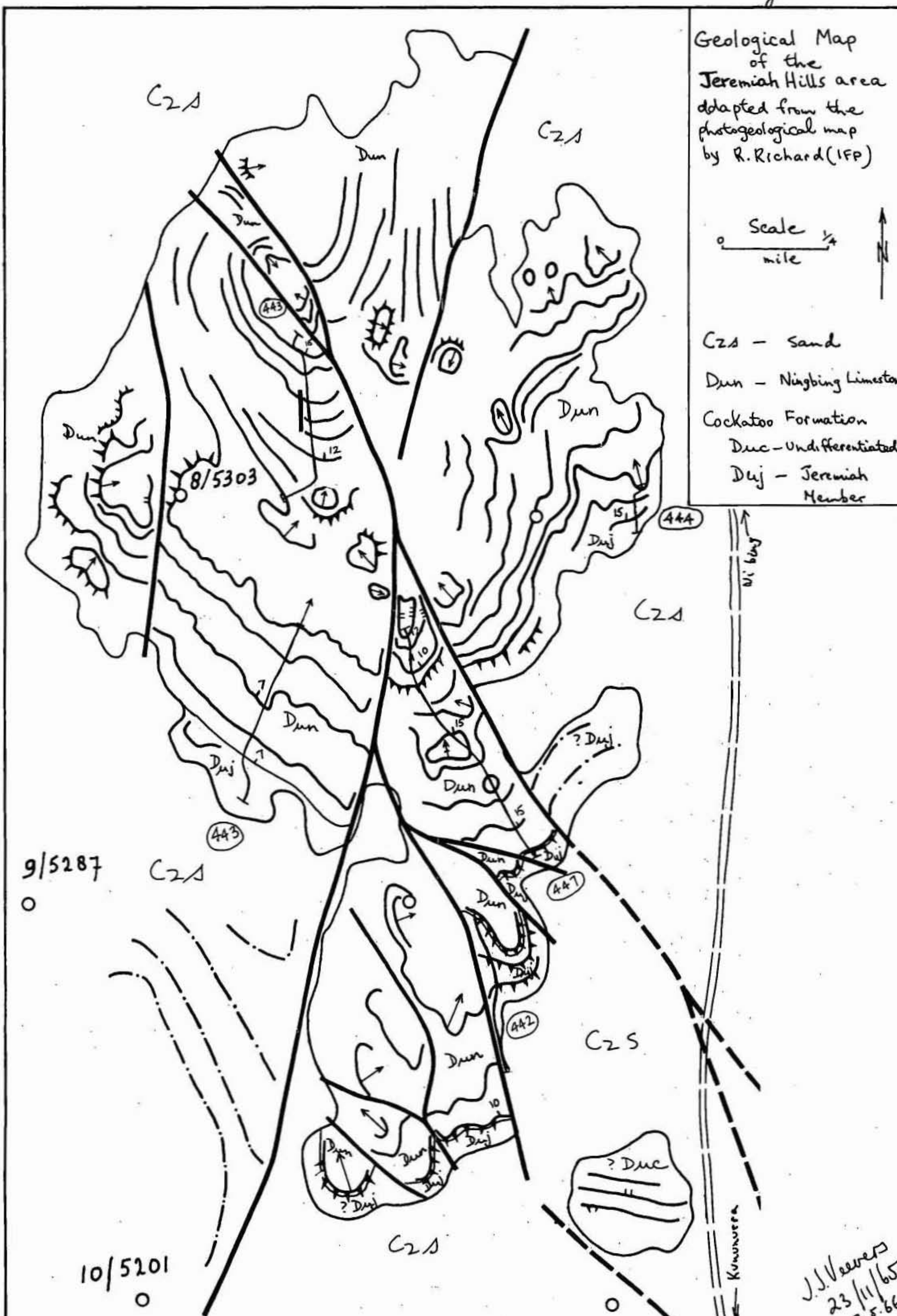
Geological Map of the Jeremiah Hills area adapted from the photogeological map by R. Richard (IFP)
Scale 1/4 mile
N
Cz s - sand
Dun - Ningbing Limestone
Cockatoo Formation
Duc - Undifferentiated
Duj - Jeremiah Member
Cz s
Dun
Duj
? Duj
? Duc
8/5303
9/5287
10/5201
443
444
447
442
Ningbing
Kununurra
J.J. Veevers 23/11/65 3.5.66

Fig. 21

Very low outcrops (Fig.31, locality 100/2, 3) on the plain 1 mile north of section 146 consist of medium-grained yellow to white quartz sandstone with Leptophloeum and indeterminate pelecypods. In this area, the faint strike-lines visible in the air photographs indicate that the sandstone at 100/2, 3, lies not far beneath the base of section 146, and may belong to the upper part of the Cecil Member.

Exposures of the lower boundary of the Jeremiah Member have not been found but because in both the Siggins Spring and 8-mile Creek areas the Jeremiah Member lies east of outcropping Cecil Member in an east-dipping sequence, there is little doubt that the Jeremiah Member rests on the Cecil Member.

B. Northern part

The only extensive and structurally simple outcrops of the Cockatoo Formation north of Hargreaves Hills are those in the Westwood Creek area. All the other outcrops of Cockatoo Formation are isolated, and are complicated by faults to which their existence as outcrops is due. Thus, with the exception of the outcrops of Westwood Creek, none of these outcrops is positively identifiable in terms of the members of the Cockatoo Formation. The only fossils found in the Cockatoo Formation in the area between Hargreaves Hills and Westwood Creek are the pelecypods and fish plates at Traves' (1955, p.60) locality 3 (our locality 46/2, 3 miles west of Surprise Creek gorge). The fossiliferous thin-bedded sandstone is probably Hargreaves Member, and the overlying jointed and cross-bedded coarse sandstone is probably Cecil Member. Similar jointed and cross-bedded sandstone at locality 47 a few miles south of locality 46/2 is tentatively identified as Cecil Member.

Outcrops at localities 42-45, north of the Onslow Hills, are all tentatively identified as Kellys Knob Member. They consist of jointed cross-bedded ripple-marked medium to coarse quartz sandstone. At locality 43/7, tabular cross-beds with an exposed thickness of 20 feet recall those at locality 239B, west of Hargreaves Hills, and are also aeolian or very large-scale subaqueous cross-beds. Farther north along this line of faults, and along those in the Gladys Spring/Leichhardt Spring area, similar sandstone is thrown down to the west against fossiliferous Cambrian Clark Sandstone (locality 263).

Bald Hill consists of at least 1,000 feet of silicified quartz sandstone with northward dips of 50 to 65 degrees. It is faulted against an exposed 50 feet of subhorizontal barren sandy dolomite and barren coarse laminated pebbly quartz sandstone, which is either part of the Cambrian succession or, more probably, part of the Westwood Member of the Cockatoo Formation.

Elephant Hill is bounded on two sides by faults, and consists of silicified cross-bedded ripple-marked quartz sandstone. The large unnamed hill (locality 40) 2 miles north-west of Elephant Hill consists of unsilicified quartz sandstone, regularly cross-bedded in tabular sets 2 feet thick. Ripple-marks are common.

Virtually all our knowledge of the sequence of the Cockatoo Formation in the north-western part of the basin comes from studies made in the

Westwood Creek area (Fig.22). The first published reference to the geology of this area was made by Veevers et al. (1964), who followed on Utting's (pers.comm.) discovery 5 years earlier.

Westwood Member (new name)

The Westwood Member is defined as the thick sequence of interbedded limestone or dolomite and fine to medium thin-bedded quartz sandstone in the Westwood Creek area. Section 459 (Fig.22) is designated type, and sections 12 and 13 complement it. The geographical co-ordinates of the base of the type section are Lat.14°52'S, Long.128°30'E. South of locality 460, the Westwood Member is seen to overlie, probably conformably, poorly exposed barren sandstone, tentatively identified as Kellys Knob Member. The top of the Westwood Member is eroded in section 13, and elsewhere the upper part of the member is covered. 1880 feet of dipping strata are almost continuously exposed on tidal flats in section 13. This section lies on the western limb of the pitching anticline shown in Figure 22, and sections 12 and 459, and, if the anticline continues so far south, section 460 are on the eastern limb.

The type section is 555 feet thick, and consists of sandy stromatolitic limestone (incipient reef limestone) interbedded with pelecypod coquinite at the base, and overlain by interbedded sandy organic limestone and sandstone, with 100 feet of jointed thin-bedded yellow-brown quartz sandstone at the top. Lateral lithological changes between sections 459 and 12 amount to small differences in the quartz sand content of equivalent beds. Section 13, whose relations with the other measured sections are shown in Figure 23, is much sandier than its equivalents in the other sections, but poor exposure in the interval 100 to 430 feet rules out further comparison. Large colonies of corals (Hexagonaria) at locality 12/2 were not seen elsewhere in Section 12. The upper part of the Westwood Member is seen in section 13 only, and consists of thin-bedded to laminated fine to medium yellow quartz sandstone with three thin interbeds of limestone. Beds with converging strike at locality 12/5 indicate rapid wedging or faulting.

Fossils have not been shown in the sections, because they are almost ubiquitous. Fossils in the limestone include algae, brachiopods, conodonts, corals, crinoid ossicles, gastropods, ostracodes and stromatoporoids, and, in the sandstone, brachiopods, ostracodes, pelecypods, and plants. As noted above, the build-up of stromatolites and the abundance of Renalcis, a reef alga, in the conical outcrops in the basal 100 feet of section 459 indicate an incipient reef.

The last outcrops of Cockatoo Formation to be described in the middle province are from the north-west extremity of the basin, in the Cone Hill and Shakespeare Hill area (Fig.24). Numerous faults, most with a north-west trend, cross the area. Except Cone Hill, all the outcrops contain uniform sequences of generally white cross-bedded quartz sandstone which is silicified near faults. A pebble bed, 10 feet thick, was found at locality 130/2. About 800 feet of quartz sandstone were measured at locality 130 on Shakespeare Hill. All these outcrops are tentatively regarded as Kellys Knob Member.

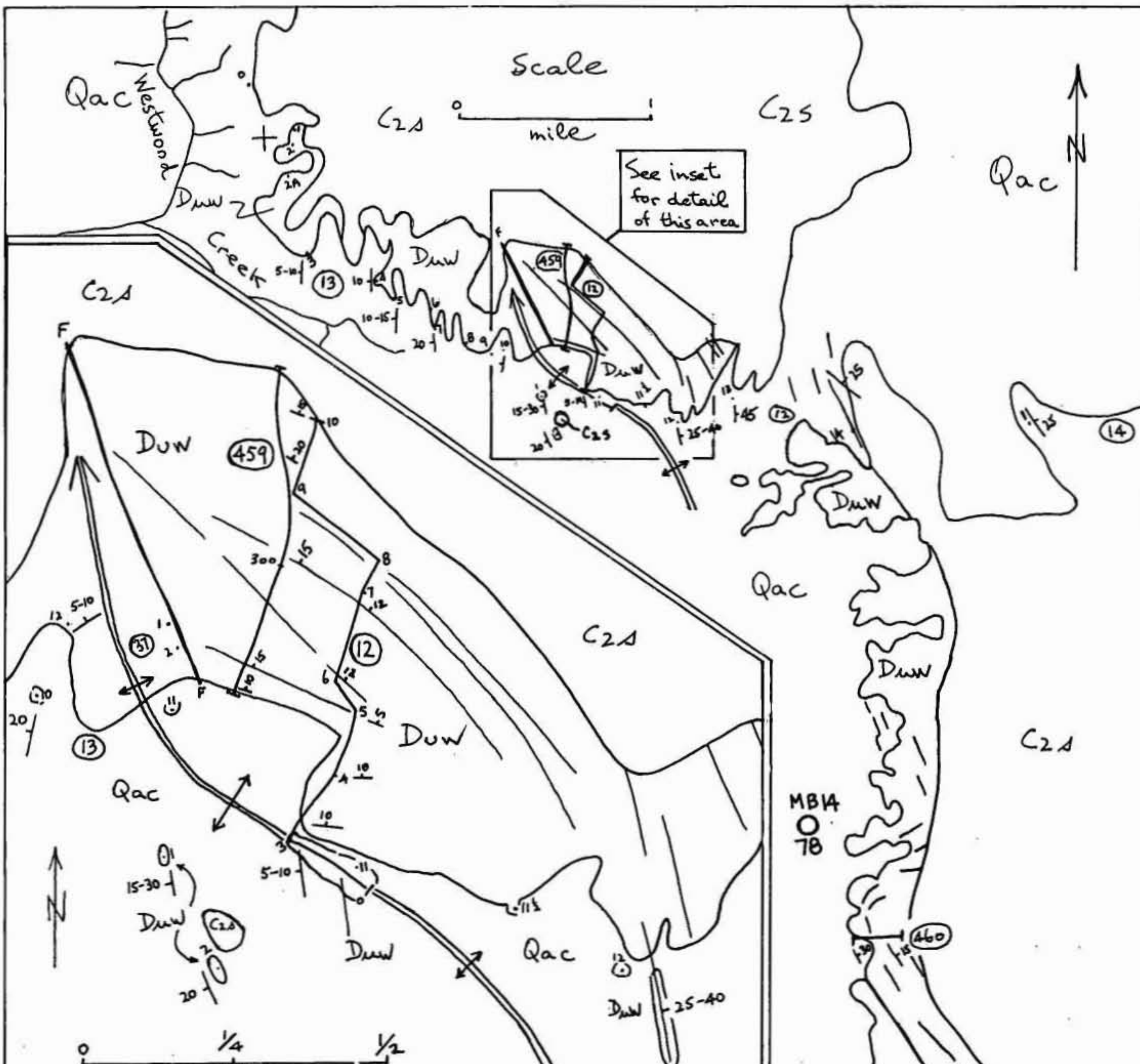

Figure **22**

Geological map of the Westwood Creek area.

Qac – tidal mud-flats

C2s – sand

<u>Cockatoo Formation</u>

Duw – Westwood Member

Duk – Kellys Knob Member

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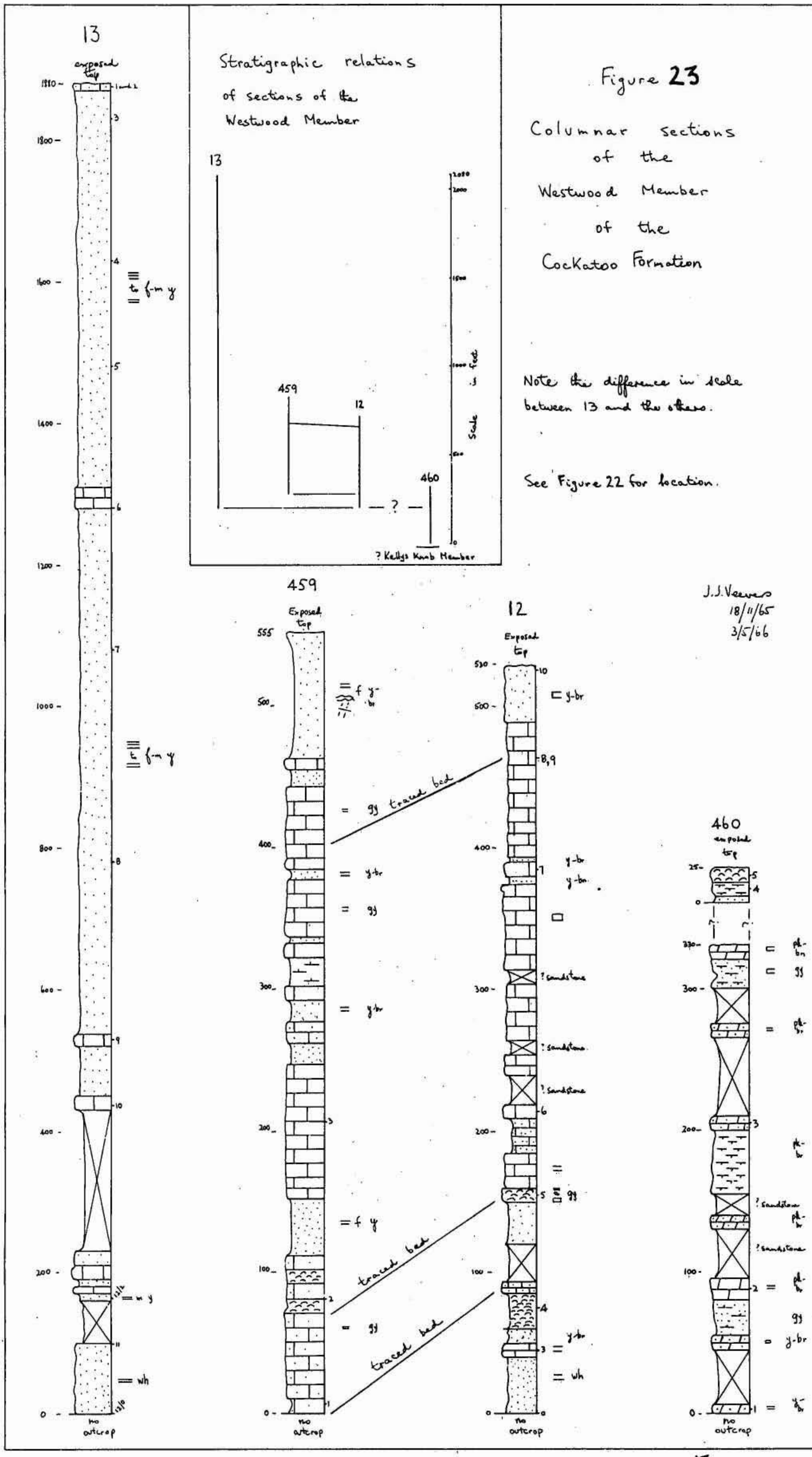
Figure 23
Columnar sections of the Westwood Member of the Cockatoo Formation
Note the difference in scale between 13 and the others.
See Figure 22 for location.
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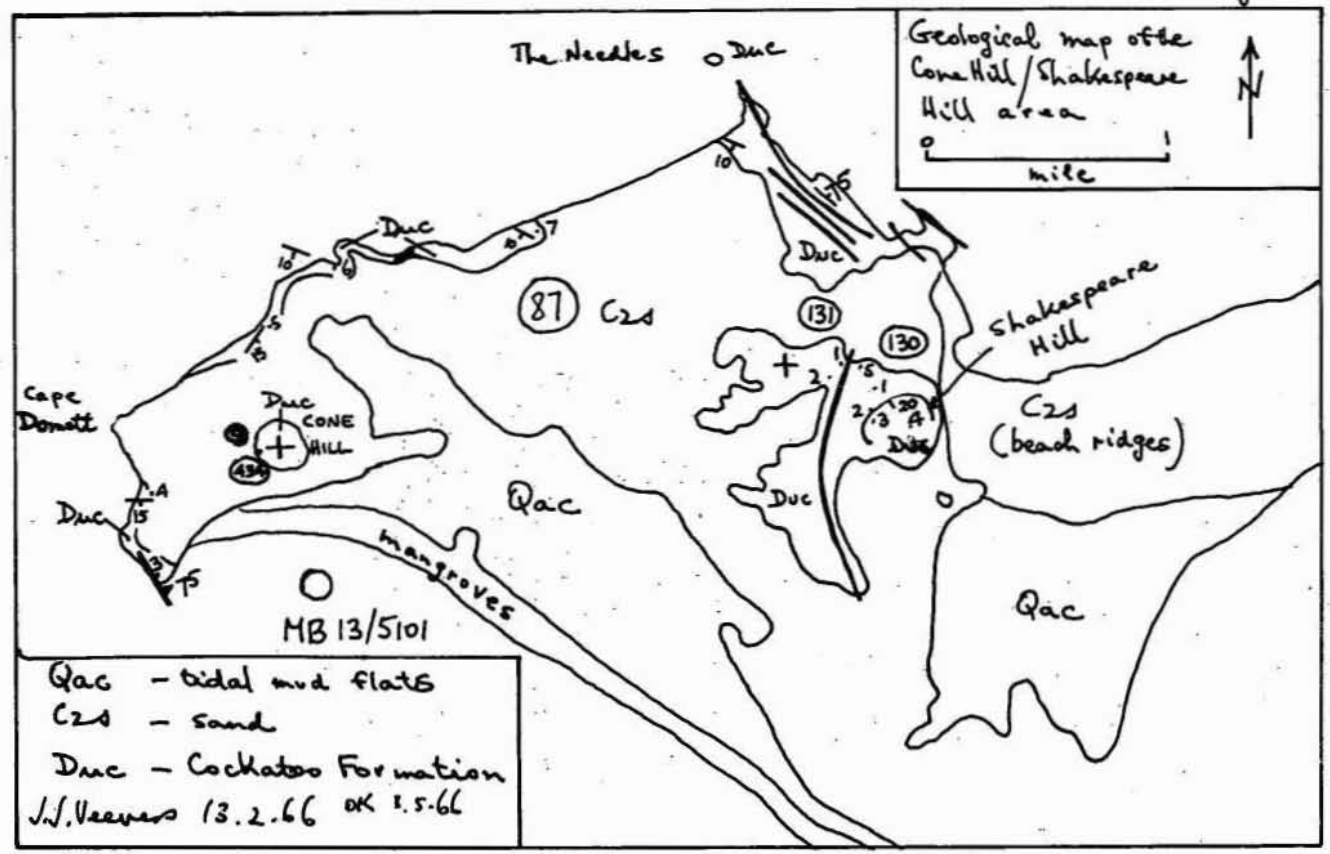
3/5/66
Stratigraphic relations of sections of the Westwood Member
13
459
12
460
Scale feet
? Kellys Knob Member
exposed top
no outcrop
traced bed
? sandstone
f-m y
f y-br
gg
y-br
m y
wh
pk-br

Fig. 23

Fig. 24



Geological map of the Cone Hill / Shakespeare Hill area
mile
N
The Needles
Duc
Cape Domett
CONE HILL
Shakespeare Hill
C2s
C2s (beach ridges)
Qac
Mangroves
MB 13/5101
Qac - tidal mud flats
C2s - sand
Duc - Cockatoo Formation
J.J. Veevers 13.2.66 OK 1.5.66

At Cone Hill, a poorly exposed subhorizontal sequence, possibly 100 feet thick, of yellow quartz sandstone and sandy limestone and marl is overlain by white quartz sandstone with layers of clay pellets. An indeterminate gastropod was collected from the sandy limestone. According to E.C.Druce, limestone samples collected from this place do not contain conodonts. The calcareous beds possibly represent the top of the Westwood Member, and the overlying sandstone the Cecil Member.

Age of the Cockatoo Formation and its members

General

A. Superposition

By reference to superposition alone, the base of the Cockatoo Formation is younger than Lower Ordovician (the age of the youngest rocks in the underlying sequence); and the top of the Formation is Famennian (to II) (the age of the base of the conformably overlying Ningbing Limestone and Buttons Beds) or slightly older.

B. Contained fossils

Only the middle part of the Cockatoo Formation (Westwood, Hargreaves, and Kununurra Members) contains abundant fossils. This is thus the only part of the Formation in which isolated sections can be correlated by fossils (local correlation) and also the only part which, by means of fossils in the Westwood, Hargreaves, and Kununurra Members, can be correlated with the Upper Devonian standard (intercontinental correlation).

The age of the upper half of the formation can consequently be estimated by interpolation between the age of the middle part and that of the base of the conformably overlying Ningbing Limestone and Buttons Beds. The lower part of the Formation, between the base and the middle, is thus the only part whose age, within broad limits, is not known. The only means of estimating the age of the base of the Cockatoo Formation is by extrapolation from the oldest known age of the Formation, which is middle Frasnian. On this basis, the base is estimated to be early Frasnian or late Givetian (Middle Devonian).

C. Regional considerations

Rattigan & Veevers (in Veevers & Wells, 1961, pp.31, 33), postulated a diastrophism during the Frasnian in the northern part of the Canning Basin. One line of evidence was the appearance in the Frasnian of an almost bewildering variety of lithological units, in contrast to the relative uniformity of the lower, Givetian, part of the Pillara Formation. This diastrophism, which continued intermittently through the rest of the Upper Devonian, probably started early in the Frasnian. In comparison with the Bonaparte Gulf Basin, this was a short time before the deposition of the Westwood Member.

Thus, if the first diastrophism in the Bonaparte Gulf Basin, marked by the deposition of the base of the Cockatoo Formation, was contemporaneous with the Canning Basin diastrophism (we stress the 'if'), we could deduce the age of the basal Cockatoo Formation as early Frasnian. We would, of course, prefer to reverse this argument, and induce that the diastrophism was contemporaneous because the basal deposits were themselves known to be contemporaneous. This cannot yet be done, because the fossils at the base of the Ragged Range Member do not indicate a precise date.

Age of the members

The members will be treated in order of decreasing precision of their age determination.

1. The Westwood, Hargreaves, and Kununurra Members contain conodonts which indicate to I [illegible] that is within the upper half of the Frasnian.

2 The Abney Member is probably slightly younger than the Kununurra Member.

3. The Jeremiah Member, from its conformable position beneath the Famennian Ningbing Limestone, is earliest Famennian or latest Frasnian, or both. Conodonts found in the type area of the Jeremiah Member (Fig. 21, localities 442/12, 444/4) are apparently Tournaisian but this is an anomalous age because at these localities the Jeremiah Member is overlain by Ningbing Limestone dated as Famennian on the basis of conodonts and brachiopods. This indicates that the conodonts in the Jeremiah Member have been introduced by a stratigraphic leak, or that they have been misidentified due to poor preservation (E.C.Druce, pers.comm.).

4. The Cecil Member, lying beneath the earliest Famennian or latest Frasnian Jeremiah Member and above the Westwood, Hargreaves, and Abney Members of the upper half of the Frasnian, is late Frasnian.

5. The Kellys Knob Member probably lies within the lower half of the Frasnian.

6. The age of the Ragged Range Member ranges from the age of the Kununurra Member to older than the Kellys Knob Member, and thus spans at least the lower half of the Frasnian, and possibly extends into the Middle Devonian.

Palaeontology

The fossil content of the middle part of the Formation increases in both number of species and of individuals from a minimum in the Kununurra Member, near the basin edge, through the Hargreaves Member to the Westwood Member, which is farthest from the eastern edge. Many groups in the Westwood Member (algae, corals, ostracodes, and stromatoporoids) are not found in the equivalent members. This seems to be a clear indication of the adverse influence of terrigenous deposition on organisms in the marginal province.

This horizontal variation in ecology is matched by even sharper vertical variation. In places, the products of coarse terrigenous deposition (the Kellys Knob Member, Cecil Member, and even conglomerate in the Ragged Range Member) contain pelecypods, but nowhere are they abundant. Fish plates are also scattered through the Cecil Member. Even near the eastern edge of the basin, the vertical contrast in fossil content is marked, for example, between the Kununurra Member and the other, conglomeratic, members in the type section of the Cockatoo Formation across Matheson Ridge. The Jeremiah Member also contrasts with the Cecil Member in its relatively high fossil content.

Plants (most of them ?Leptophloeum) have been found in the Ragged Range, Kellys Knob, Kununurra, Hargreaves, Westwood, Jeremiah, and Cecil Members. Their distribution seems to be independent of the distance from the eastern edge of the basin.

Sedimentology

The terrigenous component of the Cockatoo Formation is almost entirely quartz or quartzite, indicating an overwhelming concentration of these materials in the source area; any material finer than sand was almost completely separated in the marginal and middle provinces (except during the deposition of the Kununurra, Hargreaves, and Westwood Members), and deposited elsewhere. That the sand was intensely worked by water is evident from the ubiquitous cross-bedding. The description of cross-bedding and other sedimentary structures, an analysis of directional structures, and a description of the rocks, will be made in a subsequent report.

Depositional environment

1. Deposition by water or wind

With one possible exception, the entire Cockatoo Formation was deposited in water. The exception is the sandstone with very thick sets of cross-beds at and near locality 239A-C (Fig.17). Further analysis of the cross-bedding at these localities is being made now. Suffice it to say that the evidence now available from the cross-bedding indicates deposition by wind or by water.

2. Deposition in fresh-water or sea-water

The fish plates and plants do not help in answering this question. The only other fossils found outside the indubitably marine middle part of the Formation are pelecypods, and, because these pelecypods are commonly associated with marine fossils in other parts of the Formation, they too are taken to indicate marine deposition.

3. Depth of water

Abundant algae, including stromatolites and oncolites, in the limestone of the Westwood Member indicate deposition in very shallow (and probably clear) water. The only other fossils in the Cockatoo Formation indicate nothing narrower than the neritic zone. The ubiquitous trough and planar cross-bedding in the Kellys Knob andCecil Members indicates shallow rather than deep neritic deposition.

4. Water temperature

The build-up of incipient algal and coral reefs in the Westwood Member possibly indicates deposition in warm to warm-temperate water.

Summary

The Cockatoo Formation was probably deposited in a uniformly shallow to very shallow warm sea. The horizontal and vertical variations in the Formation are attributable not to differences in the environment of deposition but to tectonic movements of the eastern edge of the basin. Uplift of the Pincombe Inlier and of the land bordering the eastern edge of the basin, probably by block-faulting, caused deposition of conglomerate (Ragged Range Member) close to the shore, and of sandstone (Kellys Knob Member) offshore. With the waning influence of these movements (by lowering of the land by erosion), expressed by a decreased supply of terrigenous sand, deposition of very fine sand, silt, and carbonate sediment became dominant (Kununurra, Hargreaves and Westwood Members), culminating in the deposition of incipient reefs at Westwood Creek. A repetition of this cycle, by renewed uplift of land along the eastern edge of the basin, but not by uplift of the Pincombe Inlier, produced the Cecil and Jeremiah Members.

According to this depositional model, the Cockatoo Formation is the product of two cycles of uplift and erosion of the land bordering a uniformly shallow warm sea. Subsidence of the sea-floor kept pace with the deposition of 5,000 feet of sediment, which, by comparison with Frasnian sequences elsewhere in the world, accumulated rapidly.

FAMENNIAN

The Famennian Ningbing Limestone and the equivalent Buttons Beds succeed the Frasnian Cockatoo Formation with little or no hiatus and altogether these three units make up the Upper Devonian succession of the marginal and middle provinces of the Bonaparte Gulf Basin. In the outer province, the Upper Devonian, probably the Famennian, is represented by the oldest known part of the Bonaparte Beds in the Bonaparte No.1 Well. Because of its extensive outcrop, the Ningbing Limestone is the best known of the three Famennian units, and it is described first.

NINGBING LIMESTONE (new name)

The Ningbing Limestone is defined as the belt of limestone that crops out between the north-western part of the Pincombe Range and a point 3 miles north-north-west of Knob Peak. Most of this outcrop lies within the Ningbing Range, and almost all the rest in the Jeremiah Hills. The Ningbing Limestone conformably overlies the Jeremiah Member of the Cockatoo Formation, and is unconformably overlain by, or faulted against, Visean Utting Calcarenite or Burvill Beds, or its top is eroded. The uppermost 660 feet of section 21 (Fig.25) at the south-western corner of the Ningbing Range, are designated type. The co-ordinates of the top of section 21 are Lats.15°18'S., Long.128°37½'E. Section 443, 1085 feet thick, in the Jeremiah Hills is the thickest measured section.

The Ningbing Limestone is a reef complex in which four facies are recognised: reef, fore-reef, back-reef, and inter-reef. The back-reef predominates in outcrop.

Previous work

Hitherto the Ningbing Limestone has been regarded as part of the Burt Range Formation.

The first published reference was Reeves (1951, pp.2499, 2500), who briefly noted the 'stromatoporoid reefs' near Ningbing Homestead. In his earlier unpublished report, Reeves (1948) gave some details, such as an estimated thickness of 500 feet of limestone near Ningbing, its age as possibly Upper Devonian Stage IV, and alluded to the 'stromatoporoid reefs'. He noted the structure of minor domes and basins, which he considered to be associated with the 'stromatoporoid reefs'.

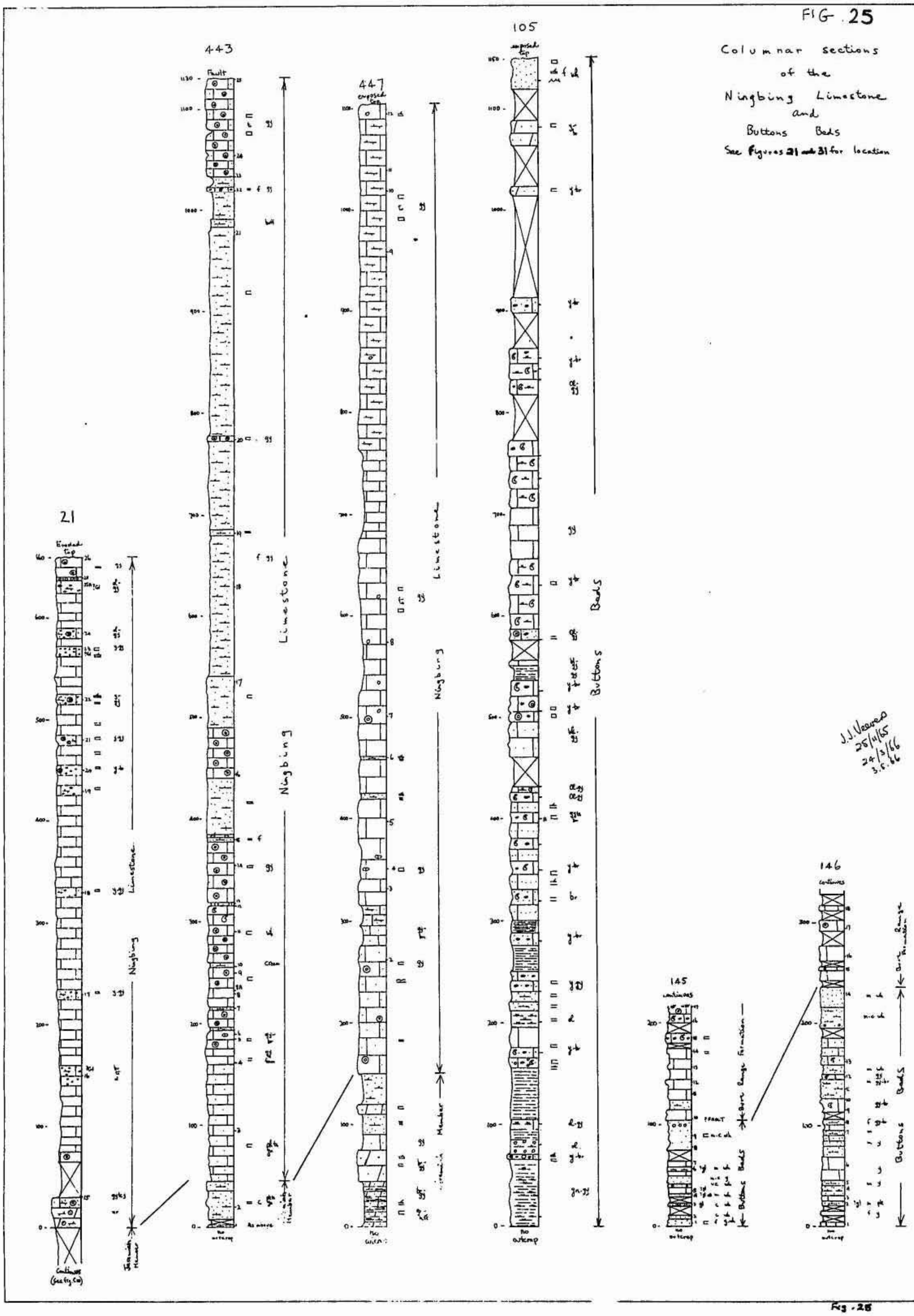


FIG. 25 Columnar sections of the Ningbing Limestone and Buttons Beds

See Figures 21 and 31 for location

Fig. 25

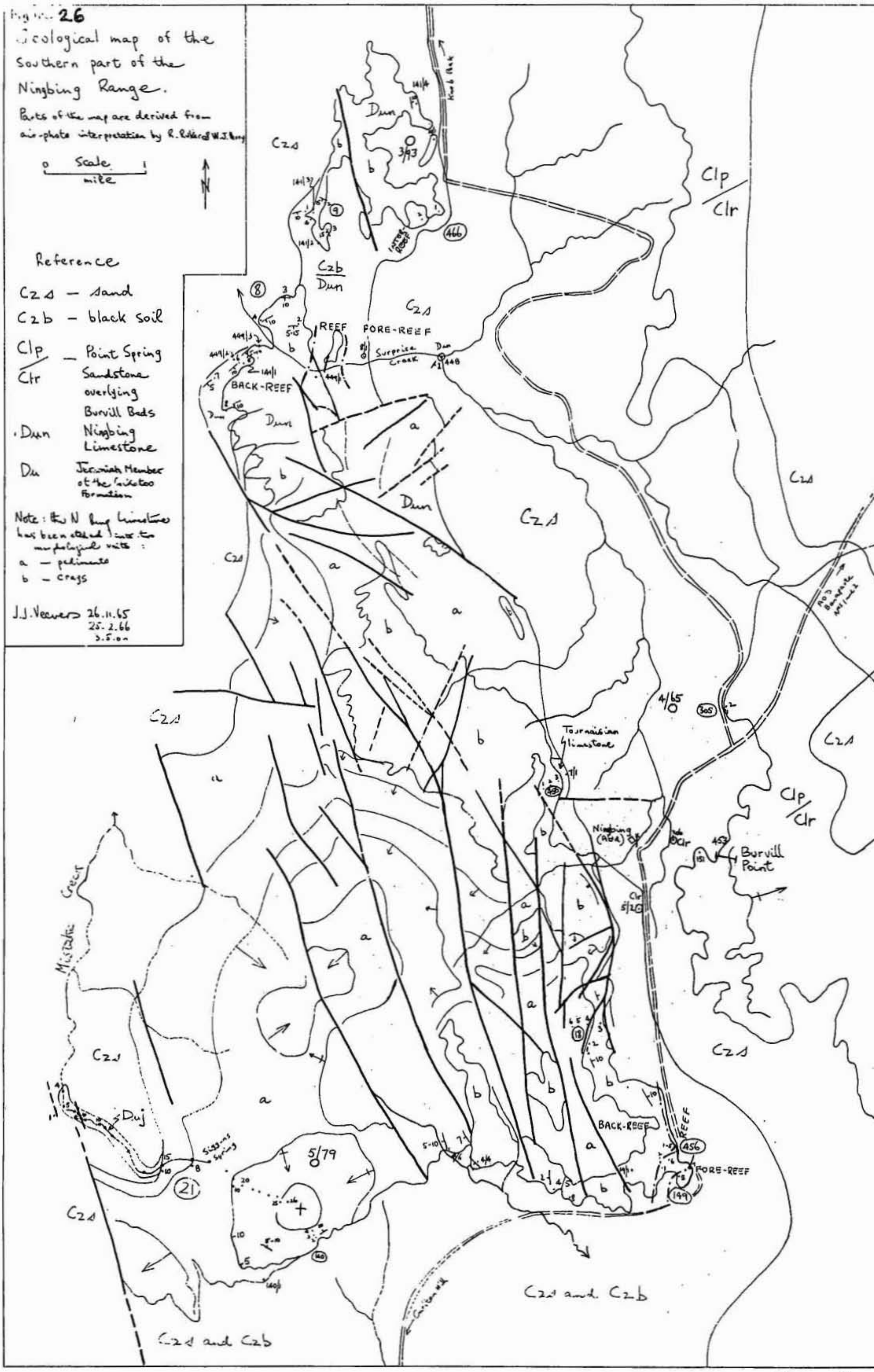

26
Geological map of the Southern part of the Ningbing Range.
Parts of the map are derived from air-photo interpretation by
Scale
mile
N
Reference
Czs — sand
Czb — black soil
Clp/Clr — Point Spring Sandstone overlying Burvill Beds
Dun Ningbing Limestone
Du
Note:
a — pediments
b — crags
J.J. Veevers 26.11.65
25.2.66
Czs
Dun
Czb/Dun
REEF
FORE-REEF
BACK-REEF
Surprise Creek
Clp/Clr
Tournaisian Limestone
Ningbing (ABA)
Burvill Point
Mistake Creek
Duj
Siggins Spring
5/79
4/65
3/93
Czs and Czb

Fig. 26

Noakes et al. (1952) did not mention the limestone at Ningbing.

Traves (1955) mapped the Burt Range Limestone, in which he included the Ningbing outcrops, and briefly described the outcrops south of Ningbing, and between Ningbing and Surprise Creek. He briefly referred to the reefs, which he called bioherms, and associated fossiliferous biostromal limestone which dips away from the reefs; like Reeves, he supplied few details.

Utting (pers.comm.) mapped the Ningbing Limestone in some detail; though pointing out the likelihood of the limestone being a reef complex, he did not find indisputable evidence thereof. Nor did Veevers et al. (1964), who continued to identify the limestone as the Burt Range Formation, which by this time was dated as Lower Carboniferous.

It remained until 1966 for Playford et al. to demonstrate that unequivocal evidence had been found that the Ningbing Limestone was a reef complex, and for Jones & Druce to demonstrate that the limestone was Famennian, both confirming what Reeves had said at the outset.

The 15-year delay betweenReeves' (1951) bald assertion that the limestone at Ningbing was, at least in part, a Famennian reef complex, and the confirmation of these assertions in 1966 is in large part attributable to the complexity of the Ningbing Limestone, which we glimpsed for the first time only after our second field season in 1965. Added to this complexity is the difficult access to and within the limestone, due to its surface of sharp rugged knobs deeply dissected by ravines and grass-covered pediments, surrounded by plains of deeply cracked black soil.

In what follows, the Ningbing Limestone will be described in terms of its four facies, starting with the widespread back-reef.

BACK-REEF

Not only is the back-reef the only widely-exposed facies; it is also the only one in which sections thicker than 100 feet can be measured. Hence by default of the other facies, the back-reef contains the type section, which is designated as the uppermost 660 feet of section 21 (Figs 25, 26) situated 6 miles west-south-west of Ningbing Homestead. It consists of uniformly medium-bedded fairly pure grey to yellow limestone and minor dolomite, in which micrite-grain calcarenite is the commonest type. Except near the base, outcrop is continuous. The base of the section is marked by the first extensive outcrop of grey to orange carbonate rock that overlies the poorly exposed Jeremiah Member of the Cockatoo Formation. This boundary is clearly visible in the air photographs, both here and in the Jeremiah Hills. Elsewhere in the Ningbing Range, the base of the Ningbing Limestone is covered or faulted. The top of the type section is the youngest preserved bed in a small structural basin. This and other broad structures south-west of Ningbing Homestead are well shown in the air photographs.

As mentioned above, micrite-grain calcarenite is the main type of carbonate rock in this section. A one-foot bed of limestone conglomerate with rounded pebbles and cobbles of dolomite, vein quartz, quartzite, and coralline algae (Solenopora) is found near the top. Further description of the petrology will be given in the account of the limestone at Jeremiah Hills.

Fossils in the type section are abundant, and are dominated by calcareous and porostrome algae. Most of the porostromes (Girvanella) are in the form of oncoliths, and the calcareous algae are fragmented and rolled masses of Solenopora. Crinoid ossicles, brachiopods, bryozoans, ostracodes, and Umbellina are also common. Few of these fossils provide a precise means of correlation, and ostracodes and conodonts in other sections are the only reliable fossils for dating the limestone.

In Figure 26, the back-reef, which constitutes almost the entire outcrop, is mapped in two units on the basis of its morphology as seen in the air photographs. Unit a is a pediment or rock surface, indicated in the air photographs by its uniformly layered light-grey pattern, and unit b consists of crags, tens to hundreds of feet high, which in the air photographs are dark-grey to black, and appear to be massive. In the air photographs, the two morphological units may mislead the observer into interpreting them as reef (unit b) and back-reef (unit a). This interpretation is quickly disproved by inspection on the ground: in all respects except morphology, the rock in the crags is identical to that in the pediment; that is, it is a medium-bedded mainly micrite-grain calcarenite. The erosion of the Ningbing Limestone into pediments and crags seems therefore to be caused solely by morphological processes.

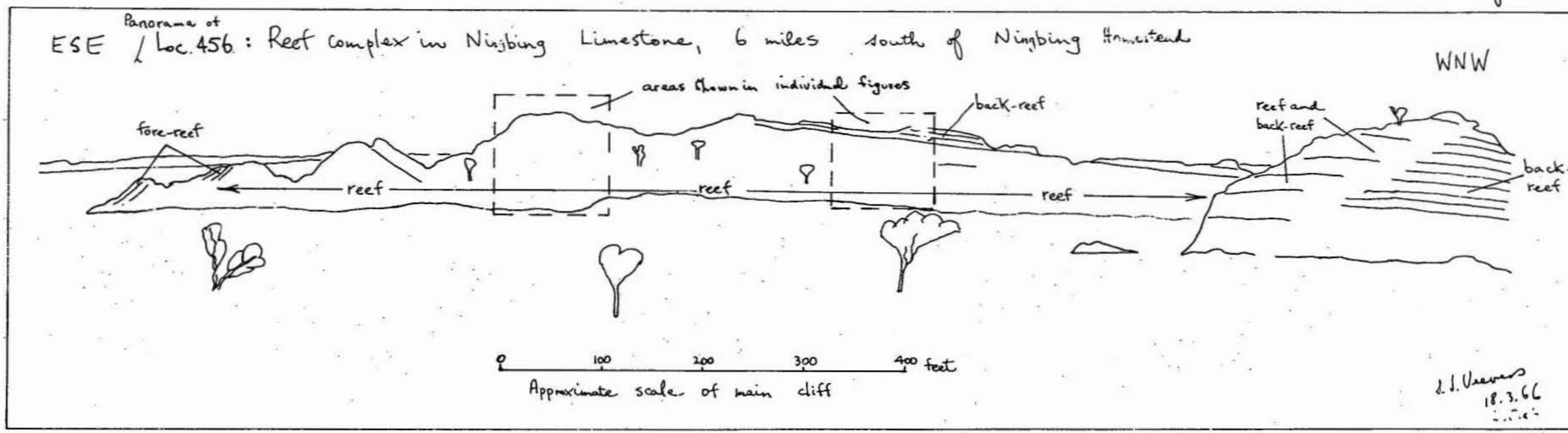
At localities 149 and 456, at the south-eastern tip of the Ningbing Range, the reef crops out in crags; elsewhere in the Range, it crops out in pediments also. In fact, the reef is barely distinguishable from the other facies in the 1:50,000 air photographs, which are the only available ones, and Reeves' observing of reefs from an aeroplane must be questioned.

The back-reef is exposed in pediments and crags in a gorge cut by Surprise Creek through the Ningbing Range. On the western side of the range (locality 449/2, 8/5-8), medium-bedded oncolitic limestone has weathered to yield free specimens of brachiopods. In a crag immediately eastward, at locality 449/3, similar medium-bedded limestone contains stromatoporoids. Incidentally, in contradiction to Reeves and Traves, we found very few stromatoporoids in the Ningbing Limestone. Crags at locality 9, 1½ miles northward, contain medium-bedded oncolitic limestone.

As mentioned earlier, thicker sections of the Ningbing Limestone were found in the Jeremiah Hills, and this area will now be described.

The Jeremiah Hills are a group of several broad limestone hills, some 200 feet high and a few miles across, 10 miles south-west of Point Spring. A map of the western part of the Jeremiah Hills is shown in Figure 21. This area is broken into blocks by faults clearly visible in the air photographs. In nearly all the blocks, the dip is northerly and, except at faults, is not known to exceed 15 degrees. The morphological division of the area into pediments and crags is not so clear-cut as it is in the Ningbing Range, and has not been mapped. All the Ningbing

Fig. 27


ESE
Panorama of Loc. 456: Reef complex in Ningbing Limestone, 6 miles south of Ningbing Homestead
WNW
areas shown in individual figures
back-reef
reef and back-reef
fore-reef
reef
reef
reef
back-reef
0
100
200
300
400 feet
Approximate scale of main cliff
J. J. Veevers
18.3.66

20.6.66

Limestone mapped in Figure 21 is back-reef. Section 443 (Figure 25) contains 1085 feet of Ningbing Limestone between the Jeremiah Member of the Cockatoo Formation at the base and a fault at the top. Almost half the section is dolomitic, and section 447, which contains less dolomite, provides better material for description. This section is 950 feet thick between the Jeremiah Member and the exposed top. In broad terms, section 447 consists of sandy oncolitic limestone, birdseye limestone, Stromatactis limestone, and, towards the top, dolomitic limestone. Brachiopods and crinoid ossicles are common throughout, and calcareous algae, colonial corals, and stromatoporoids are also common in the uppermost 200 feet. Rare rounded pebbles and cobbles of vein quartz, quartzite, and sandstone, up to 4 inches across, were found in the upper half of the section. The only terrigenous pebbles found in section 443 are in a thin bed a few feet above 443/15.

Some other outcrops of Ningbing Limestone in the area south-west of Point Spring are shown in Fig.19. The outcrops at locality 422 and at 423/2 are altered by faulting, and silicification is common. In contrast, the limestone at locality 424, only one mile from the outcropping Precambrian of the Pincombe Range, is unaltered, and consists of uniformly medium-bedded grey limestone with rare pebbles and cobbles of vein quartz.

REEF

The best-exposed reefs in the Ningbing Limestone were found in the southern part of the Ningbing Range (Fig.26). At localities 149 and 456, at the south-east tip of the Range, the reef (Fig.27) is nearly $\frac{1}{4}$-mile wide, consists of massive limestone that crops out in caverned pinnacles, and is flanked by thick-bedded back-reef limestone on the west, and by medium-bedded fore-reef limestone, including breccia, on the east. The reef consists of massive algal (Renalcis) limestone, 'reef tufa', stromatolitic limestone, Stromatactis limestone, and much recrystallized limestone and dolomite. Clusters of fossils, mainly brachiopods, occur in the limestone, and geopetal structures are common. On the ground, the outcrop of the reef in massive caverned pinnacles is diagnostic, but it is barely distinguishable from the other facies in the available air photographs.

The second well-exposed reef was found at the eastern end of the gorge cut through the range by Surprise Creek (locality 449/1). The reef consists of limestone with abundant intact masses of calcareous algae (Solenopora) as well as the rock types found at localities 149 and 456. The reef is exposed in a 100-foot high cliff, and is separated horizontally into two equal parts by 6 feet of medium-bedded back-reef limestone.

Reefs were also found intermittently along the eastern edge of the Ningbing Range, and the northernmost outcrop of the Limestone, at locality 11/3, (Plate 1), 3 miles north-north-west of Knob Peak, is reef, as shown by abundant reef tufa. None of these reefs is as well exposed as those in the southern part of the range, and their relationships with the other facies are not clear. Locality 463

(Fig.48), 1 mile south-west of Utting Gap, is a good example of such an area. Locality 463/1 and 2 are probably back-reef, 463/3 and 4 reef, and 463/5 fore-reef. The Ningbing Limestone west of locality 108 (Fig.48) contains a narrow reef flanked by breccia on the east side and by back-reef with tongues of reef on the west side.

The minimum thickness of the reef can only be estimated by the height of the outcrops. The highest outcropping reef is at locality 456, and it is an estimated 150 feet high.

FORE-REEF

The only place where fore-reef was seen next to the reef is the south-eastern tip of the Ningbing Range (localities 149, 456, Fig.26). Here the fore-reef is a talus breccia which dips away from the reef at 20 degrees, and consists of blocks, up to 6 feet long, of reef set in thin-bedded calcarenite. Fragments of stromatolites and calcareous algae are common in the calcarenite.

An isolated outcrop in the bed of Surprise Creek (locality 448), 1 mile east of the exposed reef, consists of thick-bedded breccia which dips 2 degrees south-eastward. Geopetal structures, Renalcis, and Stromatactis are common in the matrix. Ten miles northward and two miles north of Tanmurra Creek, an isolated outcrop (locality 17/4) of medium-bedded pebble to boulder fore-reef conglomerate contains angular to rounded fragments of limestone up to 12 inches wide. The conglomerate dips 15 degrees eastward.

INTER-REEF

Outcrops of platy grey and pink sandy pisolitic limestone at locality 455/1, 3 (Fig.28) are interpreted as inter-reef. This limestone contains the same brachiopods as those in the nearby reef (locality 455/2). The inter-reef limestone dips 30 degrees away from the reef.

Locality 466/2, 1½ miles north of Tanmurra Creek, was the only other place where inter-reef was found, and, as at 455/1, 3, it consists of platy sandy limestone with brachiopods.

Tournaisian limestone near Ningbing Homestead

E.P.Utting (pers.comm.) discovered richly fossiliferous limestone at a locality near Ningbing Homestead, which we later visited and called locality 7/1 (Fig.26). The fossiliferous limestone lies at the eastern edge of the limestone outcrop of the southern Ningbing Range, and is apparently continuous with this outcrop. It was therefore a surprise to find that the brachiopods and conodonts at 7/1 independently indicate correlation with locality 100/23-25, 685-815 feet above the base of the type section of the Burt Range Formation, or middle Tournaisian (Tn2c).

Locality 7/1 is part of limestone pediment, and consists of massive recrystallized limestone with very large Stromatactis, and clusters of brachiopods with rare trilobites in a matrix that contains conodonts. Except by its fossils, this limestone is indistinguishable from the reef limestone of the Ningbing Limestone.

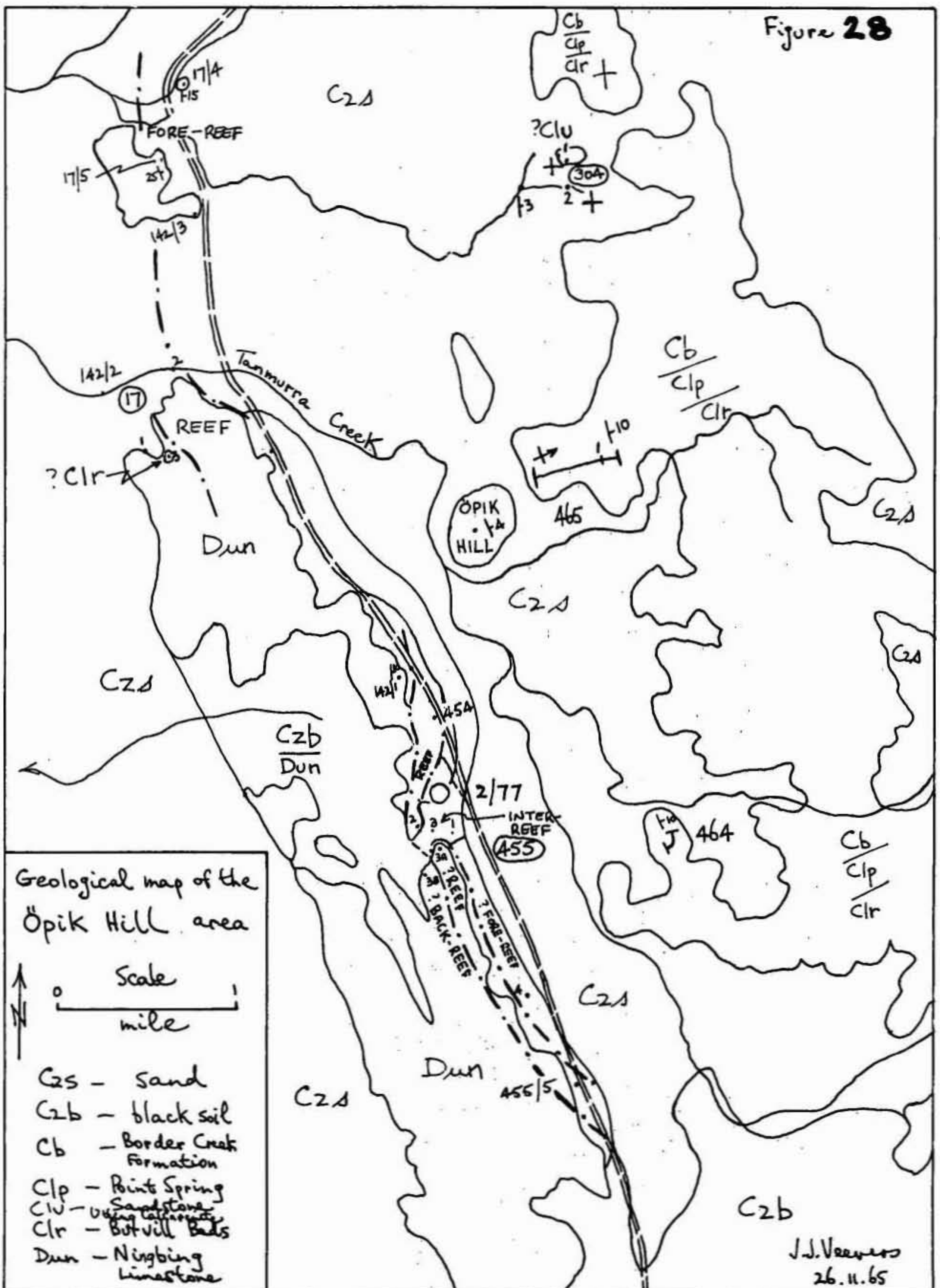


Figure 28
Cb
Clp
Clr
Czs
17/4
F15
FORE-REEF
17/5
?Clu
304
142/3
142/2
17
Tanmurra Creek
REEF
?Clr
Cb
Clp
Clr
10
ÖPIK HILL
465
Dun
Czs
Czs
Czs
142/1
454
Czb
Dun
2/77
INTER-REEF
455
464
Cb
Clp
Clr
?REEF
?BACK-REEF
?FORE-REEF
Czs
Dun
Czs
455/5
Czb
Geological map of the Öpik Hill area
Scale
0
1
mile
N
Czs – sand
Czb – black soil
Cb – Border Creek Formation
Clp – Point Spring Sandstone
Clu – Unnamed calcarenite
Clr – Butvill Beds
Dun – Ningbing Limestone
J.J. Veevers
26.11.65

3.5.66

Fig. 28

On the ground, the field relations of the massive limestone at 7/1 to the adjoining limestone are obscure because of low outcrop; the structure is obscure in the air photographs too.

The following extreme possibilities may be considered (Fig.30):
(a) the limestone at 7/1 is the youngest known part of the Ningbing reef complex. In favour of this view, the limestone at 7/1 is indistinguishable from the Famennian reef limestone, suggesting continuous reef deposition.
(b) the limestone at 7/1 unconformably overlies the Ningbing Limestone. At locality 210/6, on the northern edge of the Pretlove Hills, Tournaisian breccia, probably slightly younger than the limestone at 7/1, unconformably overlies the Cockatoo Formation, and indicates a Tournaisian marine transgression in this area. The limestone at 7/1 is a slightly older deposit of this transgression. Against this view is the unlikelihood that reef limestone indistinguishable from the Famennian reef limestone would re-establish itself above an unconformity.
(c) the bulk of the limestone at 7/1 is Famennian, and the clusters of brachiopods and conodonts are Tournaisian infillings of cavities and were deposited during a Tournaisian transgression. This process, like (b), is possible but unlikely.

We adopt the view outlined in (a), but remain fully aware of the other possibilities.

Age

The age of the greater part of the outcropping Ningbing Limestone, determined from conodonts, varies from Famennian to II - to III. The back reef appears to be wholly to II - to III, but the reef and fore-reef contain limestone dated as to V (localities 463/5 and 141/5), to VI (locality 17/4), and lower to middle Tournaisian (locality 7/1). This suggests that there may have been continuous reef growth throughout the Famennian and even into the Tournaisian. The significance of the Tournaisian outcrop at locality 7/1 is discussed above. The absence of younger back reef is probably due to erosion of the reef complex.

Overlying strata

Only one locality is known where the relationships between the Ningbing Limestone and overlying strata are visible. This is locality 17/3 (Fig.28), ½-mile south of Tahmurra Creek, where ten feet of white silicified quartz sandstone in tumbled blocks unconformably rests on the Ningbing Limestone. The sandstone overlies the Limestone in a valley, indicating that much of the Limestone, at least in the immediate vicinity, has been recently exhumed. The overlying sandstone is barren; it is probably part of the basal transgressive beds of the Visean, and is tentatively mapped as Burvill Beds. The only other contact seen was at locality 108 (Fig.48), and this is probably faulted. Near Ningbing Homestead (Fig.26), Burvill Beds are exposed at locality 5/2, only a few hundred yards from the exposed eastern edge of the Ningbing Limestone; steep erratic dips in the Burvill Beds in this area indicate complex faulting.

Obscure as the field relations may be, it seems from a regiew of all the evidence, including the regional picture, that the Ningbing Limestone is unconformably overlain by the basal deposits of the Visean transgression, which are represented in the southern Ningbing Range area by the Burvill Beds.

BUTTONS BEDS (new name)

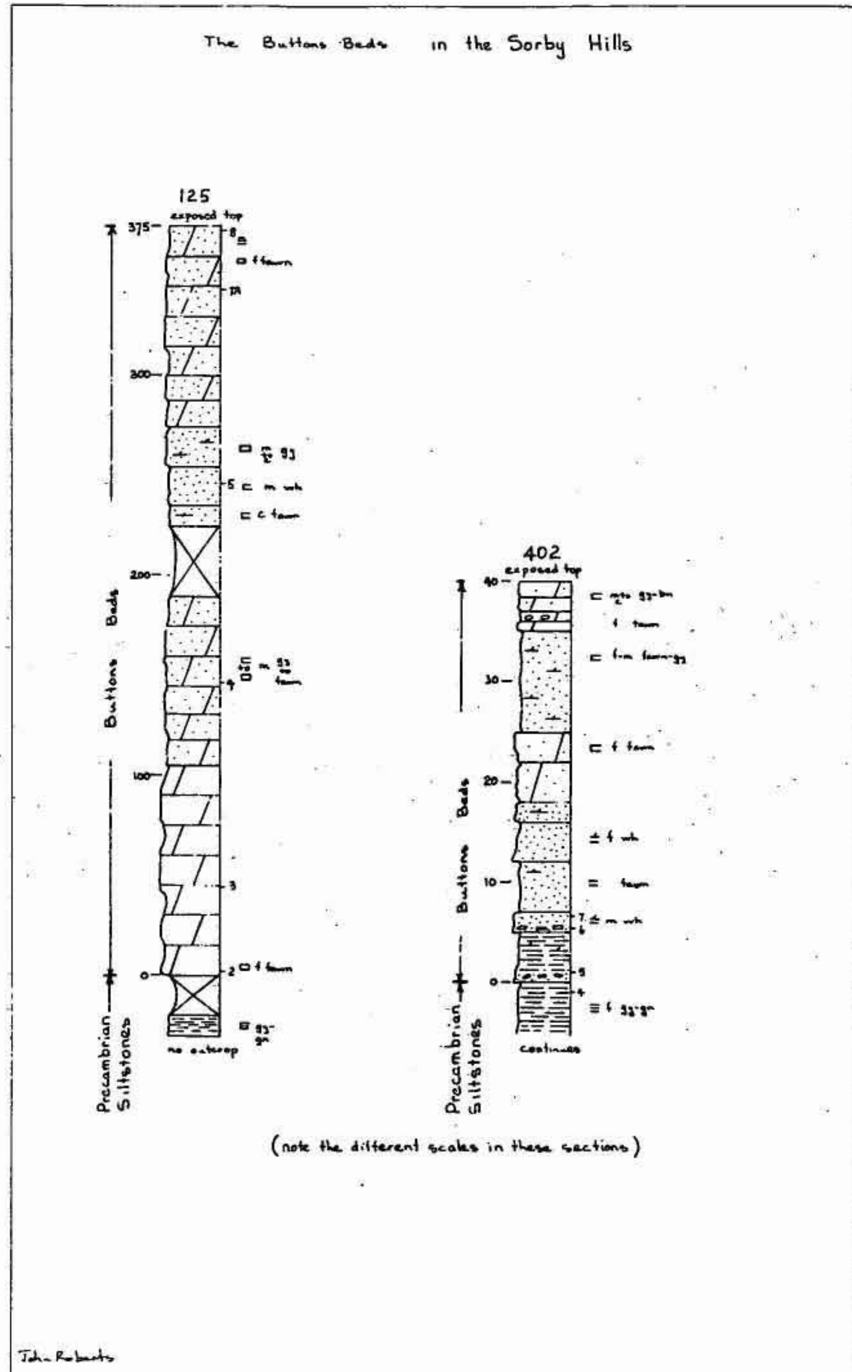
The Buttons Beds are defined as the Famennian sandy and silty limestone that crops out in the bed of the Ord River north of Buttons Crossing (Fig.16). The only other known outcrops are situated in the 8-mile Creek area, and in the Sorby Hills. The Buttons Beds overlie, presumably unconformably, the Jeremiah Member of the Cockatoo Formation, except at Sorby Hills, where the Buttons Beds unconformably overlie Precambrian siltstone. On the Ord River, the top of the Buttons Beds is faulted, and in the 8-mile Creek area is unconformably overlain by the Burt Range Formation. The top is eroded in the Sorby Hills. Section 105 on the Ord River is designated type. The co-ordinates of the base of the type section are Lat.15°38'S, Long.128°42'E. The Buttons Beds are equivalent to at least part, probably the lower part, of the Ningbing Limestone; contrary to earlier opinion (Playford et al., 1966), we do not regard them as part of the Ningbing Limestone reef complex.

Previous work

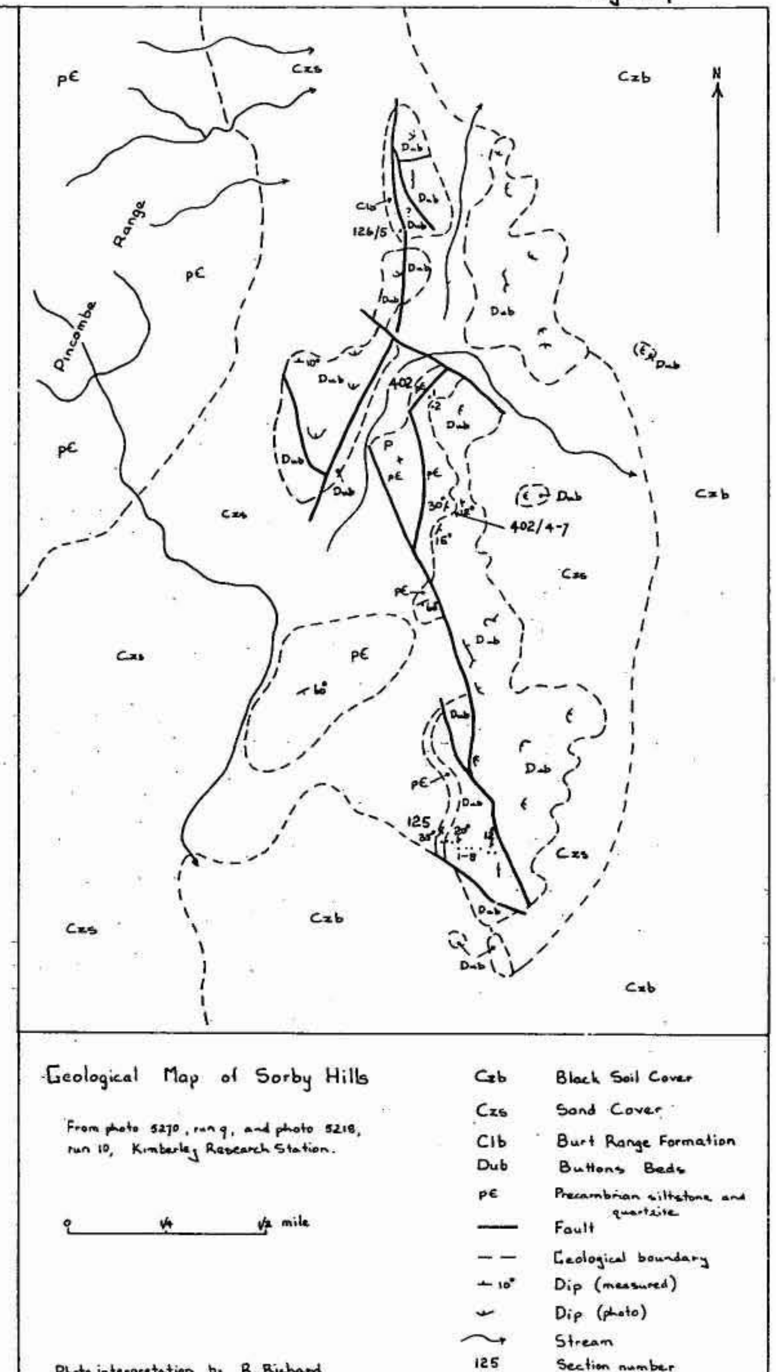
Matheson & Teichert (1948, p.84, pl.11) mapped and described the outcropping limestone near Buttons Crossing as part of the Devonian Burt Range Series. According to Matheson & Teichert, Buttons Crossing is situated within the outcropping limestone, but the Ivanhoe 1-inch map published in 1944 showsButtons Crossing a few miles southward, where we have shown it on Figure 16. Matheson & Teichert gave the total exposed thickness as about 1,000 feet, outlined the sequence of faunas, and referred the limestone to the middle part of the Upper Devonian, all of which we have confirmed. The 'cross-bedded brown sandstone' (Matheson & Teichert, p.84) that crops out on the west bank downstream from the limestone is now known to be Cambrian Clark Sandstone. The 'small occurrence of limestone with Syringopora, rugose corals, and ostracodes on the east bank' farther downstream was not seen, possibly because while we were there it was covered by alluvium. What outcrops were seen in this area are all Cambrian (Kaulback &Veevers, 1967, Fig.10) and their association with Devonian limestone indicates the structural complexity of the area.

Traves (1955, Pl.1, his locality 10) showed only a small outcrop of limestone in the Ord River near its junction with Spring Creek (mistakenly called Buttons Crossing), and suggested that this is the southern extension of the limestone near Ningbing. His assertion that biohermal limestone was found at this locality has not been confirmed. Dr.Öpik identified some of the fossils and pointed out that 'the fauna bears a marked similarity to that mentioned previously from 5 miles west of Mt.Septimus'. Our detailed studies show that this is not so; the Buttons Beds are Upper Devonian; the other fauna mentioned, from the Burt Range Formation, is Lower Carboniferous.

Fig. 29



The Buttons Beds in the Sorby Hills
125
exposed top
375
300
200
100
0
Buttons Beds
Precambrian Siltstones
no outcrop
402
exposed top
40
30
20
10
0
Buttons Beds
Precambrian Siltstones
continues
(note the different scales in these sections)
John Roberts
29.3.66
7.5.66



N
pЄ
Czs
Czb
Pincombe Range
Dub
Clb
126/5
402
402/4-7
125
Geological Map of Sorby Hills
From photo 5270, run 9, and photo 5218, run 10, Kimberley Research Station.
0 1/4 1/2 mile
Czb Black Soil Cover
Czs Sand Cover
Clb Burt Range Formation
Dub Buttons Beds
pЄ Precambrian siltstone and quartzite
Fault
Geological boundary
10° Dip (measured)
Dip (photo)
Stream
125 Section number
Photo interpretation by R. Richard

Fig. 29

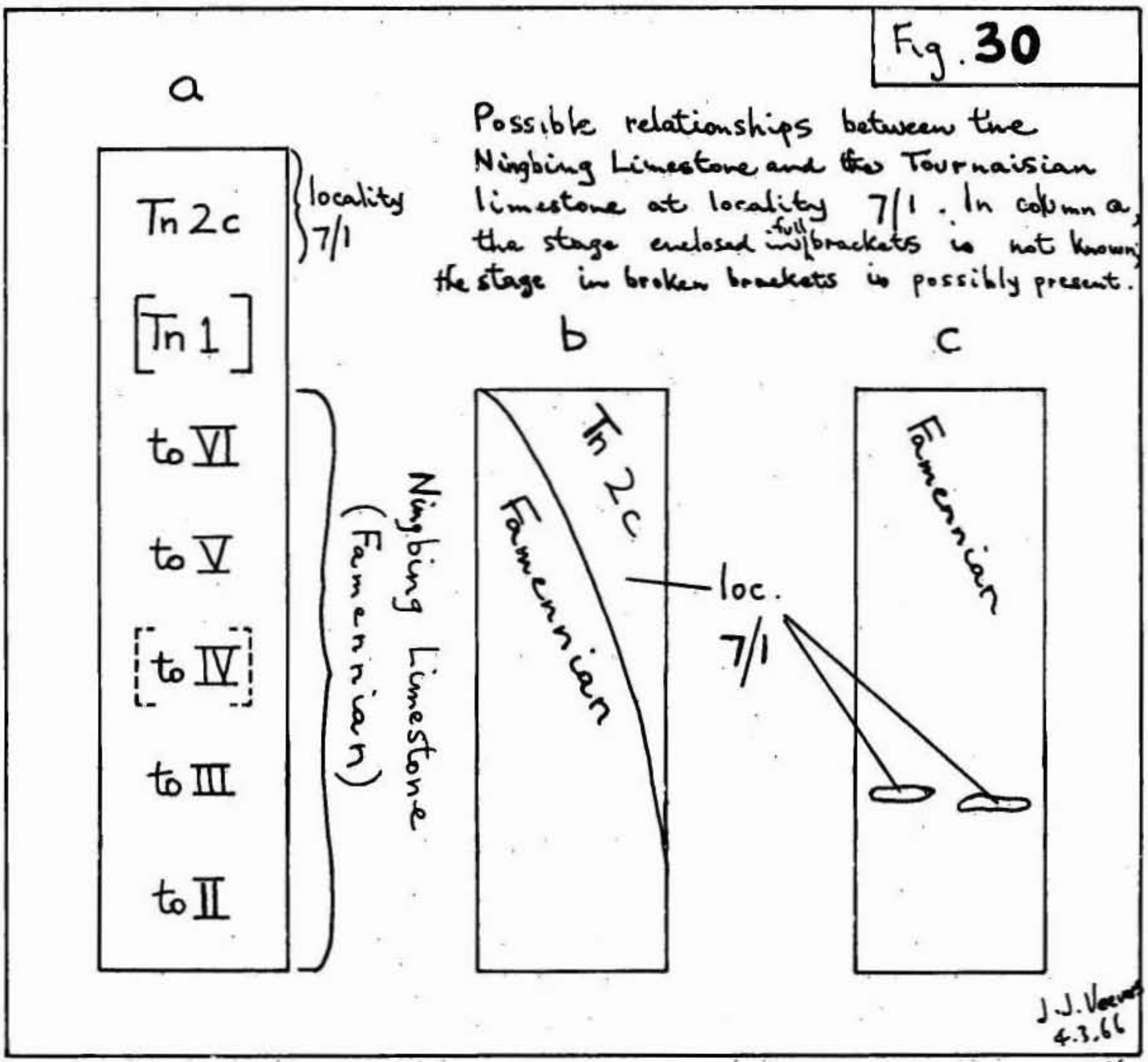


Fig. 30

Possible relationships between the Ningbing Limestone and the Tournaisian limestone at locality 7/1. In column a, the stage enclosed in full brackets is not known; the stage in broken brackets is possibly present.

J.J. Veevers
4.3.66
20.6.66

The poorly exposed Buttons Beds beneath the type section of the Burt Range Formation do not seem to have been hitherto recorded.

<u>Type section north of Buttons Crossing</u> (Fig.16)

The type section (105) is probably conformable on the Cockatoo Formation at Buttons Crossing but, as mentioned in the chapter on the Cockatoo Formation, this is not certain because of the complex structure of this area. The top of the type section is marked by an inferred covered fault, which brings the Cambrian Clark Sandstone and the Buttons Beds together.

The type section (Fig.25) consists of silty micrite (0-65 feet), pebbly limestone, with terrigenous fragments, including basalt (65-85 feet), sandy skeletal micrite-grain calcarenite, with interbedded calcareous sandstone and calcisiltite (85-1015 feet), sandy and silty dolomite (1015-1090 feet), and finally, feldspathic quartz sandstone (1090 - 1150 feet). Fossils are abundant, and include algae (porostromes, <u>Solenopora</u>, <u>Umbellina</u>), bryozoans, brachiopods, conodonts, corals, crinoid ossicles, fish plates, gastropods, ostracodes, stromatoporoids, and plants (<u>Leptophloeum</u>). Of these, only the ostracodes indicate detailed local correlation. According to P.J.Jones (pers.comm.), ostracodes in the interval 350-430 feet in the type section indicate correlation with locality 21/22 in the type section of the Ningbing Limestone, and with locality 100/4 in the Buttons Beds in the 8-mile Creek area. Correlation by means of other fossils is general. Conodonts at 820 feet in the type section indicate <u>to</u> II β - III γ, and brachiopods from different parts of the type section all indicate Upper Devonian, probably Famennian. Hill (1954) described two coral species, <u>Palaeosmilia contexta</u> Hill and <u>Syringopora patula</u> Hinde from the Buttons Beds of the Ord River.

<u>Eight-mile Creek area</u> (Fig.31)

Two poorly exposed sections of the Buttons Beds (Fig.25, sections 145, 146) were measured in the 8-mile Creek area. Both sections are covered at the base, and are overlain by the Burt Range Formation. No structural break is visible at this boundary, either on the ground or in the air photographs, but fossils on either side show that the boundary is a hiatus. In section 146, the Buttons Beds are 125 feet thick and consist of sandy skeletal limestone interbedded with pebbly calcareous sandstone. In section 145, pebbly sandstone and glauconitic calcareous sandstone are the only types exposed. Pelecypods at locality 146/4 are similar to those found at locality 266, south-east of Spirit Hill. The common Upper Devonian assemblage of brachiopods, pelecypods, gastropods, and <u>Leptophloeum</u> are found in this section, and at 146/13, the association of the same stromatoporoids and calcareous algae as those in the upper limestones of section 105 indicates the same facies if not the same age. The only firm evidence for finer correlation is provided by the ostracodes at locality 100/4 (Fig.33), near the preserved top of the Buttons Beds, which according to Jones (pers.comm.) indicate correlation with the interval 350-430 feet in section 105.

Sorby Hills (Fig.29)

The Sorby Hills comprise five small hills rising from the plain a short distance from the northeastern tip of the Pincombe Range. On the air photographs the rocks have a well-bedded pattern and soft grey tone which distinguishes them from the nearby Precambrian rocks.

The Sorby Hills consist of Buttons Beds which overlie, with slight angular discordance, Precambrian siltstone. A downfaulted sliver of Burt Range Formation is the only other formation found. The unconformity between the Buttons Beds and the Precambrian shows that the Pincombe Inlier was above sea level in the Upper Devonian. There is no visible contact between the sliver of Burt Range Formation and the Precambrian and, apart from the sandy nature of the rocks in the fault sliver, there is no evidence to tell whether the Pincombe Inlier persisted as a landmass into the Carboniferous.

The best exposures of the contact between the Buttons Beds and the Precambrian are at the localities marked 402 in Figure 29. In section 402 (shown as 402/4-7 in Figure 29) the Precambrian consists of hardened, thin-bedded grey-green siltstone. The siltstone is unconformably overlain by a thin basal breccia having angular lath-like fragments of siltstone and small rounded pebbles of milky quartz in a sandy matrix. A second similar breccia, slightly higher in the section, is followed by dolomitic sandstone and sandy dolomite. The only fossils collected from this part of the Buttons Beds come from locality 402/1, where indeterminate gastropods and an unidentified crinoid calyx were found in rubble beneath the lowermost outcrops of the formation.

In section 125, measured on the southern part of the same hill (Figure 29), 375 feet of Buttons Beds rest with angular unconformity on Precambrian siltstone. The overlying rocks are mainly hard, thickly bedded fawn to grey sandy dolomite which becomes sandier in the middle and upper parts; a white quartz sandstone is present 250 feet above the base of the section. Conodonts from locality 125/4 indicate an Upper Devonian age of not older than zone to III and not younger than zone to V. The only other fossils collected are poorly preserved, indeterminate gastropods and pelecypods from locality 125/7A.

UPPER DEVONIAN PART OF THE BONAPARTE BEDS (Fig.47)

Belford, Jones & Roberts (in LeBlanc, 1967) date the cores in the interval 8310-9279 feet in AOD Bonaparte No.1 Well as Upper Devonian on the basis of fossils, principally the pelecypod Buchiola. In the well the oldest dated core above this interval is Core 24 (6616-6620 feet) which is Tournaisian; no fossils were found in cores below 9279 feet, to the lowest core at 10,234 feet. The total depth is 10,530 feet. On this basis, the estimated thickness of the Upper Devonian in the well ranges from a minimum of 969 (8310-9279) feet to a maximum of 3,910 (6,620-10,530) feet. What part of the Upper Devonian is represented in the well is not known, because Buchiola ranges through the entire Upper Devonian. However, because the section beneath the Tournaisian at 6620 feet seems to be continuous, most if not all of the Upper Devonian is probably Famennian. This interpretation is shown in Fig.7.

The estimated minimum Upper Devonian, in the interval 8310-9279 feet, consists, according to LeBlanc (1967), of some 750 feet of light to dark grey shale and siltstone with minor interbedded sandstone, underlain by some 220 feet of sandstone and siltstone with minor shale. The estimated maximum Upper Devonian (6620-10,530 feet) includes additionally 1,251 feet at the bottom of the well, distinctively sandier than the overlying section and including 232 feet of varicoloured shale, and 1,690 feet of silty shale, siltstone, and siliceous sandstone. A dipmeter survey indicates a dip change at 7,480 feet. The angular difference amounts to a few degrees only, and whether this indicates an unconformity or slightly more intense flowing of the deeper shale and siltstone is not known.

For further details, LeBlanc's description should be consulted.

Summarized geological history of the Famennian

The marginal and middle provinces in which the Cockatoo Formation was deposited in the Frasnian are still recognisable in the Famennian (Fig.7), if due allowance is made for the general shift from terrigenous to biogenous deposition. Additionally, a third, outer, depositional province is recognised, in which part or all of the lower third of the section cut in AOD Bonaparte No.1 Well was deposited during the Famennian. The recognition of this outer province completes the classical sequence of equivalent facies, going from an inshore or marginal facies influenced by terrigenous deposition, a middle province of pure, in this example, reef, limestone, and an offshore or outer province of fine terrigenous sediment, mainly shale and siltstone.

Compared with the Frasnian, the Famennian was tectonically quiet, at least along the eastern edge of the basin. Perhaps, as Rattigan & Veevers (in Veevers & Wells, 1961) suggest as the cause of the start of Upper Devonian reef growth in the Canning Basin, the floor of the basin was block-faulted to provide bathymetric conditions suitable for reefs. If this were so, and we have no direct evidence for or against, the trend of the reef along the eastern edge of the Ningbing Range would indicate a major structural as well as bathymetric trend in the Famennian.

Most if not all of the sediments discussed above were deposited in sea-water. The Ningbing Limestone was deposited in shallow, clear, and probably warm sea-water. The rare terrigenous pebbles scattered through parts of the back-reef of the Ningbing Limestone were possibly rafted by Leptophloeum trunks and branches, which are common in the limestone. The rare conglomerate bed in the back-reef probably indicates a brief emergence.

The Buttons Beds in the 8-mile Creek area received abundant quartz and quartzite pebbles from the eastern edge of the basin; 15 miles westward, the Buttons Beds near the exposed base contain only one bed with pebbles, some of which are basalt probably derived from nearby land, possibly from the Pincombe Inlier. The terrigenous material in the rest of the section is very fine. The Buttons Beds were also deposited in shallow and probably warm sea-water which was turbid, and reef growth was inhibited.

Any sediment in the outer province equivalent to the reef complex must be marine because the reef could not have grown unless it faced on to the open sea. This argument also carries with it the implication that the outer province was an area of deeper water. The fossils in the interval 8310-9279 feet of Bonaparte No.1. Well show that at least this part of the section in the outer province is marine.

Comparisons with the Canning Basin

Playford et al. (1966) have pointed out the near-identity of the Ningbing reef complex and parts of the Upper Devonian reef complex of the Canning Basin. The outer province facies of both basins are no less alike. The intervals 3557-7504 feet in Wapet Frome Rocks No.2 Well and 2195-2697 feet in Wapet Babrongan No.1 consist of shale, siltstone, and minor sandstone, and parts of these intervals contain Buchiola. These are the same facies and probably also the same age as the lower interval of Bonaparte No.1 Well.

The marginal facies of the Canning Basin in the Famennian consists of conglomerate, which has no obvious representative in theFamennian of the Bonaparte Gulf Basin.

CARBONIFEROUS

BURT RANGE FORMATION

Almost all the outcrops of the Burt RangeFormation are found in the southeastern and eastern parts of the Bonaparte Gulf Basin between the Pincombe Range and the margin of the basin, east of the Burt Range. Smaller outcrops occur discontinuously along the eastern margin of the basin, running in a northeasterly direction from Spirit Hill to Sandy Creek and on to Flapper Hill near Legune Station (Plate 1).

Matheson and Teichert (1948) used the name Burt Range 'Series' for the limestone, calcareous sandstone and sandstone cropping out between Eight Mile Creek and the western flank of the Burt Range.

Noakes et al. (1952) changed the name to Burt Range Limestone and separated out the quartz sandstone, at the top of the sequence, which Traves (1955) called the Enga Sandstone. Traves included the limestone at Ningbing and on the Ord River in the Burt Range Limestone.

In this work 'Burt Range Formation' is substituted for 'Burt Range Limestone' because of the presence of different rock-types within the formation, thus following the use of the term by Utting (1958, unpublished) and Hare et al. (1961, unpublished). The formation is further restricted by excluding the limestone at Ningbing, the limestone at Buttons Crossing on the Ord River, as well as the western-most beds of limestone and calcareous sandstone exposed in a narrow belt five miles southeast of Martin Bluff (Fig.B1). The latter beds are mapped as Buttons Beds and are Famennian (to II - to III) in age; they are unconformably overlain by Carboniferous limestones of the Burt Range Formation. In the Burt Range area the break in sedimentation between the two carbonate sequences is equivalent to the upper half of the European Famennian Stage (zones to IV, V and VI) and also possibly the very basal part of the Carboniferous (Fig.32).

Burt Range Area

The Burt Range Formation crops out on tree-covered plains and low

GEOLOGICAL MAP OF THE BURT RANGE AREA

Fig. 31

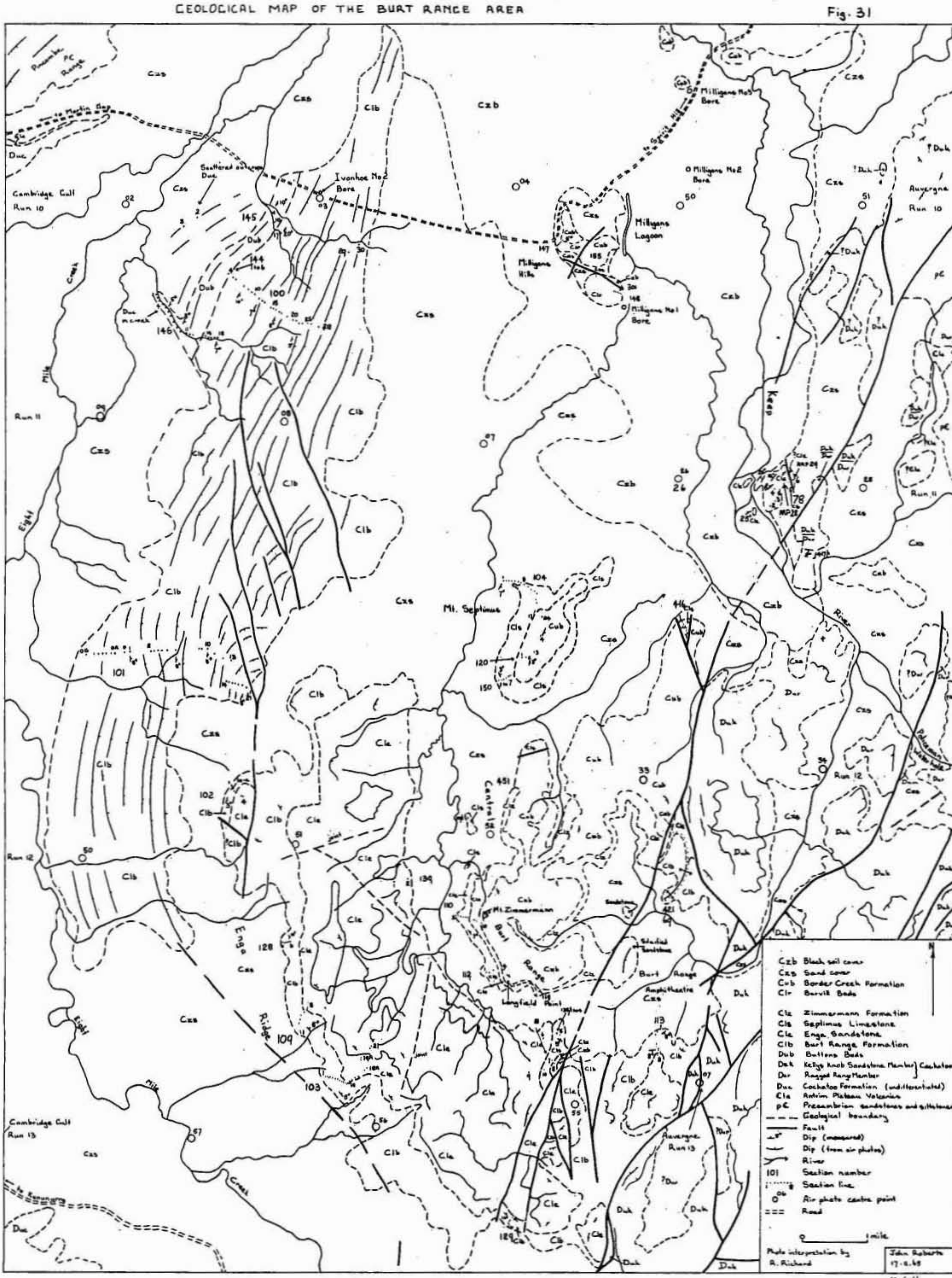
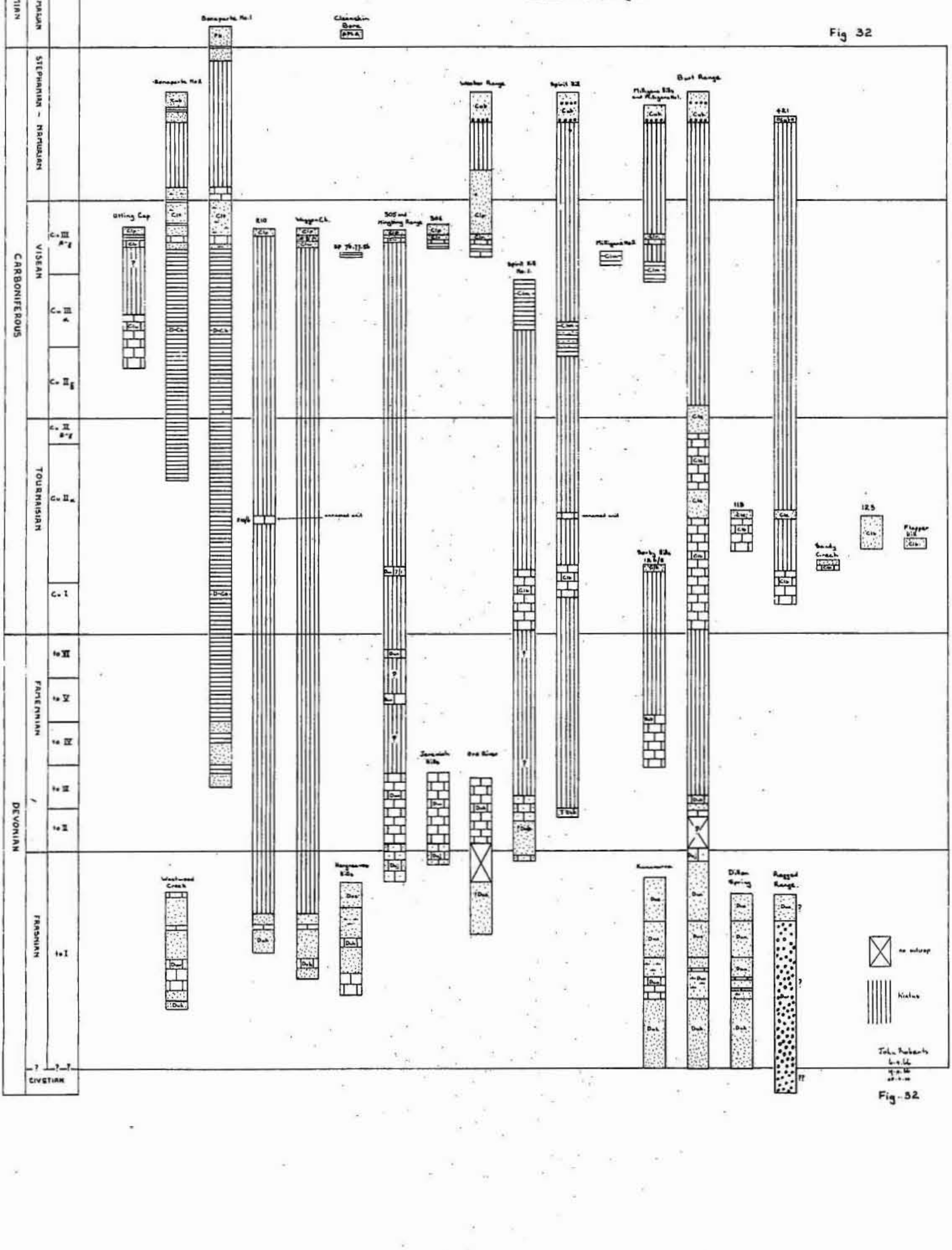


Fig. 31



Correlations in the Bonaparte Gulf Basin

See plate 1 for letter symbols

Fig 32

ridges mid-way between Martins Gap and Mt.Septimus, on the eastern side of Eight Mile Creek, and also along the steep western face of Enga Ridge (Fig.31).

The lower and middle parts of theformation form a low divide between Eight Mile Creek and an unnamed creek on the western side of Mt.Septimus. On the air photographs the outcrops have a stfiped pattern of alternating hard ribs of limestone and linear areas of soil cover. The more resistant parts of the formation form prominent strike ridges which are interrupted by minor faults and are breached by subsequent tributaries of Eight Mile Creek. Utting (pers.comm.) believed the beds beneath the soil cover to be shales and shaley limestone, but an examination of the rocks on either side of sections 100 and 101 shows that they are limestones slightly softer than those forming the resistant ribs.

The reason for the lack of major limestone outcrops south of section 101, in the area between the Matheson andEnga Ridges, is not clear. Ina converging area such as this dips should be higher and outcrops should be even more pronounced than those around the type section. On the contrary however, there are virtually no outcrops of Burt Range limestones on the plain and only faint bedding patterns appear on the air photographs. It is suggested either that the formation has become sandier because it was deposited in a region of more clastic sedimentation nearer the shore, or that the Cenozoic sand cover derived from the hills to the south is much thicker than elsewhere.

To the north, the lower part of the formation extends out on to the Keep River plain where it is covered by black soil and sand. The apparent 'lensing out' of the formation in this direction (Fig.31) may be due to a change in lithology, the sediments becoming silty and even shaley towards the north.

The upper part of the formation crops out as regular benches below cliffs of Enga Sandstone on the western face of Enga Ridge. The resistance to erosion of this part of the formation is at least partly due to the protection afforded by the cliffs of the overlying Enga Sandstone. The rocks have a regularly layered pattern on the air photographs. In places it is interrupted by quartzite 'blows' and irregular areas of silicification along fault planes. The ffaults trend northwest along the length of the ridge and generally have little throw; most are best regarded as joints and consequently are not shown on the geological map.

Outcrops of the Burt Range formation support a vegetation of Eucalyptus and yellow-flowered native cotton trees.

Seven detailed stratigraphic sections have been measured in the Burt Range area; two from the lower and middle parts of the formation and five from the upper part. The localities of the sections are shown in Figure 31 and their columnar sections in Figures 33 and 34.

Type section

Until the present investigation little was known of the lower and middle parts of the Burt Range Formation, and the sequence remained without a type section. Section 100, measured two miles south of the track running between Martin Bluff and Milligans Lagoon is designated the type section. The co-ordinates of the base of the section are Lat.15°38'S, Long.128°55'E. This section unconformably overlies Upper Devonian Buttons Beds and is 950 feet thick (Fig.33); it comprises the lower and portion of the middle part of the Burt Range Formation. The type section is complemented by section 101 measured through the lower and middle parts of the formation 6 miles to the south, and by section 103 measured through the upper part of the formation on Enga Ridge, (Fig.35). By using fossils to correlate between these three sections we have been able to establish a composite stratigraphic section, 1,510 feet thick, through the Burt Range Formation (Fig.B2); brachiopods and conodonts indicate that 100/13C is equivalent to 101/2, and 100/25 to 101/13. There could be a slight gap between the top of the 101 section and the base of the 103 section because of faulting, but short-ranging brachiopods in both of these parts indicate that the break, if any, is very slight.

In the type section the lowermost 150 feet consist of alternating hard and soft beds of thin-bedded, olive-grey, crinoidal calcarenite, with occasional sandy beds. A bed of stromatolitic limestone containing dome-shaped heads of '<u>Malacostroma concentricum</u>' Gurich 1906 up to 2 feet in diameter and 9 inches high is present 150 feet above the base of the formation. Finer grained, thin-bedded, grey, skeletal, crinoidal calcisiltite characterises the interval from 150 feet to 400 feet. From 400 feet to 700 feet there are olive-grey, crinoidal calcarenites containing abundant brachiopods. The rocks become sandier between 700 feet and the top of the section at 950 feet and are mainly olive-grey or olive-brown, sandy, skeletal calcarenites, also containing brachiopods.

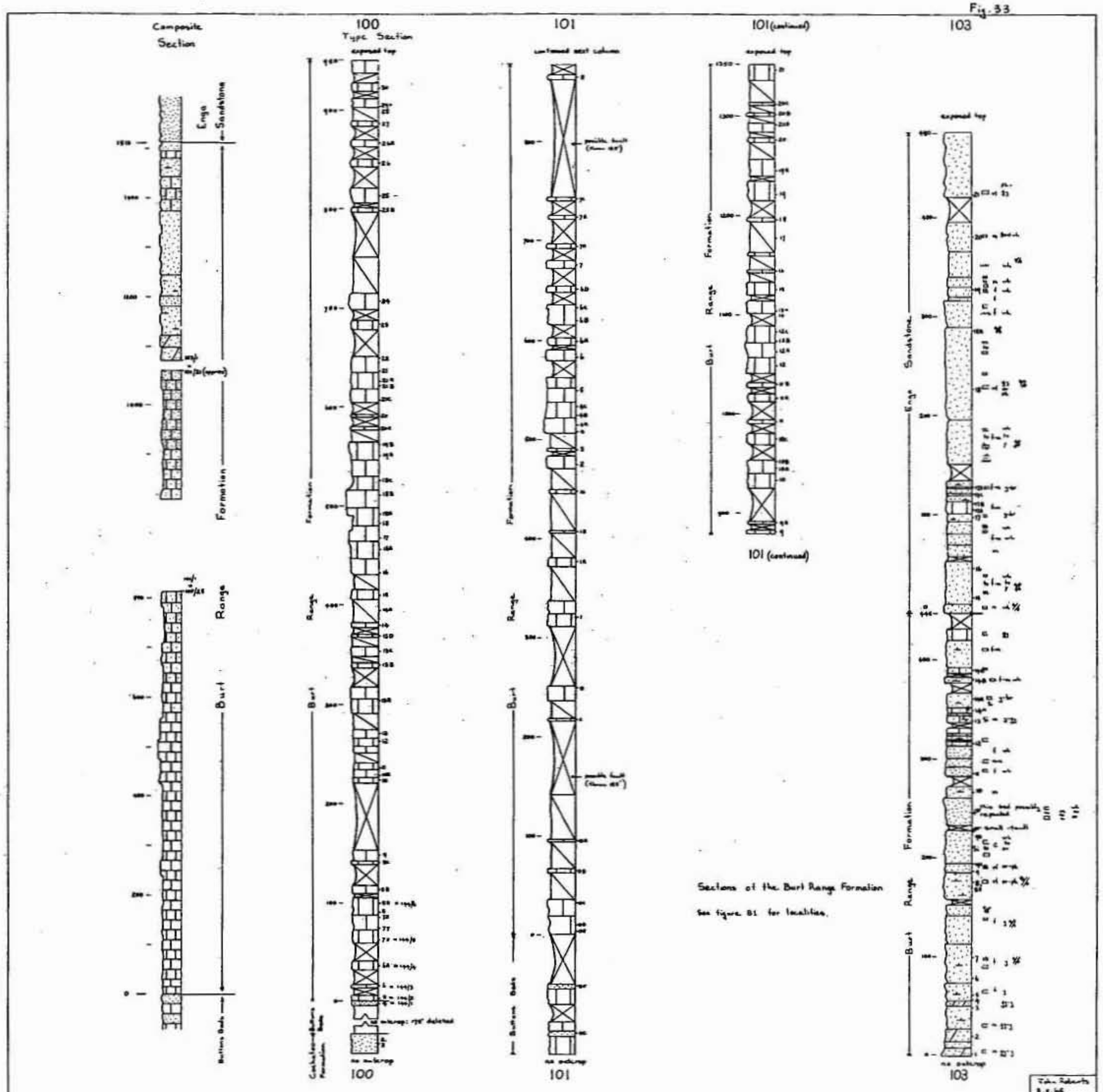
<u>Other sections</u>

The stratigraphic relationships between all of the sections measured through the Burt Range Formation are shown in Figure 35. Section 101 extends 250 feet stratigraphically higher than the type section and is used to describe the middle part of the formation. In this description the middle part of the formation is taken from 100/25, or its equivalent 101/13, to the top of the 101 section at 101/21; i.e., roughly between 800 and 1,100 feet above the base of the composite section.

Most of the lower part of the formation in section 101 is poorly exposed. However, prominent ribs crop out between 500 and 700 feet above the base of the section, and at locality 101/3 nigger-heads of tabulate coral are preserved in their living position together with a fauna of gastropods and brachiopods.

The middle part of the Burt Range Formation consists of alternating hard and soft beds of yellow-brown to olive-grey, sandy calcarenite. Those in section 101 are sandier and more thickly bedded than the equivalent calcarenites in the topof the type section, which suggests that at least the middle part of the formation is sandier in the south. At locality 101/2 a bedding plane contains a mass of straight nautiloids with their sharp ends oriented between 10° and 15°, indicating a current flowing from that direction. The sandy calcarenite at 101/12 is cross-bedded and also contains lenses of broken brachiopods. The rocks towards

Fig. 33



Sections of the Burt Range Formation

See figure 81 for localities.

Fig. 33

Fig. 34

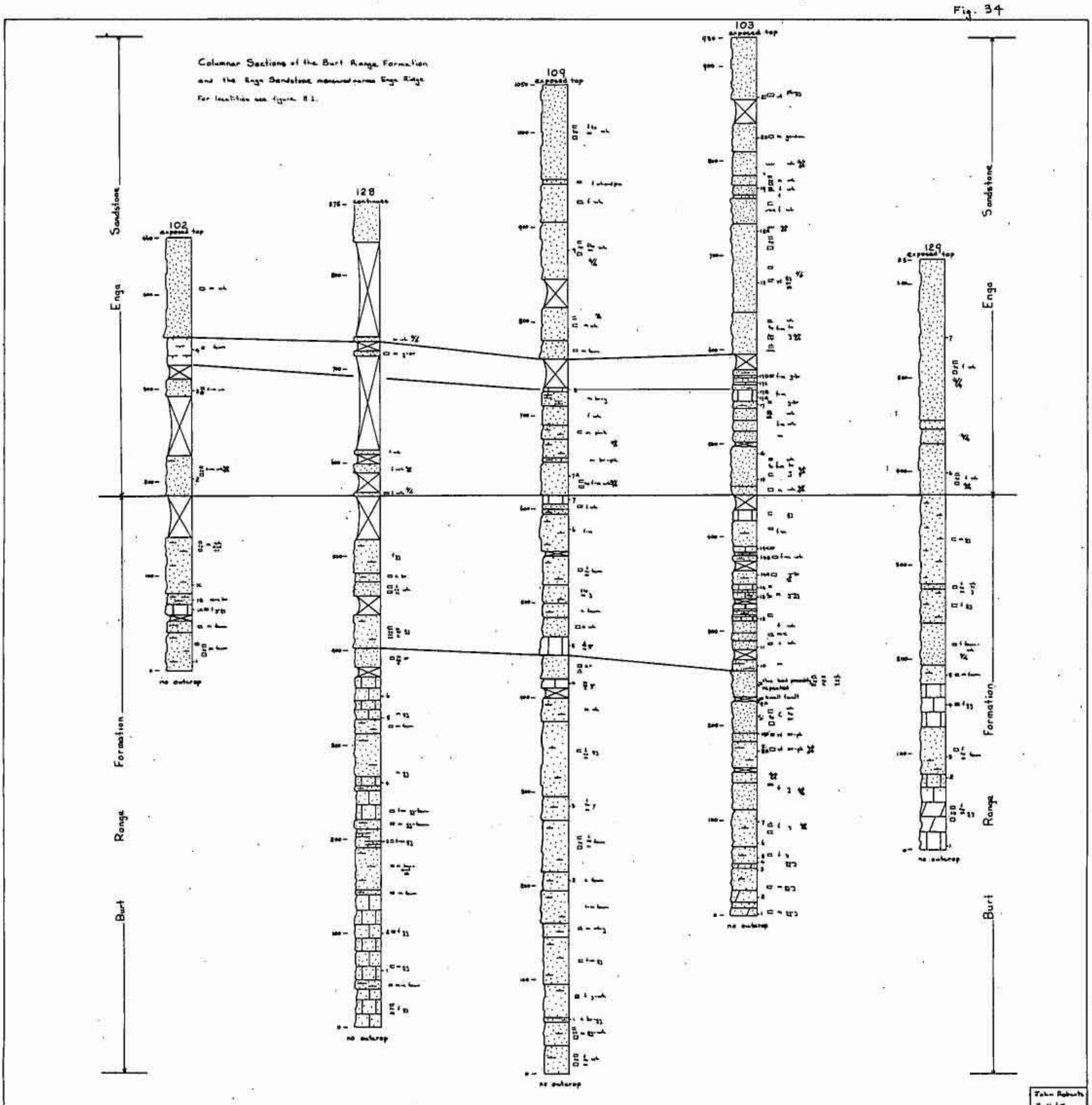
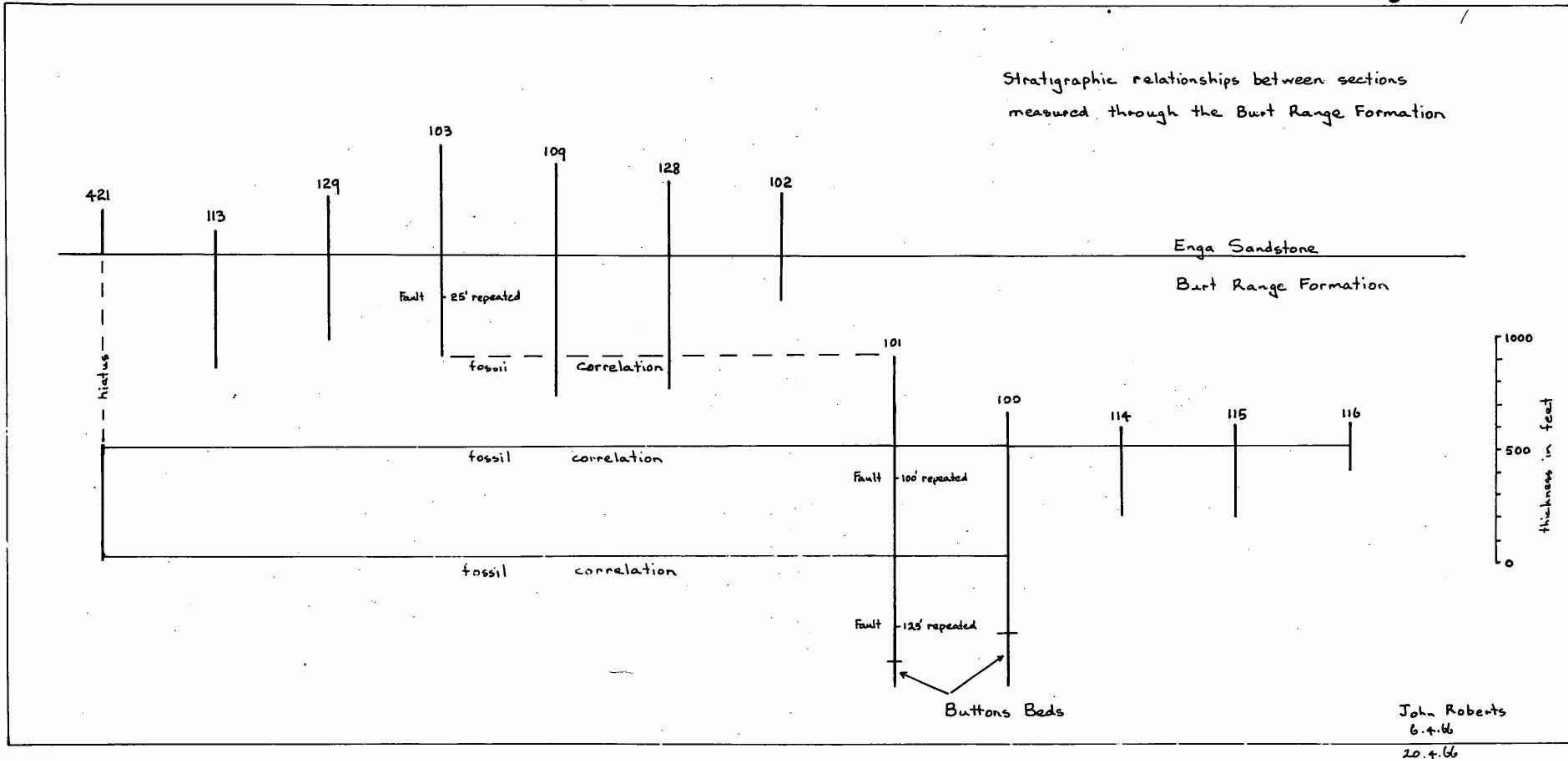

Columnar Sections of the Burt Range Formation
and the Enga Sandstone measured across Enga Ridge
For location see figure 8.1.
Enga Sandstone
Burt Range Formation
102
exposed top
no outcrop
128
continues
no outcrop
109
exposed top
no outcrop
103
exposed top
no outcrop
129
exposed top
no outcrop
John Roberts
7-11-68

Fig. 34

Fig. 35



Stratigraphic relationships between sections
measured through the Burt Range Formation
421
113
129
103
109
128
102
Enga Sandstone
Burt Range Formation
Fault
25' repeated
hiatus
fossil
correlation
101
100
114
115
116
1000
500
0
thickness in feet
fossil
correlation
Fault
100' repeated
fossil
correlation
Fault
125' repeated
Buttons Beds
John Roberts
6.4.66
20.4.66

the top of the section are poorly exposed but are lithologically close to those at the base of the 103 section.

The upper part of the formation, taken from section 103, consists of fine to medium-grained, yellow-grey, dolomitic quartz sandstone at the base, followed by medium to coarse-grained, white to orange, friable quartz sandstone, in turn overlain by alternating beds of fine to medium-grained, brown calcareous sandstone and grey-brown sandy limestone. The upper parts of the formation grade into the overlying Enga Sandstone, the boundary between the two formations being taken at the base of a prominent bench of quartz sandstone containing long vertical tubes.

Four other stratigraphic sections have been measured through the upper part of the Burt Range Formation from Enga Ridge (Fig.34). The additional sections were measured fortwo main purposes; firstly to determine lateral variation (if any) within the upper part of the formation, which is well exposed along the length of Enga Ridge; and secondly, to obtain additional fossil samples for stratigraphic control in the upper part of the formation.

Correlations between the sections along Enga Ridge are shown in Figures 34 and 35. With the exception of the correlation line from localities 102/4 to 109/8 to 103/17, all the lines are based on lithological evidence. In Figure 34 the lowermost line between sections 128, 109 and 103 is drawn at the top of a medium to coarse-grained, orange to white quartz sandstone which is characterised by a rounded castellate outcrop. The line at the base of the Enga Sandstone is drawn at the base of a thick pipe-rock sandstone which forms a prominent bench along the length of the ridge. The topmost line is drawn at the base of a high cliff which caps most of the higher parts of the ridge. Palaeontological evidence from brachiopods, ostracods and conodonts shows that the 102/4, 109/8 and 103/17 localities are the same age. Further correlation lines will probably be added when the study of the fauna is complete.

An examination of the columnar section shows that the rocks have little lateral variation and that the main lithologies recognised in the reference section (103) extend along the length of Enga Ridge.

<u>Fauna</u>

The describable fauna of the Burt Range Formation is dominated by brachiopods, conodonts and ostracods all of which are useful for correlating within the basin. Brachiopods and conodonts have also proved invaluable for correlations with overseas sequences. Conodonts were found in most of the limestones and calcareous sandstones throughout the formation; brachiopods occur abundantly above the 300 feet level; and ostracods were most commonly found in the middle part of the formation.

Crinoid columnals are perhaps volumetrically the most important fossil, and in places constitute up to 90% of the rock.

Other organisms present in smaller numbers include gastropods, nautiloids, corals, trilobites, polyzoans, scolecodonts and pelecypods in the sandier upper part of the formation. In the upper part of the formation there are trace fossils and wood fragments. Algae are scattered throughout the limey beds, and a stromatolitic layer (described above) occurs at 150 feet above the base of the formation.

Age

The Burt Range Formation was originally dated as Upper Devonian by Matheson and Teichert (1948) by way of a correlation of the lower part of the formation with the '*Productella* limestone' in theFitzroy Basin. Öpik (in Traves, 1955) agreed with the Upper Devonian age and thought that the top of the formation coincided with the end of the Devonian period.

The formation is now finally dated as Lower Carboniferous (lower to middle Tournaisian). From conodonts, E.C.Druce (pers.comm.) has dated the lower beds of the formation as lower Tournaisian (Tn1b inBelgium or lowermost K in Britain) and the upper beds as middle Tournaisian (Tn2b-c in Belgium, uppermost K in Britain and $CuII_a$ in Germany). Brachiopods support the lower Tournaisian age for the base of the formation. The brachiopod fauna from the basal beds of the overlying Enga Sandstone is correlated with one in the Pierson Limestone in Missouri and thence with the $CuII_a$ of Germany.

Burt Range Amphitheatre

In the Central Burt Range area, the Burt Range Formation crops out at the northern and southern ends of the Burt Range Amphitheatre. The Amphitheatre consists of a flat, tree-covered plain almost entirely surrounded by hills: Central Burt Range to the west and northwest, Enga Ridge to the south and southwest, and an unnamed range of Cockatoo Formation to the east (Fig.36). Access to the amphitheatre is either by way of a valley running between Enga Ridge andCentral Burt Range or by a narrow watergap in the eastern wall.

The Burt Range Formation is contained within a fault block bounded by the Amphitheatre and Cockatoo Faults (Figures 31 and 36), the movements on the faults having stepped the rocks upwards towards the east so that successively older formations are exposed in that direction. The outcrops at either end of the Amphitheatre are well layered on the air photographs and are exposed as rocky benches on the scarps.

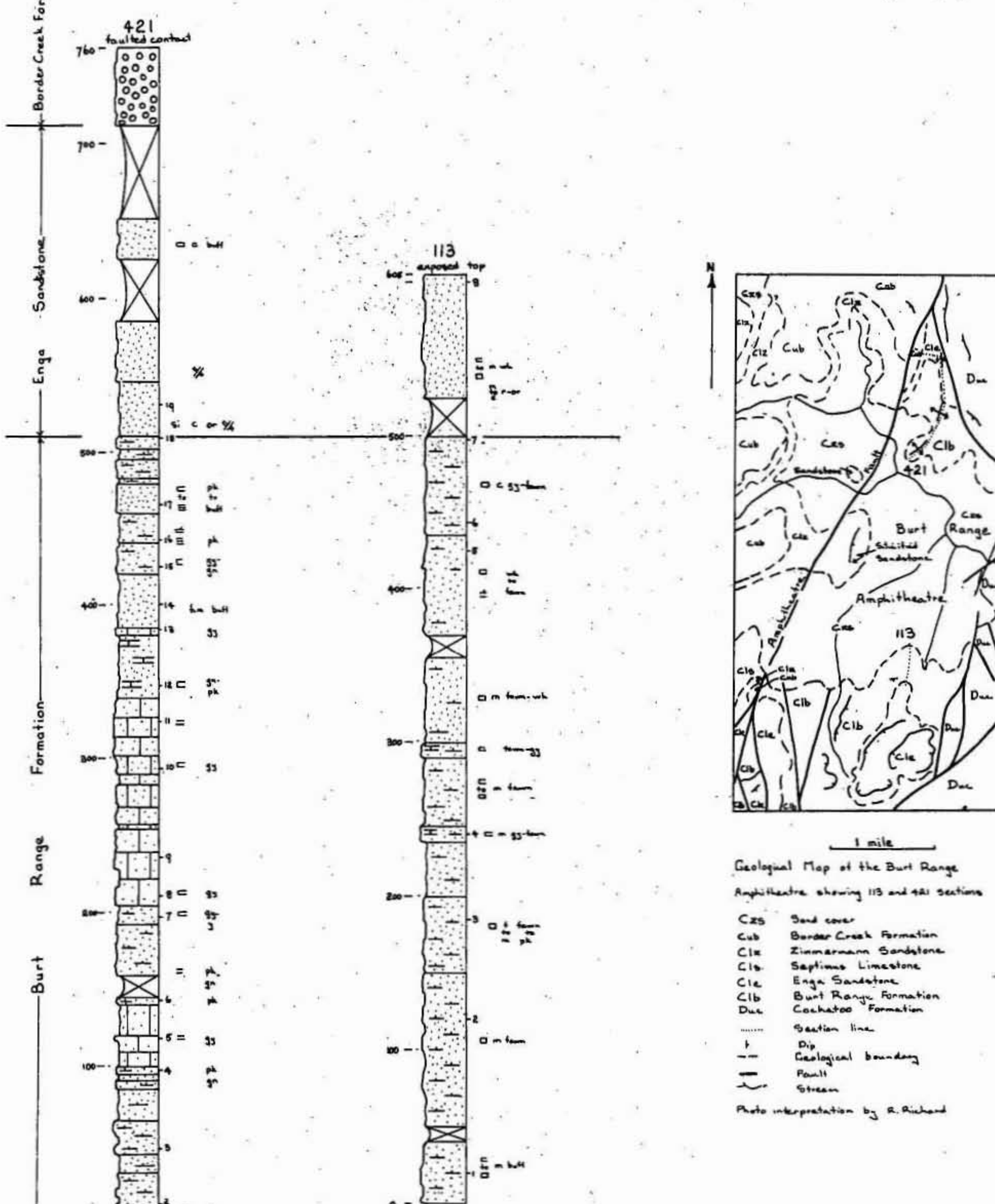
Sections

The northern section (421) is measured along the axis of a small anticline in the 'key stone' between the junction of two faults (Figs.31 and 36). The anticline, which was first mapped by Traves (1955), gives the impression of having been formed by drag movements along the faults. However, the eastern block of Cockatoo Formation has moved upwards in relation to the Burt Range Formation andEnga Sandstone in the central block, showing that vertical movement on the faults could not have been responsible for the east-dipping flank of the anticline. Lateral movements may have formed the anticline.

The rocks in section 421 can be subdivided into three kinds: pinkish, grey-green, calcareous sandstone in thin to moderately thick beds, with some interbedded sandy limestone cropping out from 0 to 200 feet; medium bedded, grey, sandy limestone from 200 to 380 feet; and laminated, locally cross-bedded, buff, calcareous sandstone from 380 to 510 feet.

Fig. 36

Columnar Sections in Burt Range Amphitheatre



John Roberts, 10.11.65
29.3.66

Fig. 36

Brachiopods show that the section is approximately equivalent to the middle part of the Burt Range Formation, probably to the interval 350 and 900 feet in the type section; locality 421/5 at 120 feet has the same fauna as the interval 350 to 450 feet in the type section; and locality 421/17 at 465 feet has a fauna similar to that between 800 and 900 feet in the type section.

The overlying buff to orange, quartz sandstone contains trace fossils and poorly preserved pelecypods, and is identified as Enga Sandstone. Similar sandstone outcrops which overlie the upper part of the Burt Range Formation at the southern margin of the Amphitheatre are almost certainly a continuation of the outcrops of Enga Sandstone along Enga Ridge (Fig.31). Hence, it appears that there is an unconformity between the Burt Range Formation and Enga Sandstone in the north of the Amphitheatre, and that in section 421 the upper part of the Burt Range Formation, amounting at least to about 500 of section, is missing, by erosion or non-deposition, beneath the Enga Sandstone.

The rocks in section 421 are much sandier, better exposed, and form higher outcrops than those in the equivalent part of the type section. They are dolomitised in places, especially near the faults, and this, along with the protective cap of Enga Sandstone, may have made them more resistant to erosion than the rocks in the middle part of the type section.

Section 113 was measured at the southern margin of the Amphitheatre (Figs.31 and 36). The 500 feet of Burt Range Formation exposed in this section consist mainly of medium to thick-bedded, medium-grained, fawn to grey calcareous sandstone, with some coarser beds; occasional beds of limestone are interbedded in the middle part of the section. Fossils have been collected from localities 113/5 and 113/7, from near the top of the formation, and indicate a stratigraphic position within the upper parts of the Burt Range Formation. Precise correlation cannot be made with the reference area, but it appears that there is less calcarenite in the upper part of the formation in the Amphitheatre area.

The calcareous sandstone is overlain by fossiliferous, red to white quartz sandstone identified as Enga Sandstone. The faunas on either side of the boundary indicate that the sequence is probably continuous. If a stratigraphic break does occur between the Burt Range Formation and Enga Sandstone in section 113, it is certainly much smaller than the one recognised in section 421 in the northern end of the Amphitheatre.

Sorby Hills

At locality 126/5 in the Sorby Hills a sliver of Burt Range Formation has been downfaulted into Upper Devonian Buttons Beds (Fig.29). The rocks are altered fine-grained quartz sandstone and contain well preserved brachiopods and pelecypods. The brachiopods are the same age as those between 800 and 900 feet above the base of the formation and are dated as middle Tournaisian.

There is no visible contact between the fault sliver and the nearby Precambrian which, elsewhere in the Sorby Hills, is overlain by Upper Devonian Buttons Beds. The sandy nature of the Burt Range Formation suggests that it may have also lapped on to the Pincombe Inlier, but it could equally well have extended as a sheet over the Inlier.

Sandy Creek - Legune Area

Scattered outcrops assigned to the Burt Range Formation occur in a narrow belt stretching from Sandy Creek to Flapper Hill, near Legune Station (see Fig.37 and Plate 1). The rocks crop out in low, resistant hills, frequently capped with banded porcellanite. Many of the outcrops, such as those at Flapper Hill, are completely silicified; others are strongly ferruginised and usually deeply weathered. Because of the alteration no distinct outcrop pattern is visible on the air photographs and the exposures appear as low, rounded hills rising out of a flat, timbered plain.

The rocks at the Sandy Creek crossing have been examined by a number of geologists. Noakes et al. (1952) termed the rocks 'Sandy Creek Limestone', and on the basis of fossils tentatively correlated them with the Point Spring Sandstone and the 'Flapper Hill Sandstone'.

Traves (1955) mapped the outcrops at Sandy Creek as Spirit Hill Limestone, then considered to be part of the Permian Weaber Group. Thomas, Appendix D in Traves, 1955; and 1962), however, considered the brachiopods from Sandy Creek to be most closely allied to Lower Carboniferous species.

The rocks at Sandy Creek are well-bedded, medium-grained, fawn to greyish-pink dolomite and silicified limestone containing silicified fossils. Overlying the dolomite is a poorly bedded, yellow-brown, medium-grained, fossiliferous sandstone which has been silicified and ferruginised; it crops out as a mass of rounded boulders. Near the eastern bank of Sandy Creek, the silicified sandstone is faulted against the underlying dolomite and limestone.

The brachiopod assemblage from both rock-types is similar to that in the Burt Range Formation. However, a precise correlation with the type section cannot be given because the ranges of some of the brachiopods collected from Sandy Creek appear to differ from those in the type area. The majority of the brachiopods suggest a correlation with the middle part of the Burt Range Formation.

Rocks also identified as Burt Range Formation crop out in a group of low hills, five miles northeast of the Sandy Creek exposures (see localities 123/5, 6 and 7 in Fig.37). They are faulted and many have been silicified and ferruginised. At locality 123/5 are exposed a silicified quartz sandstone and thinly bedded, fine-grained, white and purple quartz sandstone containing indeterminate plant remains. These rocks appear to be underlain by fine to medium-grained, fawn, calcareous sandstone (locality 123/6) which is generally medium-bedded and, in places, cross-bedded. A fault, with the downthrow to the east, separates the calcareous sandstone from rocks of similar lithology at locality 123/7.

Fig. 37

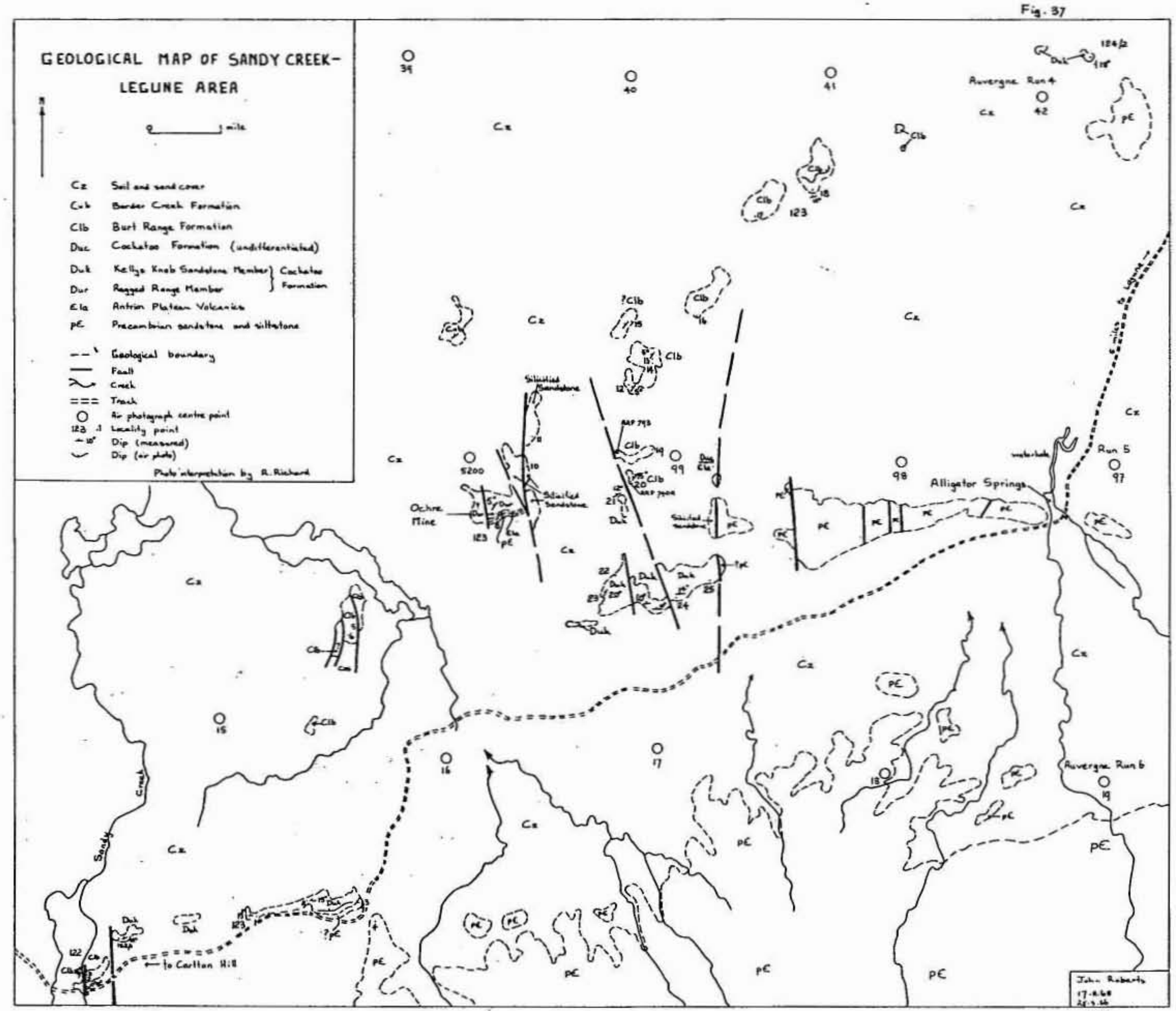

GEOLOGICAL MAP OF SANDY CREEK-LEGUNE AREA
N
0 1 mile
Cz Soil and sand cover
Cub Border Creek Formation
Clb Burt Range Formation
Duc Cockatoo Formation (undifferentiated)
Duk Kellys Knob Sandstone Member
Dur Ragged Range Member
Cockatoo Formation
Ela Antrim Plateau Volcanics
pЄ Precambrian sandstone and siltstone
Geological boundary
Fault
Creek
Track
Air photograph centre point
123 Locality point
Dip (measured)
Dip (air photo)
Photo interpretation by A. Richard
Auvergne Run 4
Run 5
Auvergne Run 6
Alligator Springs
Ochre Mine
Silicified Sandstone
Sandy Creek
to Carlton Hill
John Roberts

Fig. 37

A row of hills, all mapped as Burt Range Formation, extends from a point about two miles east of the Ochre Mine northeast towards Legune Station (Fig.37). In the southernmost hill, at locality 123/20, flaggy outcrops of white to purple, laminated siltstone and fine to medium-grained quartz sandstone containing crinoid ossicles are overlain by a coarse to medium-grained, fossiliferous, reddish feldspathic sandstone. A brachiopod from the topmost sandstone suggests that the rocks belong to the upper part of the Burt Range Formation.

A quarter of a mile north, in the hills around localities 123/19 and AAP 793 (Fig.37), interbedded yellow to white flaggy siltstone containing trace fossils, and interbedded sandstone are overlain by a coarse to medium-grained, red, fossiliferous sandstone (AAP 793). The hills are capped with banded purple and white porcellanite. Brachiopods collected from locality AAP 793 suggest a correlation with the upper part of the Burt Range Formation or even as high as the basal beds of the Enga Sandstone.

In the hills one mile further north (localities 123/12, 13 and 14 in Fig.37) a similar sequence of siltstone with trace fossils and sandstone with brachiopods overlies grey to brown, silicified, calcareous sandstone and limestone. The brachiopod fauna at locality 123/4, preserved in yellow-brown, medium to coarse-grained feldspathic sandstone, is similar to that from the upper part of the Burt Range Formation. The outcrops at locality 123/15, questionably referred to the Burt Range Formation, consist of barren coarse-grained, greyish-white quartz sandstone; some of the sandstone is cross-bedded.

Three prominent hills to the northeast (localities 123/16, 17 and 18 in Fig.37) consist of rubbly outcrops of friable, red,yellow or white medium to coarse-grained quartz sandstone. In the hill at locality 123/16 about 100 feet of sandstone is overlain by 40 feet of banded purple and white siltstone or porcellanite. Fossils from locality 123/16 are the same as those in the upper part of the Burt Range Formation in the type area, and a brachiopod from locality 123/17 is most closely compared with one from the base of the Enga Sandstone. The sandstone in the northernmost hill (locality 123/18) overlies about 25 feet of medium-bedded, grey to fawn, crinoidal clacarenite.

Noakes et al. (1952) introduced the name Flapper Hill Sandstone for the outcrops at Flapper Hill, four miles northwest of Legune Station. They were uncertain of the stratigraphic relationships of the unit but suggested that it could be older than the Point Spring Sandstone, and may interfinger with the rocks at Sandy Creek.

Traves (1955) also used the name Flapper Hill Sandstone and suggested that it may be represented by sandstones either above or below the limestone at Spirit Hill.

Thomas (1962) gave a list of fossils collected from Flapper Hill and concluded that they were Lower Carboniferous (Dinantian).

The rocks at Flapper Hill consist of silicified and ferruginised medium-grained, light grey to red quartz sandstone. Most of the hill is covered by a talus of rounded sandstone boulders, but some of the rocks at the top of the hill appear to be in situ. Glover et.al. (1955; unpublished) reported a lenticular outcrop of grey limestone, which we did not see, mid-way up the hill. Brachiopods from Flapper Hill suggest a correlation with the upper part of the Burt RangeFormation.

ENGA SANDSTONE

The Enga Sandstone crops out in the southeastern part of the Bonaparte Gulf Basin on the top of the western scarp and eastern dip-slope of Enga Ridge (Fig.31). Other outcrops are in the Burt Range Amphitheatre area and in hills four miles northeast of Mt. Septimus (Figure B1).

Matheson and Teichert (1948) included the sandstones capping Enga Ridge in the Burt Range 'Series'. Noakes et al. (1952) gave the sandstones the name of Snowie Sandstone, but this became invalid after the Lands and Survey Department of Western Australia replaced the proposed name 'Snowie Ridge' by 'Enga Ridge'. Traves (1955) called the formation Enga Sandstone.

The outcrops along Enga Ridge are regularly layered. The formation is always well exposed in the scarp on the western side of the ridge and in the castellate pinnacles on the deeply dissected eastern slope. Eucalyptus trees, low shrubs and spinifex grass grow on the Enga Sandstone.

At the southeastern margin of the basin the Enga Sandstone is cut off by the Cockatoo Fault. Immediately north of Enga Ridge it disappears beneath sand cover, and further north is thought tointerfinger with black silts and shales.

Stratigraphic sections measured through the Enga Sandstone include six from along Enga Ridge (Fig.34), three from the Burt Range Amphitheatre area (Figs.31 and 34) and one from low hills four miles northeast of Mt. Septimus (Fig.38).

Type section

The upper part of section 103 (Fig.34) measured near the middle of Enga Ridge is designated type section. The lower boundary, with the Burt Range Formation, is 445 feet stratigraphically above the base of the section at Lat.15°49'S, Long.128°56'E.

Lithologically the Enga Sandstone is a clean quartz sandstone with minor carbonate near the base. The sandstone is a well-sorted, fine to medium-grained, white, quartz sandstone having moderately to well rounded sand grains. At the surface it is porous and appears to be weakly cemented by a sparsely distributed clay mineral. The sandstone weathers to an orange-red colour.

Near the base of the formation are thin to medium-bedded, white to yellow, quartz sandstones containing long vertical 'worm' tubes, pelecypods and brachiopods. About 100 feet above the base of the formation there are 50 feet of fossiliferous calcarenites and interbedded calcareous sandstone. Above this level are fine to medium-grained white quartz sandstones; they are moderately to thickly bedded and outcrop in numerous benches or steep cliffs. Some beds are cross stratified and others contain ripple marks. Ripples at 660 feet stratigraphically above the base of section 103 are generally symmetrical, but some indicate a current flowing from a direction of 105°. At 740 feet asymmetrical ripples were formed by a current flowing from a direction of 330°. Trace fossils, including Rhizocorallium, are present in many beds, but shelly marine fossils are less common than in the lower parts of the formation. Sandstones between 795 and 825 feet above the base of section 103 have bands of black ferruginous cement. The stratigraphically highest rocks in the section are very fine grained, white quartz sandstones.

The contact with the underlying Burt Range Formation has been described above.

The topmost beds in the type section run eastwards beneath sand cover and their contact with the overlying Septimus Limestone is obscured. At the only known contact, at locality 111 near the Amphitheatre Fault (Fig.31), the Enga Sandstone is unconformably overlain by the Septimus Limestone (see below). Calcareous sandstones overlying rocks of typical Enga Sandstone lithology in section 111 have been placed in the Septimus Limestone because they are lithologically closer to the rocks in that formation. Glover et al. (1955, unpublished) referred these beds to the upper part of the Enga Sandstone.

A total of 485 feet of Enga Sandstone is exposed in the type section. Taking into account 35 feet of additional section in section 111, the thickness of the formation is estimated as 529 feet.

Other sections

The other sections measured across Enga Ridge (sections 102, 128, 109 and 129 in Fig.34) show only minor differences when compared with the type section.

Marls exposed beneath the high, cliff-forming sandstones in section 102, at the northern end of Enga Ridge, replace the calcarenite and calcareous sandstone at the same stratigraphic level in the type section and in section 109. The calcareous beds are replaced by sandstone in section 129, measured at the southern end of Enga Ridge.

Rocks identified as Enga Sandstone overlie the Burt Range Formation in the Burt Range Amphitheatre (sections 421 and 113 in Figs. 31 and 36); their relationship with the underlying formation has been discussed above. In section 421, at the northern end of the Amphitheatre, 140 feet of medium to coarse grained, well sorted, buff to orange quartz sandstone unconformably overlies carbonates of the Burt Range Formation. The sandstone is silicified at the contact with the underlying Formation, and contain poorly preserved pelecypods and trace fossils. Glover et al. (1955, unpublished) reported the occurrence of Leptophloeum in a locality near the 421 section line.

At the southern end of the Amphitheatre, about 100 feet of medium to coarse grained, well-sorted, white quartz sandstone containing pelecypods and trace fossils overlies, probably conformably, calcareous sandstone of the Burt Range Formation. The sandstones in sections 113 and 421 are coarser grained than those in the type section, and were presumably deposited closer to the margin of the basin.

Steeply dipping quartz sandstones 380 feet thick are exposed in a low hill (locality 78 in Figure B1) near the Cockatoo Fault, four miles northeast of Mt.Septimus. The sandstone is mainly a thin to medium-bedded, white to yellow, fine to medium-grained, quartz sandstone, but pebbles are present in coarse-grained sandstone near the base of section 78 (Fig.38). Many of the lower beds contain trace fossils; pelecypods, brachiopods and plant fossils have been found at localities 78/1, 2 and 3, and a shark ?Ctenacanthus (J.G.Tomlinson, pers.comm.) and an indeterminate goniatite from locality AAP 29. Above 190 feet in the section the rocks are frequently cross-bedded and contain pipe-rock beds, some of which are silicified. The sandstone in section 78 appears to overlie silicified limestone (possibly Burt Range Formation) near a fault zone on the eastern side of the hill (Fig.31). Sandstones on the eastern side of the fault contain boulders up to six inches in diameter, not seen in section 78, and large logs up to 26 inches long by 18 inches wide of Leptophloeum australe (McCoy). These rocks are tentatively identified as Enga Sandstone.

The identification of the Enga Sandstone in Spirit Hill No.1 Well (Thomas in Hare et al., 1961, unpublished; Drummond, 1963, unpublished) is rejected. Thomas doubtfully referred the interval between 2,013 and 2,469 feet to the Enga Sandstone, and Drummond called that between 1,215 and 1,561 feet Enga Sandstone. Figure 39 shows that this formation does not occur in the well. From palaeontological evidence, Thomas' ?Enga Sandstone must now be regarded as Upper Devonian ?Cockatoo Formation or Ningbing Limestone equivalent, and Drummond's Enga Sandstone as Burt Range Formation.

Fauna

Pelecypods and brachiopods have been collected from localities 103/15 and 16 in the lower part of the formation. The marl and calcarenite overlying the lowermost sandstone contain a rich fauna of brachiopods, ostracods, polyzoans and trilobites. At locality 102/4 the marls have an extremely rich fauna and many of the brachiopod species from this locality are not present at the same stratigraphic level in the south, probably because they favoured a quieter and deeper environment. Fossils are less common in the upper parts of the formation; brachiopods and pelecypods have been collected from locality 103/19; and scattered, poorly preserved pelecypods have been found at locality 139/2 near the top of the formation.

Age

Brachiopods from near the base of the formation indicate a correlation with the Pierson Limestone of Missouri, U.S.A., and thence with the middle to upper Tournaisian (Cu_{II_a}) of Germany. Conodonts from this horizon are the same as those in the lower part of the Tournaisian Z zone of Britain.

Environment

Towards the end of Burt Range sedimentation there was a gradual increase in the volume of available sand detritus in the southeast of the basin. During this time there was a gradual westerly movement of the quartz sand facies so that by the commencement of Enga sedimentation the sand facies extended well west of the present Burt Range area. It is not known whether the westerly movement was caused by a regression of the sea or by an uplift and subsequent erosion of Precambrian land to

Fig. 38

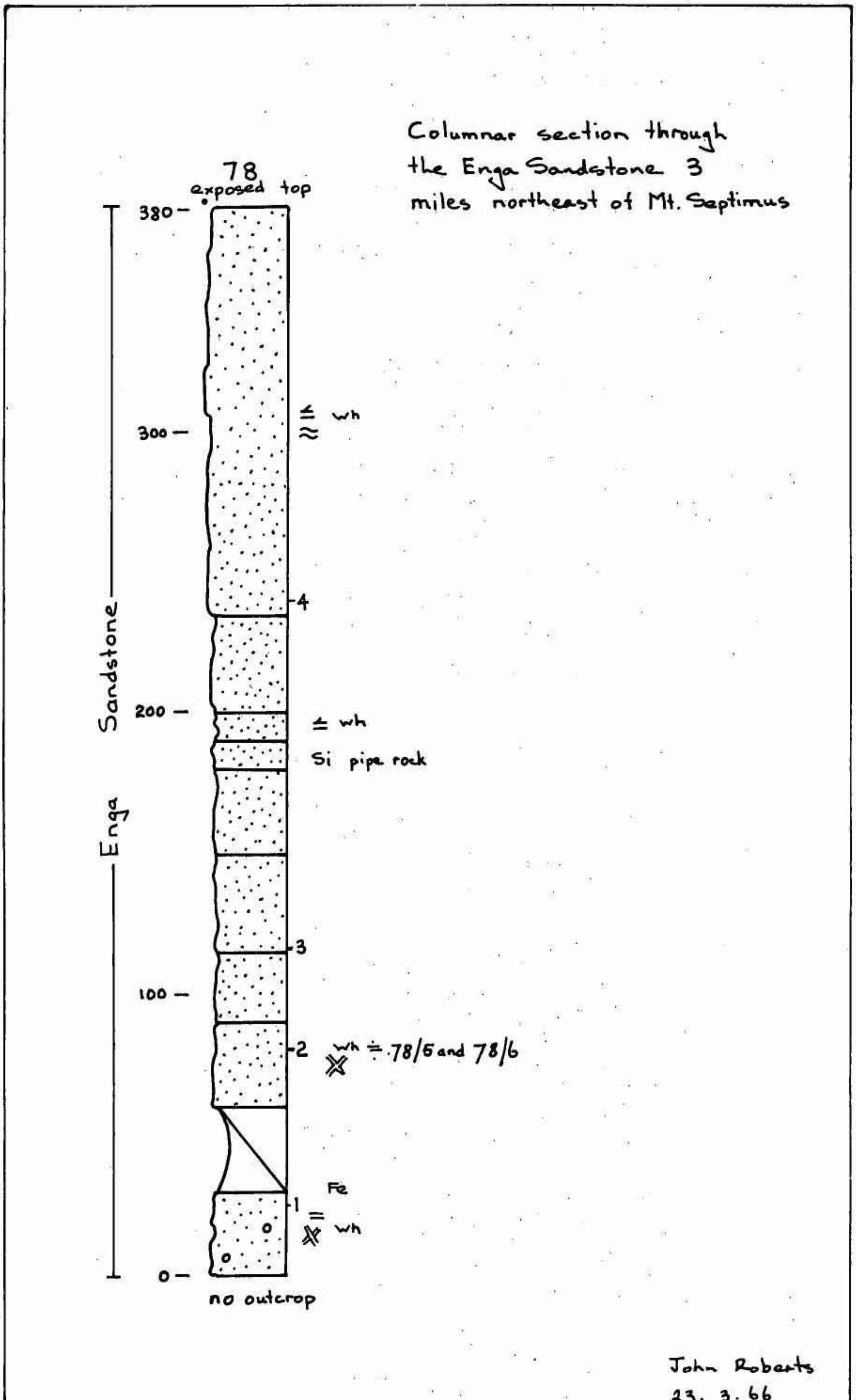

Columnar section through
the Enga Sandstone 3
miles northeast of Mt. Septimus
78
exposed top
380
300
200
100
0
Enga Sandstone
4
3
2
1
wh
Si pipe rock
wh ÷ 78/5 and 78/6
Fe
wh
no outcrop
John Roberts
23. 3. 66

Fig. 39

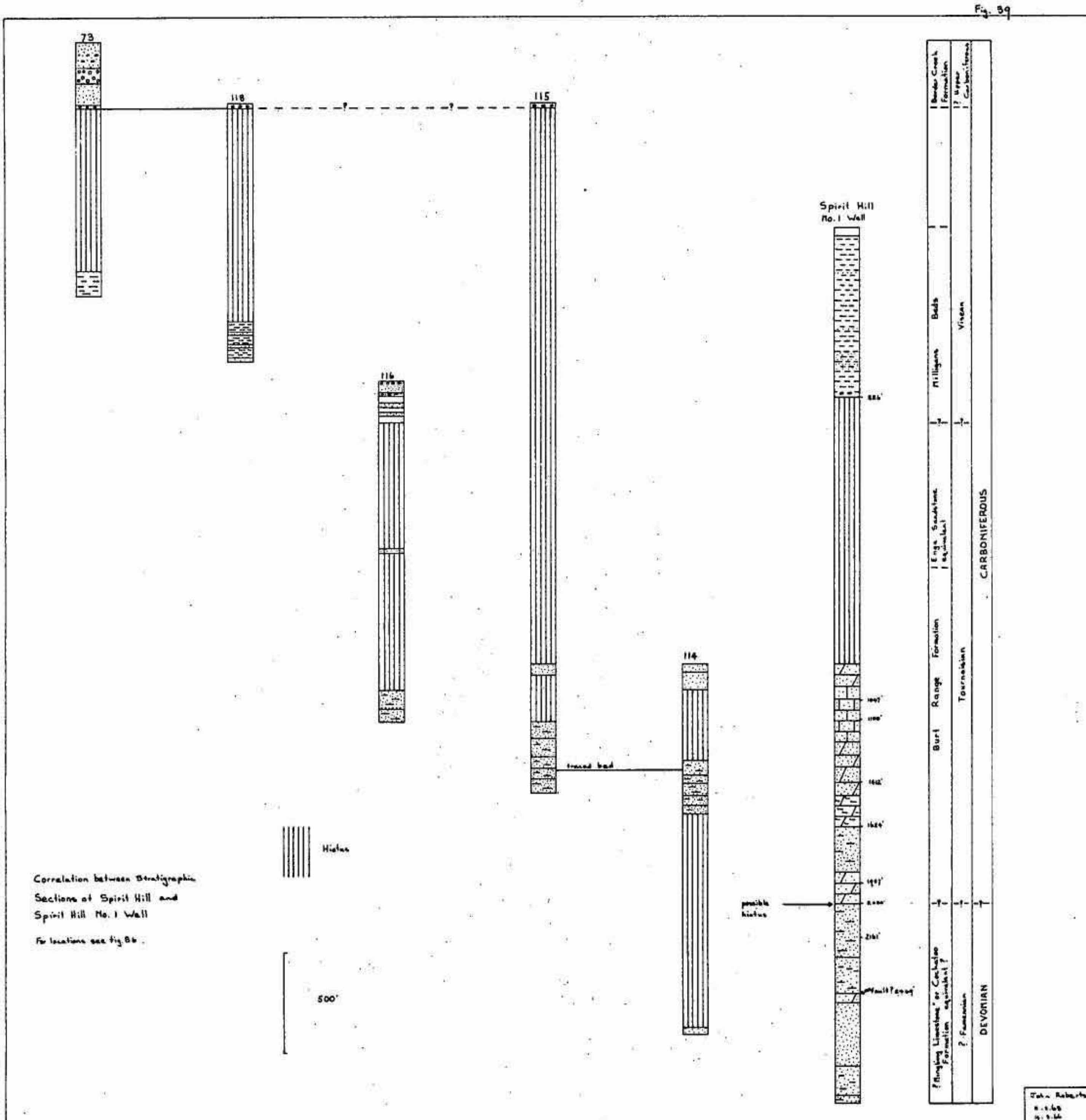
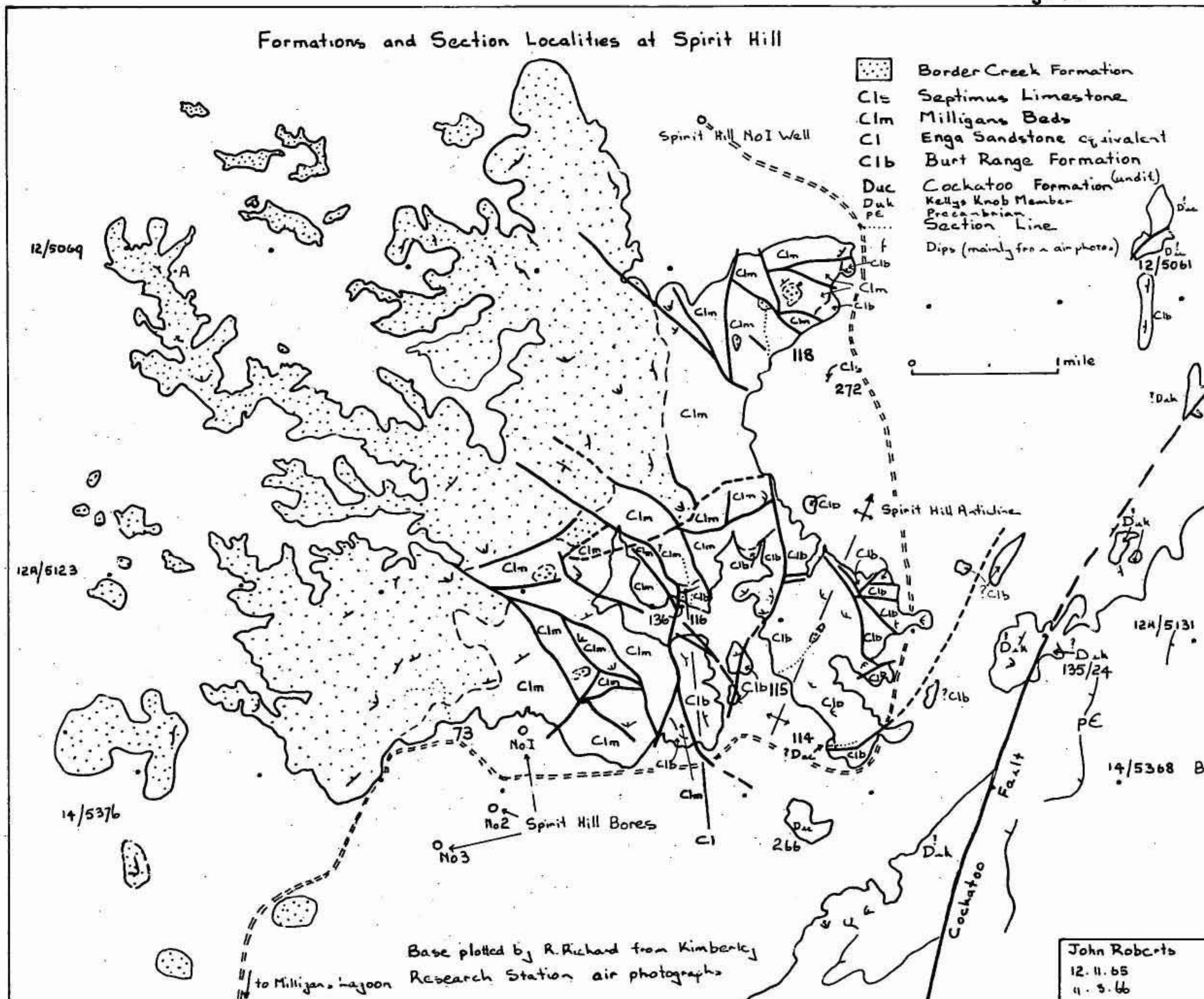

73
118
115
116
114
Spirit Hill
No. 1 Well
traced bed
possible
hiatus
Hiatus
500'
Correlation between Stratigraphic
Sections at Spirit Hill and
Spirit Hill No. 1 Well
For locations see fig. 86.
? Ringling Limestone' or Cockatoo Formation equivalent ?
Burt Range Formation
Enga Sandstone equivalent
Milligans Beds
Border Creek Formation
? Famennian
Tournaisian
Visean
? Upper Carboniferous
DEVONIAN
CARBONIFEROUS
John Roberts

Fig. 39

Fig. 40



26. 3. 66
1. 4. 66
20. 6. 66

the east and south.

Most of the Enga Sandstone was deposited in shallow sea-water away from coarser sediments near the margins of the basin. The sandstones are cross-bedded and contain oscillation and current ripple marks. Proximity to the margin of the basin is shown by the coarser sandstones in the Burt Range Amphithreatre area, to the east of the type section, and by the pebbles and boulders in the sandstones fowr miles northeast of Mt. Septimus near the Cockatoo Fault.

The northernmost extent of the sand facies is not known, but theEnga Sandstone is thought to interfinger northwards with black siltstones and shales deposited in quieter water.

SEPTIMUS LIMESTONE

The Septimus Limestone crops out mainly on the lower parts of Mt. Septimus and along the western scarp of the Central Burt Range. Smaller outcrops are in the Burt Range Amphitheatre, against the Amphitheatre Fault, on the northern tip of Central Burt Range two miles east of Mt. Septimus (Fig.31), and in an isolated locality half a mile east of Spirit Hill (Fig.40). Thomas (1962) recorded another outcrop three miles northeast of Spirit Hill which we could not find.

The limestones in the Central Burt Range were first examined by Matheson and Teichert (1948), and were dated as Carboniferous. Noakes et al.(1952) named them the Mt.Septimus Limestone, and this was later changed by Traves (1955) to the Septimus Limestone. The palaeontology of the formation was discussed by Thomas (1962).

The Septimus Limestone crops out in prominent benches on Mt. Septimus and along the Central Burt Range. It is well exposed in the middle and upper parts of the section, but the lower part is usually covered by sand. On the air photographs the limestone is evenly layered. Low native cotton trees, few Baobab trees and tall grass grow on the limestone.

Columnar sections through the Septimus Limestone (Fig.4) have been measured at regular intervals across Mt. Septimus and the CentralBurt Range (Fig.31).

Type Section

Section 104, measured on the northwestern flank of Mt. Septimus, is chosen as the type section of the Septimus Limestone and comprises 590 feet of thin-bedded yellow-brown and olive-grey sandy calcarenite, with a fawn, calcareous sandstone between 420 and 490 feet (Fig.41). The geographic co-ordinates of the base of the section are Lat. 15°43'S, Long. 128°59'E.

The contact with the underlying Enga Sandstone is not exposed. In the lowermost 100 feet there are isolated ribs of thin to medium-bedded, yellow to brown or orange, sandy, skeletal, calcarenite. Brachiopods are scattered throughout the carbonate and there is a polyzoan limestone between 65 and 80 feet. Thomas (1962) placed these fossils in his 'assemblage d'.

In the overlying 200 feet of section there are more massive outcrops of thin-bedded, olive-grey, sandy, skeletal calcarenites; some beds are cross-stratified on a small scale, and contain silicified, broken brachiopod shells. Three thin calcareous sandstones crop out immediately beneath the 300 foot level, at the footof the scarp of Mt.Septimus.

The outcrops between 300 and 420 feet are medium to thick-bedded, olive-grey, crinoidal, sandy calcarenite which contains abundant brachiopods and tabulate corals. Distinctive brachiopods from this interval ('assemblage c' of Thomas, 1962) have been used to correlate all the sections measured through the Septimus Limestone (see below and Fig.41). Some of the calcarenites consist almost entirely of crinoid columnals.

The lithology changes abruptly between 420 and 490 feet to a brown-weathering, medium bedded, pink to fawn, medium-grained calcareous and dolomitic quartz sandstone. Many beds are cross stratified, the sets being between 6 inches and 1'6" thick. An intraformational breccia containing sub-rounded to sub-angular clasts of limestone up to 9 inches long and 4 inches high in the lower part of the unit suggest that there was contemporaneous erosion of some of the Septimus Limestone. Masses of crinoid columnals as well as crinoid calices, an echinoid, brachiopods and gastropods have been collected from throughout the unit. Thomas (1962) assigned this fauna to his 'assemblage b'.

The remainder of the section to 590 feet is a crinoidal, yellow-brown, sandy calcarenite containing abundant brachiopods and tabulate corals ('assemblage a' of Thomas, 1962). The calcarenite is disconformably overlain by cliff-forming, barren, sandstone of the Border Creek Formation.

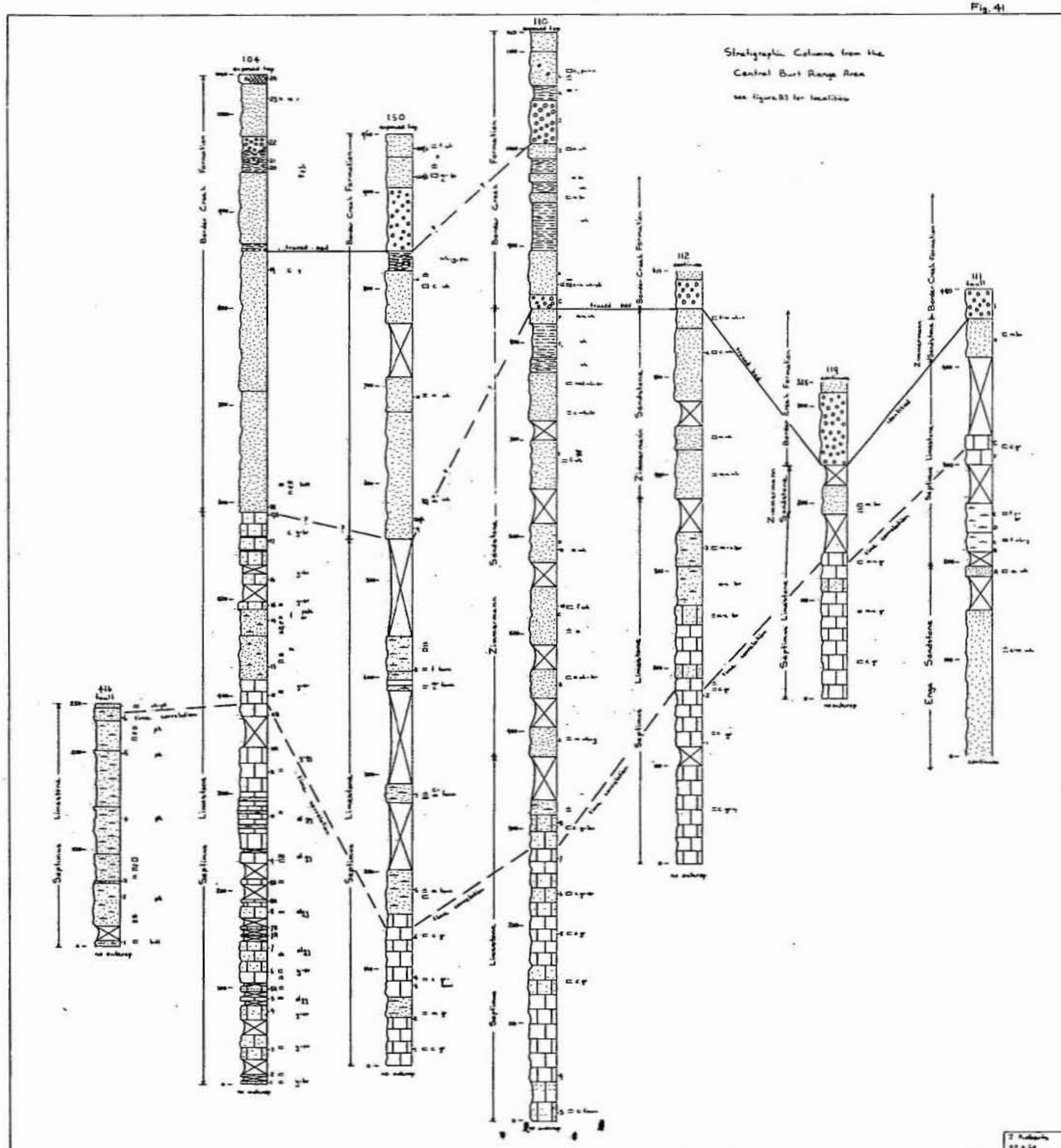
In the type area the contact with the underlying Enga Sandstone is covered by sand and the precise relationship between the Enga Sandstone and the Septimus Limestone is unknown. Fossils show that there is little likelihood of a hiatus between the two formations because conodonts from the base of the Enga Sandstone (no specimens are known from the upper beds) belong to the same conodont zone as those from the Septimus Limestone; those from the Enga Sandstone are typical of the base of the British Z zone, and those from the Septimus Limestone are known from the remainder of the same zone.

However a hiatus is thought to exist between the Enga Sandstone and Septimus Limestone at the southern end of the Burt Range Amphitheatre, where a calcarenite containing brachiopods from Thomas' 'assemblage c', together with 50 feet of barren calcareous sandstone, overlies the Enga Sandstone (Figs.41 and 42). In the type area this hiatus could be represented by some of the lowermost 300 feet of Septimus Limestone; viz. that with fossils from Thomas' 'assemblage d'.

Other sections

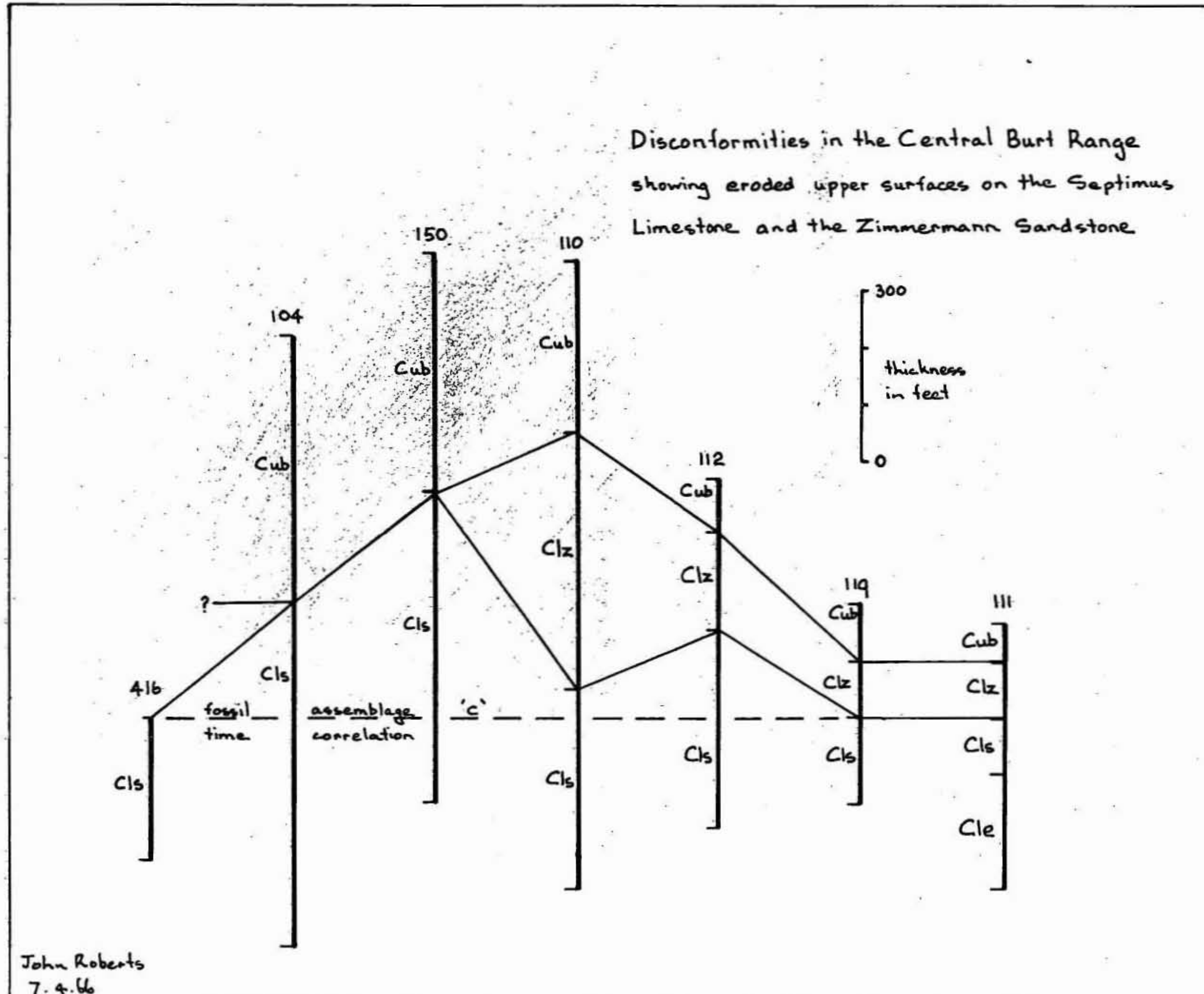
In section 150, measured on the southwestern end of Mt.Septimus, the Septimus Limestone is also overlain by the Border Creek Formation. A correlation based on brachiopods from Thomas' 'assemblage c' between

Fig. 41



Stratigraphic Columns from the
Central Burt Range Area
see figure 33 for localities
104
150
110
112
119
111
416
Border Creek Formation
Zimmermann Sandstone
Septimus Limestone
Enga Sandstone
traced bed
no outcrop

Fig 42


Disconformities in the Central Burt Range
showing eroded upper surfaces on the Septimus
Limestone and the Zimmermann Sandstone
300
thickness
in feet
0
150
110
104
112
119
111
416
Cub
Cub
Cub
Clz
Cls
Cub
Clz
Cub
Cub
Clz
Clz
?
Cls
Cls
fossil
time
assemblage
correlation
'c'
Cls
Cls
Cls
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Cls
Cle
John Roberts
7.4.66

this and the type section (Figs.41 and 42) shows that the calcareous sandstone towards the top of the formation is thicker in section 150, and that the uppermost beds of calcarenite are either absent or not exposed.

The uppermost calcarenite containing Thomas' 'assemblage a' is not known south of Mt.Septimus, and the correlation of sections 150, 110, 112, 119 and 111 (Figs.41 and 42) shows that the top of the Septimus Limestone is irregular and that, in general, the formation thins towards the south. In the two southernmost sections even the calcareous sandstone is missing and the youngest calcarenite contains brachiopods from Thomas' 'assemblage c'. The irregular upper surface and progressive thinning towards the south both suggest an erosional break before the deposition of the overlying formation (Fig.42). The erosion may have been caused by a gentle uplift associated with faulting south of the Burt Range area.

In the southern Central Burt Range the Septimus Limestone is overlain, probably disconformably, by the Zimmermann Sandstone. The sandstone contains brachiopod species, known also from the Septimus Limestone, which could suggest that part of the Zimmermann Sandstone is laterally equivalent to the missing upper part of the Septimus Limestone. All of the species so far identified, however, range well into the Visean, and have been found in the Bonaparte Beds, Milligans Beds and the Utting Calcarenite; they are not sufficiently diagnostic to tell whether the two formations are laterally equivalent. Because of the irregular surface on the Septimus Limestone we favour the idea of a disconformity between the two formations. The hiatus was brief and probably equivalent to a small part of the German $CuII_{\beta}$ zone: it is not shown in the correlation chart (Fig.32).

A closely comparable example of erosion is provided by the Zimmermann Sandstone itself, which is deeply channelled by the overlying Border Creek Formation and is much thinner at its southernmost outcrop than in the type section on the western scarp of the Central Burt Range (Figs.41 and 42).

An outcrop of sandy carbonate two miles east of Mt.Septimus on the northern tip of the Central Burt Range is identified as Septimus Limestone. The outcrop is bounded by faults on two sides and the carbonate is faulted against the overlying Border Creek Formation. Near the faults the rocks are strongly jointed and dolomitised.

In section 416 (Fig.41) 245 feet of dolomitic and calcareous sandstone is overlain by five feet of white to pink, quartz sandstone. The calcareous sandstone is pink medium to thickly bedded, sometimes cross-bedded, and medium-grained; it contains silicified brachiopods and, in places, niggerheads of tabulate coral which appear to be <u>in situ</u>.

These rocks are much sandier than their equivalents in the type section, and in the Central Burt Range (Fig.41), they contain fewer shelly fossils, and hence it is likely that they were deposited closer to the shore.

An isolated outcrop of Septimus Limestone from locality 272, half a mile east of Spirit Hill (Fig.40), is described later.

Fauna

Thomas (1962) recognised four faunal assemblages based mainly on brachiopods within the Septimus Limestone, and gave a comprehensive faunal list of brachiopod, mollusc, trilobite, coral, blastoid, ostracod and conodont species. He has also described an echinoid (Thomas, 1965a), and has in manuscript descriptions of many of the brachiopod species.

Age

Thomas (1962) suggested that the brachiopods from the Septimus Limestone indicated a late Tournaisian to early Visean age. Brachiopods described by J.Roberts support this determination, one particularly distinctive species occurring in the Tournaisian of the Kuznetsk Basin in Siberia.

Conodonts show that the Septimus Limestone is equivalent to most of the Tournaisian Z zone in Britain.

Environment

During Septimus time the low land areas around the southeastern margins of the basin provided small quantities of detrital material, and carbonate rocks accumulated in the shallow sea in the Burt Range area. Calcarenites were deposited on a shallow shelf, and calcareous sandstones closer to the shore.

On the shelf, tabulate corals formed niggerheads up to 3 feet across and 9 inches high and lived in association with a prolific crinoid, brachiopod and polyzoan fauna. From the richness of the fauna and the presence of the corals it is inferred that the sea was warm and was rich in nutrients.

The shelf was swept by currents sufficiently strong to wash in detrital sand grains and broken shell fragments from nearer the shore, and to form small cross-beds in the calcarenite. Much of the detrital carbonate may have been formed *in situ* on the shelf; for example, by boring gastropods breaking up brachiopod shells. Only gentle currents would be needed to break up the stems of dead crinoids, the columnals of which form up to 95% of some of the rocks.

Towards the end of Septimus sedimentation there was a slight regression of the sea, and sand was transported onto the shelf. The detritus formed calcareous sandstone which was frequently cross-bedded and in places contained masses of crinoid columnals.

The sediments deposited closer to the shore were similar to the calcareous sandstone mentioned above; they supported a brachiopod fauna and even colonies of tabulate corals, but the fauna was not as rich as that in the calcarenite on the shelf.

ZIMMERMAN SANDSTONE (new name)

Zimmermann Sandstone is the name given to the sandstone between the Septimus Limestone and the Border Creek Formation in the southern part of the Central Burt Range. The formation has a very limited area of only 15 square miles (Fig.31).

Traves (1955) mapped the sandstones and conglomerates overlying the Septimus Limestone in the Burt Range area as Weaber Group. In this work they are divided into two formations; the marine Zimmermann Sandstone and the fresh-water Border Creek Formation.

The Zimmermann Sandstone crops out in the scarps of the Central Burt Range, particularly on the western scarp, and at one locality on the southern edge of the Burt Range Amphitheatre. The formation is topographically subdued and crops out as thin brown bands beneath cliffs of the overlying Border Creek Formation (Fig.43). In the air photographs the sandstone has a uniform to very faintly bedded pattern.

The name of the sandstone is taken from Mt.Zimmermann, the highest point of the Central Burt Range.

Type section

Section 110 (Fig.41), measured at Mt.Zimmermann, is chosen as the type section, and consists of 460 feet of brown to white quartz sandstone, with interbedded white siltstone in the upper part. The geographic co-ordinates of the base of the section are Lat.15°47'S, Long.128°59'E.

The sandstone is a friable, well-sorted, thin to medium-bedded, medium-grained quartz sandstone with moderately well-rounded quartz grains. The grains were probably once cemented by calcite, but the cement has been leached from the outcropping rocks. Some of the sandstones are cross-bedded, and many contain trace fossils, including Rhizocorallium. Brachiopods, pelecypods and polyzoans have been collected from localities 110/10 and 110/11, and poorly preserved brachiopods recorded from between 820 and 835 feet stratigraphically above the base of the section (Fig.41).

Towards the topof the formation thin-bedded white siltstone is inter-bedded with the sandstone. This siltstone is indistinguishable in the field from that in the overlying Border Creek Formation.

The contact with the underlying Septimus Limestone is not exposed, but the irregular top on that formation suggests that it is disconformable. A more detailed discussion on the relationship between the Septimus Limestone and the Zimmermann Sandstone is given below.

The upper surface of the Zimmermann Sandstone is eroded and deeply channelled, and the formation is disconformably overlain by the basal conglomerate or basal sandstone of the Border CreekFormation. The Zimmermann Sandstone has been completely removed by erosion 2 miles north of Mt.Zimmermann (Fig.43), and in the northern Central Burt Range and Mt.Septimus the Border Creek Formation rests directly on the Septimus Limestone. In the southern part of the Central Burt Range the Zimmermann Sandstone has been cut by a large channel at least 75 feet deep and erosion has reduced the thickness of the sandstone to about 100 feet, compared with 460 feet in the type section. The channel is filled with conglomerate of the Border Creek Formation (Fig.44).

Age

The fauna showsthat the Zimmermann Sandstone is older than the Visean (CuII δ to CuIII α Utting Calcarenite. By superposition, the sandstone is younger than the Septimus Limestone and hence its fauna is dated as uppermost Tournaisian to lowermost Visean (CuII $_{\beta-\gamma}$ to CuII $_{\delta}$ zones of Germany).

Environment

At the end of the Tournaisian the southern part of the Burt Range area was up-faulted and some of the Septimus Limestone stripped off during a brief hiatus. The faulting caused a slight rejuvenation of the source area, and after erosion clean, fine to medium-grained quartz sand (Zimmermann Sandstone) was deposited in a shallow sea in the southern part of the Burt Range area. The sand was well sorted, had moderately well-rounded quartz grains, and supported a fauna of brachiopods, pelecypods, polyzoans and burrowing animals.

MILLIGANS BEDS

Milligans Beds is the name given by G.A.Thomas (in Hare et al., 1961, unpublished), in the completion report of Spirit Hill No.1 Well, to the dark shale and siltstone in the subsurface of the Keep River Plain. The name has since been used by Veevers et al. (1964).

The Milligans Beds are known from Milligans No.1 and 2 Bores at Milligans Hills, Spirit Hill No.1, 2 and 3 Bores on the southern margin of Spirit Hill, Spirit Hill No.1 Well, and seismic shot points between Milligans Hills and Spirit Hill and around Spirit Hill No.1 Well. Poor exposures identified as Milligans Beds have been mapped at Spirit Hill (Fig.40). Dark shale and siltstone, correlated with the Milligans Beds on the basis of fossil evidence, are present in Bonaparte No.1 Well, drilled 45 miles to the northwest, and in shot hole samples in the Waggon Creek Valley, 7 miles southwest of Ningbing (Jones, pers.comm.).

The Milligans and Spirit Hill Bores were percussion holes and the Spirit Hill No.1 Well was a continuously cored diamond drill-hole. Samples from all of these holes are held by the Bureau of Mineral Resources Core and Cuttings Laboratory in Canberra.

Type Section

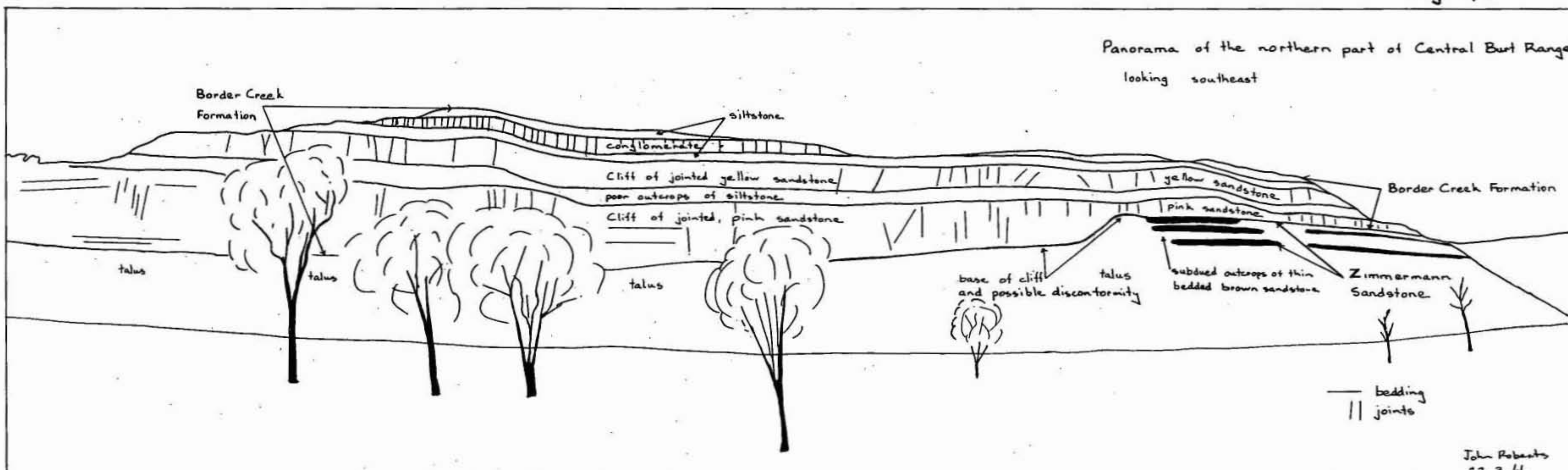
The rocks between 146 and 510 feet in Milligans No.1 Bore, drilled by Westralian Oil Limited at the southeastern corner of Milligans Hills at Lat.15°39'S, Long.129°00½'E, are chosen as the type section of the Milligans Beds.

The Milligans Beds are grey to black, silty shale which is locally calcareous, gypseous or pyritic (Rade, in Utting 1957 unpublished). The shale is soft, fissile to blocky, and contains a rich microfauna and microflora as well as shell fragments, crinoid ossicles and polyzoans.

In Milligans No.1 Bore the upper parts of the MilligansBeds are apparently transitional with a sequence of fine-grained, white calcareous sandstone, grey siltstone and fine-grained, sandy limestone which we identify as Burvill Beds, (Fig.45). However, because of the absence of an ostracod assemblage in the upper part of the bore, there may be an hiatus between the Milligans and Burvill Beds. Fossiliferous Burvill Beds consisting of ferruginised, gritty limestone, calcareous sandstone and quartz sandstone, crop out only 200 yards away from the bore site. The base of the Milligans Beds was not encountered in the bore.

In Spirit Hill No.1 Well, the only well to penetrate the Milligans Beds, the formation unconformably overlies the Burt Range Formation. The

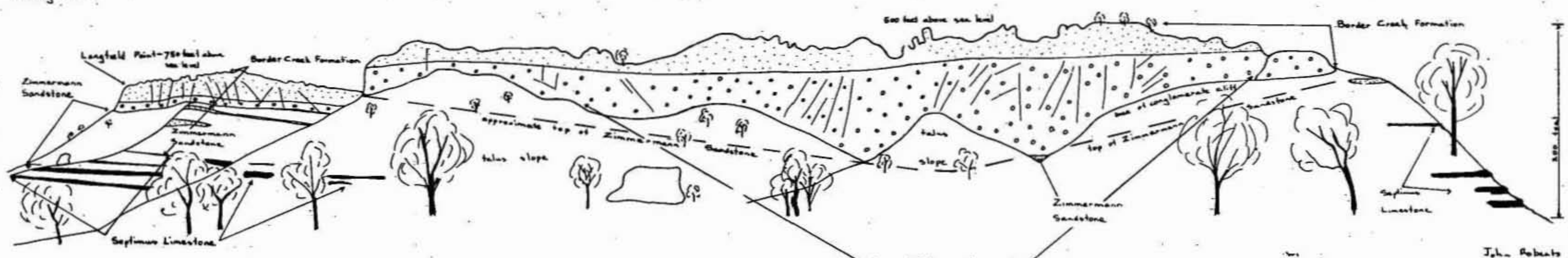
Fig. 43



Panorama of the northern part of Central Burt Range
looking southeast
Border Creek
Formation
siltstone
conglomerate
Cliff of jointed yellow sandstone
poor outcrops of siltstone
Cliff of jointed, pink sandstone
yellow sandstone
pink sandstone
Border Creek Formation
talus
talus
talus
base of cliff
and possible disconformity
talus
subdued outcrops of thin
bedded brown sandstone
Zimmermann
Sandstone
bedding
joints
John Roberts
23.3.66
29.3.66
20.6.66

Fig. 44

Panorama showing the channel fill at the southern margin of Central Burt Range. Looking north.

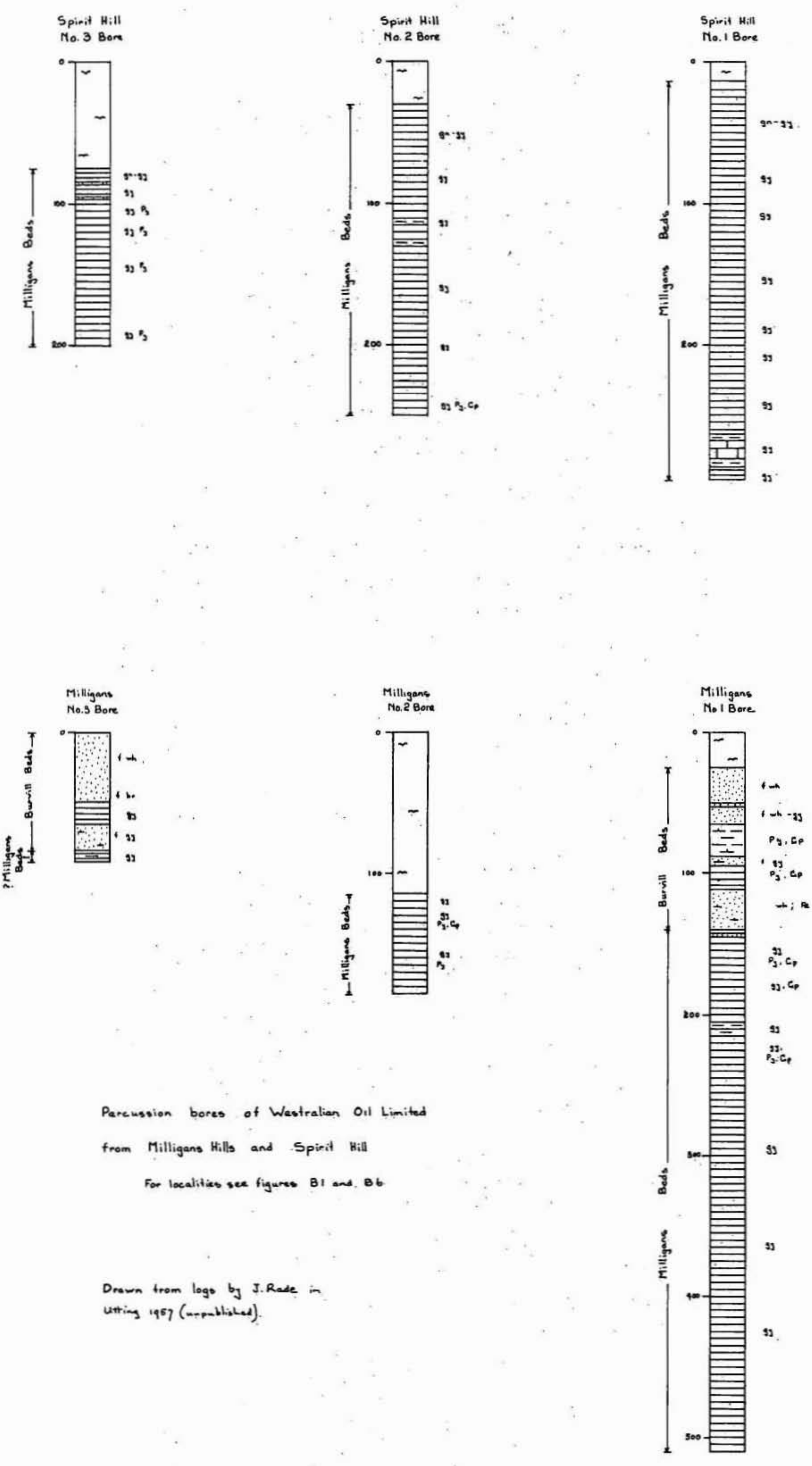


Width of panorama three-quarters of a mile

// joints

John Roberts
28.3.66
20.6.66

Fig. 45



Percussion bores of Westralian Oil Limited from Milligans Hills and Spirit Hill

For localities see figures B1 and B6

Drawn from logs by J. Rade in Utting 1957 (unpublished).

John Roberts
18.3.66
20.4.66

Fig 45

hiatus in the well extends from the middle Tournaisian to the middle Visean (Fig.32).

The thickness in the type section is 364 feet. The thickest section penetrated in the southeastern part of the basin is 826 feet in Spirit Hill No.1 Well. Because the upper beds in Spirit Hill No.1 Well are correlated with the lower beds in Milligans No.1 Bore (Jones, pers.comm.) we estimate the thickness of the formation as more than 1,000 feet.

Other Sections

Spirit Hill No.1 Well, drilled one mile north of Spirit Hill, spudded into Milligans Beds and passed through grey to black dolomitic shale with thin interbeds of sandstone and conglomerate to a depth of 826 feet (Fig.42). At the base of the formation is a pebble conglomerate containing rounded pebbles of quartzite and laths of siltstone and shale set in a coarse grained quartz sandstone matrix. The conglomerate unconformably overlies the Burt Range Formation. Microfossils have been found throughout, particularly at 50 feet and 99 feet; a spiriferoid brachiopod has been found in a conglomerate at 736 feet. Loughnan (Appendix 1), found that the shale contained a high percentage of the mineral kaolinite and he thought that it was deposited close to the edge of the basin. The Visean shale in Bonaparte No.1 Well correlated with the Milligans Beds has a rich microfauna and a high illite and low kaolinite content. This is consistent with our theory that the shale towards the centre of the basin is marine and was deposited well away from the margins.

Milligans No.2 Bore, 2 miles northeast of Milligans Hills (figure B1), was drilled to a depth of 186 feet and penetrated unconsolidated sediments and 70 feet of Milligans Beds in the lower part of the hole. The shale contains two ostracod assemblages the older of which is correlated with an assemblage in Milligans No.1 Bore (Jones, pers.comm.).

Only eight feet of grey, silty shale, tentatively identified as Milligans Beds, was encountered at the Bottom of Milligans No.3 Bore, drilled to a depth of 90 feet, 3 miles northeast of Milligans Hills. The shale is overlain by sandstone and shale, identified as Burvill Beds, which correlate lithologically with the rocks overlying the Milligans Beds in Milligans No.1 Bore (Fig.45).

Three stratigraphic test holes, Spirit Hill Nos. 1, 2 and 3 Bores, have been drilled by Westralian Oil Limited south of Spirit Hill (Figure 40). All of these bores penetrated a sequence, identified as Milligans Beds, of virtually barren, hard grey shale, containing calcite, gypsum and pyrite and having thin interbeds of sandy limestone and siltstone (Fig.45).

Visean brachiopods have been collected from shale, which most likely lies stratigraphically above that in the Spirit Hill Bores, at locality 73, one mile west of Spirit Hill No.1 Bore (Fig.40). The outcrops at Spirit Hill will be described later.

Palaeontology

Fossils found in the Milligans Beds include ostracods, foraminifers, (including endothyrids), conodonts, small pelecypods, immature brachiopods, crinoid columnals, gastropods, echinoid spines and tubercles, polyzoans, holothurian sclerites, fish scales, scolecodonts, tracheid plant fragments, and spores. Most of the macrofossils are small, stunted specimens.

Jones (pers.comm.) notes that the Milligans No.1 Bore lacks foraminifers but has abundant brachiopods, gastropods, pelecypods, crinoids and echinoids, whereas the fauna from the B.M.R. seismic shot holes north of Spirit Hill is rich in foraminifers and holothurian and fish remains.

Rare microfossils, including foraminfers, ostracods, scolecodonts and megaspores, have been recovered from throughout the shale, particularly from 50 and 99 feet, and a brachiopod from 736 feet in Spirit Hill No.1 Well. Balme (1961, in Hare et al., unpublished) identified a large microflora from the well.

The most useful fossils are the ostracods and foraminifers. Jones (pers.comm.) has recognised two assemblages of ostracods from the Milligans Bores. Both ostracods and foraminifers have enabled correlation between Milligans No.2 Bore and the interval between cores 6 and 8 in Bonaparte No.1 Well.

On the basis of a distinctive ostracod assemblage, the lower part of the shale penetrated by Milligans No.2 Bore is correlated with the entire shale sequence in Milligans No.1 Bore (Jones, pers.comm.). Some of the species in this assemblage have been found at 50 feet in the Milligans Beds in Spirit Hill No.1 Well and indicate the correlation of the top part of the section in the well with the bottom part of that in Milligans No.1 Bore. This correlation is contrary to Balme's suggestion (1961, Hare et al., unpublished), based on the microflora, that the shale in the upper part of Spirit Hill No.1 Well can be correlated with the interval between 191 feet and 392 feet (the middle part) of Milligans No.1 Bore.

A second ostracod assemblage at the top of the shale in Milligans No.2 Bore indicates a correlation with the shale in B.M.R. shot points in Waggon Creek valley, southwest of Ningbing, and with shale between cores 6 and 8 at a depth of 1,840 feet in Bonaparet No.1 Well.

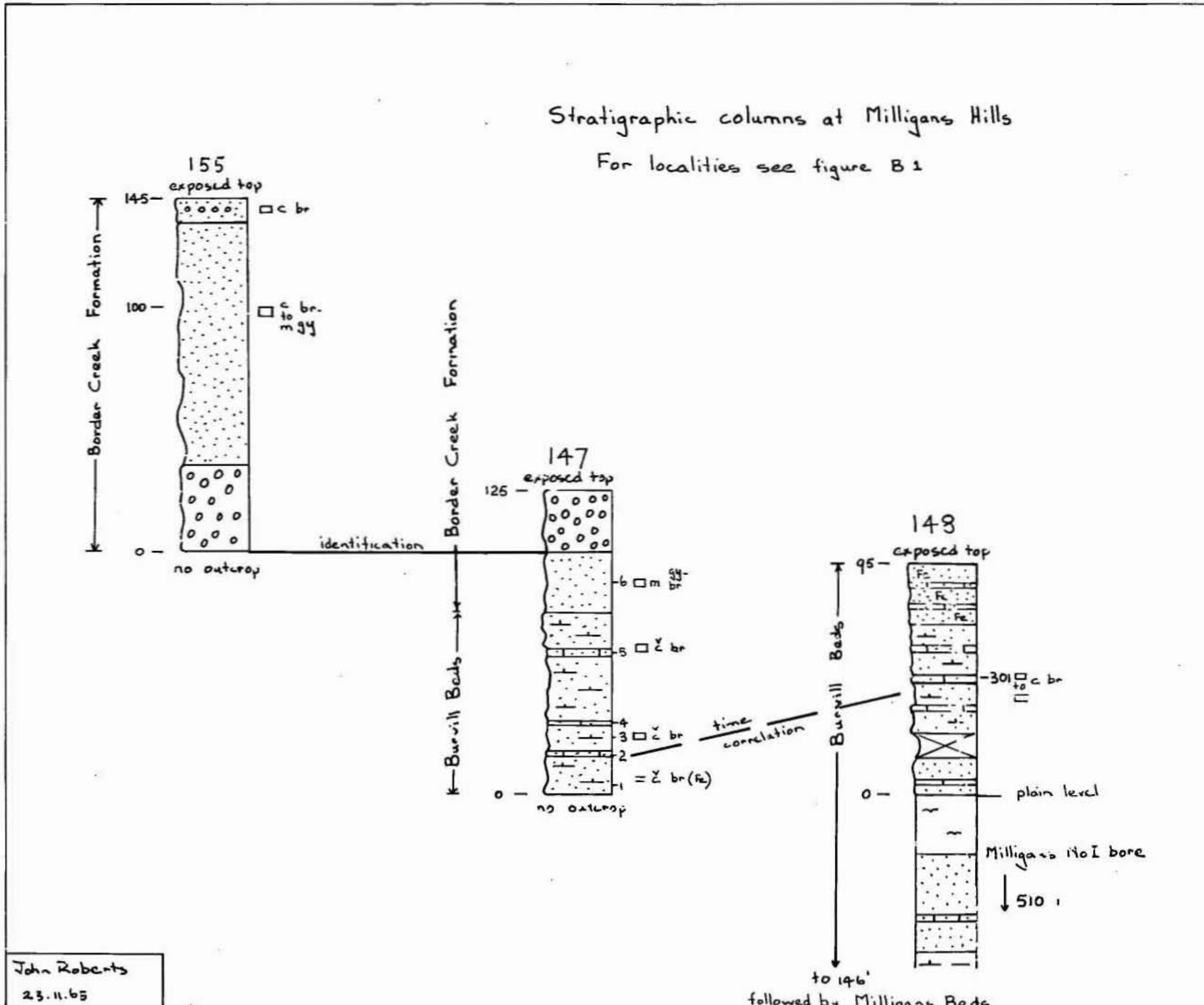
The absence of the second ostracod assemblage in Milligans No.1 Bore possibly indicates that there was a brief hiatus in the upper parts of the area immediately around Milligans Hills; shale was either not deposited or was stripped off before deposition of the Burvill Beds.

Age

Foraminifers from Milligans No.2 Bore are correlated with a fauna between cores 6 and 8 in Bonaparte No.1 Well which has been dated by Belford and Mamet (pers.comm.) as Visean (V3b-c).

At Milligans Hills the Burvill Beds, at locality 301 (Fig.31), which apparently overlie the section in Milligans No.1 Bore (Fig.46), contain a brachiopod fauna which has been recognised in the Burvill Beds in the Weaber Range. Thomas (1962) identified the brachiopods and dated them as upper Visean to lower Namurian. Conodonts from the type section of the Burvill Beds in the Weaber Range indicate a correlation with the upper half of the CuIII β zone of Germany.

Fig. 46


Stratigraphic columns at Milligans Hills
For localities see figure B 1
155
exposed top
145
100
0
c br
c to m gy
Border Creek Formation
no outcrop
identification
147
exposed top
125
Border Creek Formation
Burvill Beds
gy-br
no outcrop
time correlation
148
exposed top
95
Burvill Beds
301
c br
0
plain level
Milligans No I bore
510
to 146'
followed by Milligans Beds
John Roberts
23.11.65

The above evidence suggests that the age of the upper part of the Milligans Beds is CuIII$_\alpha$ to possibly CuIII$_\beta$, or middle to upper Visean. The age of the base of the formation has not been accurately determined but is thought to be lower to middle Visean (Fig.32).

BONAPARTE BEDS (new name)

Bonaparte Beds are defined here as the thick sequence of dark shale, siltstone and sandstone beneath the Tanmurra Formation in Bonaparte No.1 Well (interval 1,630 to 10,530 feet (total depth). The well was drilled by Alliance Oil Development at Lat.15°01'S, Long.128°44'40"E, 16 miles east-north-east of Ningbing Station. The beds are also known from beneath the Tanmurra Formation in Bonaparte No.2 Well, drilled 5 miles south-south-west of Bonaparte No.1 Well.

The Bonaparte Beds are named after the Bonaparte No.1 Well. They constitute a 'shale facies' in the central part of the Bonaparte Gulf Basin and, because they extend from the Upper Devonian into the Lower Carboniferous, are laterally equivalent to most of the sandstones and limestones deposited near the margins of the basin.

The succession in both Bonaparte No.1 and No.2 Wells are described by Le Blanc (1964, 1965, both unpublished), and the lithological details in the graphic logs (Fig.47) are derived from these reports.

Type section

The Bonaparte Beds consist of varying proportions of shale, siltstone, sandstone, and carbonate rock. Le Blanc (1964) distinguishes the following lithological units in Bonaparte No. 1 Well:

1630 - 3800 feet	: shale with rare siltstone interbeds
3800 - 6453 feet	: shale with some interbedded porous sandstone
6453 - 7100 feet	: silty shale with common interbedded siliceous sandstone
7100 - 7480 feet	: shale
7480 - 7865 feet	: shale
7865 - 8195 feet	: shale and siltstone
8195 - 8300 feet	: sandstone
8300 - 9035 feet	: shale and siltstone
9035 - 9260 feet	: sandstone
9260 - 9492 feet	: variegated shale
9492 - 10530 feet(T.D.)	: sandstone, siltstone, shale.

The sandstone is siliceous and silty. Most of the shale is variegated. The siltstone is slightly calcareous and commonly siliceous. In the interval 10280 - 10320 feet, the siltstone grades into silty microcrystalline limestone.

The colour of most of the shale in the Bonaparte Beds ranges from medium dark grey (N4) to dark grey (N3), as defined in the Rock Chart of the Geological Society of America. According to Dr.F.C.Loughnan (pers.comm.), the dark pigment is organic carbon, which constitutes about 1% by weight of the shale. The variegated shale near the bottom of Bonaparte No.1 Well is mainly green, with minor black, brown and rust. The shale of many cores has flowed plastically, probably before it was consolidated, and is commonly sheared, as shown by slickensides.

Lenticles of sandstone and siltstone are widespread in the shale.

Loughnan's mineralogical analysis of cores from the Bonaparte No.1 Well (Appendix 1) shows breaks between the Tanmurra Formation and the top of the Bonaparte Beds (between cores 5 and 6), and between cores 26 and 27. From core 27 downward, the Bonaparte Beds contain more quartz (40% or more) and small amounts of chlorite, calcite, and dolomite, which are not found above. Among the clay minerals in the Bonaparte Beds, mixed-layer minerals predominate, and, except for a few cores with 20 to 25% kaolinite, this mineralogy is in accordance with a "marine origin."

The interval between cores 26 and 27, marked by a mineralogical break, is further marked by a structural break detected by a dipmeter survey. Above 7472 feet, the dip is northward whereas from 7520 to 8524 feet it is east-south-eastward, and from 8524 to 9949 feet (the greatest depth surveyed) the dip is southward or south-eastward. From cores, the amount of dip is known to be generally 2 to 3 degrees from thetop to 7480 feet, and 4 to 6 degrees from 7480 feet to the bottom. Le Blanc interprets this information as an angular unconformity in the interval 7472 to 7520 feet.

In Bonaparte No.2 Well, Le Blanc distinguished the following units:

1577 - 3274 feet	:	shale with rare interbeds of siltstone
3274 - 4541 feet	:	silty shale with common interbedded sandstone, including pebbly sandstone from 3562 to 3568 feet
4541 - 4950 feet	:	shale with several beds of sandstone
4950 - 5548 feet	:	shale
5548 - 6675 feet	:	silty to sandy shale with interbedded sandstone
6675 - 7008 feet (T.D.)	:	shale and sandstone

A zone of faulting was found between 4950 and 5100 feet. The dip from 5100 feet to the total depth is south-eastward at 3 to 4 degrees.

Fauna

Belford, Jones and Roberts have identified the fauna, mainly from cores, in both of the Bonaparte Wells (appendices in Le Blanc (1964, 1965, both unpublished).

Richly fossiliferous beds in the upper parts of the Bonaparte Beds in Bonaparte No.1 Well contain foraminifers, ostracods, brachiopods, pelecypods, and conodonts. Fossils are less common lower in the sequence and many of the rocks are barren or contain only fragmentary fossils. The sandstone at the bottom of the well is barren.

The fossils show that the Bonaparte Beds are almost entirely marine. The conchostracans from core 29 (8,8556 feet) in Bonaparte No.1Well typically indicate a brackish environment, but they are associated with pelecypods and trilobites and are thought to have been washed into marine sediments.

The sequence in Bonaparte No.2 Well contains even fewer fossils: all that we have been able to find are fragmentary conodonts in cores 3 and 5, immature ostracods in core 7, and foraminifers, brachiopods and conodonts in core 11 at 4,920 feet.

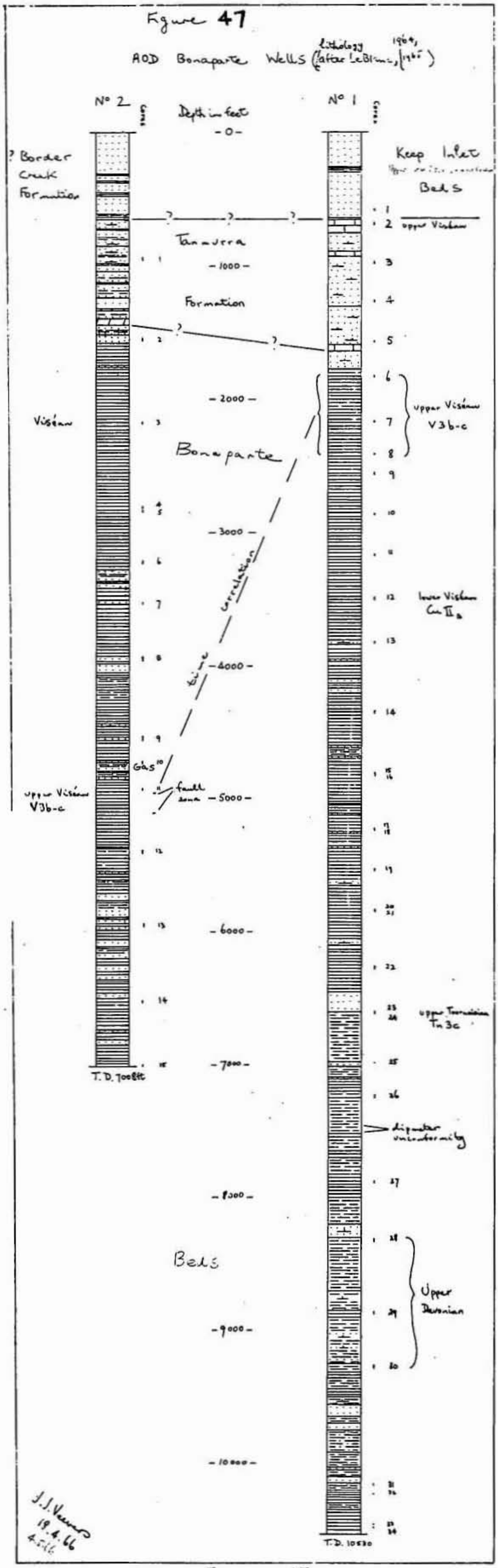


Figure 47
AOD Bonaparte Wells (lithology after LeBlanc, 1964, 1965)
No 2
No 1
Depth in feet
-0-
-1000-
-2000-
-3000-
-4000-
-5000-
-6000-
-7000-
-8000-
-9000-
-10000-
? Border Creek Formation
Keep Inlet Beds
upper Viséan
Tanmurra Formation
Viséan
Bonaparte Beds
Upper Viséan V3b-c
time correlation
Gas
fault zone
upper Viséan V3b-c
lower Viséan Cu IIa
upper Tournaisian Tn3c
dipmeter unconformity
Upper Devonian
T.D. 7008ft
T.D. 10530
J.J. Veevers 19.4.66

Figure 47

Age

The Bonaparte Beds range in age from Upper Devonian (probably Famennian) to Lower Carboniferous (upper Visean). Le Blanc (1964) reports a dipmeter unconformity between 7,472 and 7,520 feet in Bonaparte No.1 Well which may represent a break between the Devonian and Carboniferous. The rocks immediately on either side of the dipmeter unconformity are barren and it cannot be dated precisely. The nearest dated rocks are Upper Devonian rocks in core 28 (8,310 feet) and Lower Carboniferous rocks in core 24 (6,610 feet), so that the interval between these cores is thick enough to contain a conformable Devonian - Carboniferous sequence.

The Bonaparte Beds in Bonaparte No.1 Well are dated as follows: cores 6 to 8 (1,840 - 2,410 feet) upper Visean (V3b-c) from foraminifers; core 12 (3,500 feet) lower Visean ($CuII_{\delta}$) from conodonts; core 24 (6,610 feet) upper Tournaisian (Tn3c (lower)) from foraminifers; and core 28 (8,310 feet) Upper Devonian from pelecypods.

In Bonaparte No.2 Well conodonts in core 3 (2,170 feet) suggest a Visean age, and foraminifers date core 11 (4,920 feet) as upper Visean (V3b-c).

Correlation

The upper Visean foraminifers and ostracods show that the interval between cores 6 and 8 (1,840 - 2,410 feet) in Bonaparte No.1 Well is equivalent to core 11 (4,920 feet) in Bonaparte No.2 Well. This probably means that, if the rate of deposition was uniform, there is about 2,600 feet of shale immediately beneath the Tanmurra Formation in Bonaparte No.2 Well which is not represented in Bonaparte No.1 Well because of an unconformity beneath the Tanmurra Formation. Alternatively, the extra section could have been deposited in a faster-sinking area contemporaneously with the shale above core 6 in Bonaparte No.1 Well; or, as discussed in the Tanmurra Formation, it could be laterally equivalent to the Tanmurra Formation in Bonaparte No.1Well (in which case the rocks between 608 and 1,577 feet, identified as Tanmurra Formation, in Bonaparte No.2 Well would be younger than the Tanmurra Formation).

The same upper Visean foraminiferal fauna has been recognised in the upper parts of the Milligans Beds in Milligans No.2 Bore at Milligans Hills.

The lower to middle Visean Utting Calcarenite is equivalent to shale around core 12 in Bonaparte No.1 Well (Fig.32).

The Bonaparte Beds contain sediments equivalent to most of the Famennian to upper Visean parts of the outcropping succession, namely the Ningbing Limestone, the Buttons Beds, the Burt Range Formation, the Enga Sandstone, the Septimus Limestone and the Zimmermann Sandstone (Fig.32). Whether the Bonaparte Beds are complete or contain numerous hiatuses cannot be determined because of limited palaeontological data. The question may, however, be settled by the microflora being studied by G.Playford.

The drills have not penetrated deeply enough in the centre of the basin to reach the equivalent of the Cockatoo Formation, if it exists here; when and if it is penetrated we expect it to be a dark shale, siltstone and sandstone continuous with the Bonaparte Beds.

TANMURRA FORMATION

The Tanmurra Formation is the name given by Le Blanc (1964, unpublished) to the carbonate and sandstone between 638 and 1,630 feet in Bonaparte No.1 Well drilled by Alliance Oil Development Australia N.L. 16 miles east-north-east of Ningbing Station. He defined the formation as follows:

> 'The formation consists of an upper carbonate unit (86 feet), a medial sandstone unit (84) feet), and a basal carbonate unit (65 feet).
> The upper carbonate unit is buff to medium grey, sandy and silty, medium grained oolite which grades downwards to very sandy, slightly oolitic, coarse grained calcirudite, thence to a slightly arenaceous, very fine grained to fine grained calcarenite.
> The medial sandstone unit consists predominantly of white to medium grey, very fine grained to medium grained, angular, quartz sandstone with good intergranular porosity. The sandstones which are calcareous in the upper part of the unit, become dolomitic towards the base. Interbeds of micro-crystalline and very finely crystalline silty and sandy limestone and of recrystallised calcarenite are common near the top of the unit. In the lower part of the unit interbeds of dolomite, consisting of altered crinoidal, bioclastic and fragmental carbonates, are common and locally the sandstone may contain as much as 40 percent of dolomitic carbonate matrix. Medium grey, calcareous siltstone is present between 830 feet to 860 feet and as thin interbeds elsewhere in the unit.
> The lower carbonate unit is a light brown, very fine grained to fine grained sandy calcarenite, which is in part pelletoidal'.

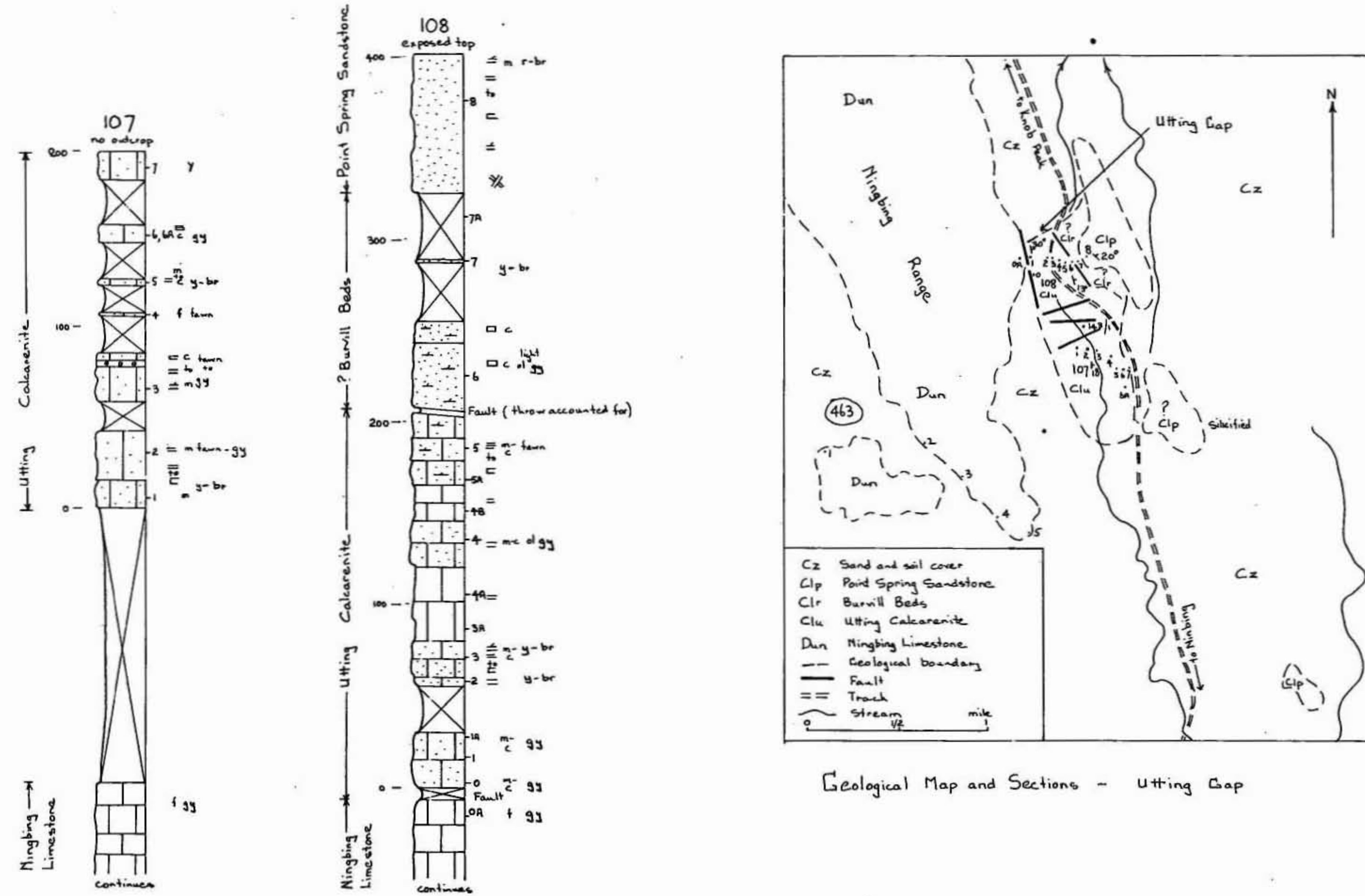
There is gradational contact with the underlying Bonaparte Beds and the base of the lower carbonate is chosen as the base of the formation (Fig.47). Loughnan (Appendix 1) has also noted a distinct mineralogical break at this boundary.

The Tanmurra Formation is unconformably overlain by 622 feet of medium to coarse-grained sandstone identified as Keep Inlet Beds because a silty shale between 250 and 295 feet contains Upper Carboniferous to Lower Permian spores (Evans, pers.comm.), and a sandstone between 295 and 390 feet contains up to 20% of coloured mineral grains and lithic fragments.

In Bonaparte No.2 Well, drilled 5 miles south-south-west of Bonaparte No.1 Well, a sequence of sandstone, dolomite, siltstone and shale between 608 and 1,577 feet is identified as Tanmurra Formation (Le Blanc, 1965, unpublished). The section is dominantly calcareous sandstone with thin interbeds of shale, siltstone and dolomite; it contains less carbonate than the type section (Fig.47).

Le Blanc noted the abrupt contact with the underlying Bonaparte Beds in contrast to the gradational contact in Bonaparte No.1 Well, and thought that it might indicate an unconformity. Palaeontological evidence, on the other hand, indicates that the unconformity is more likely to be between the Tanmurra Formation and the Bonaparte Beds in Bonaparte No.1 Well. Foraminfers in core 11 at 4,920 feet in Bonaparte No.2 Well are the same as those in the interval between cores 6 and 8 (1,840 - 2,410 feet) in Bonaparte No.1Well, which means that there is

Fig. 48



Geological Map and Sections - Utting Gap

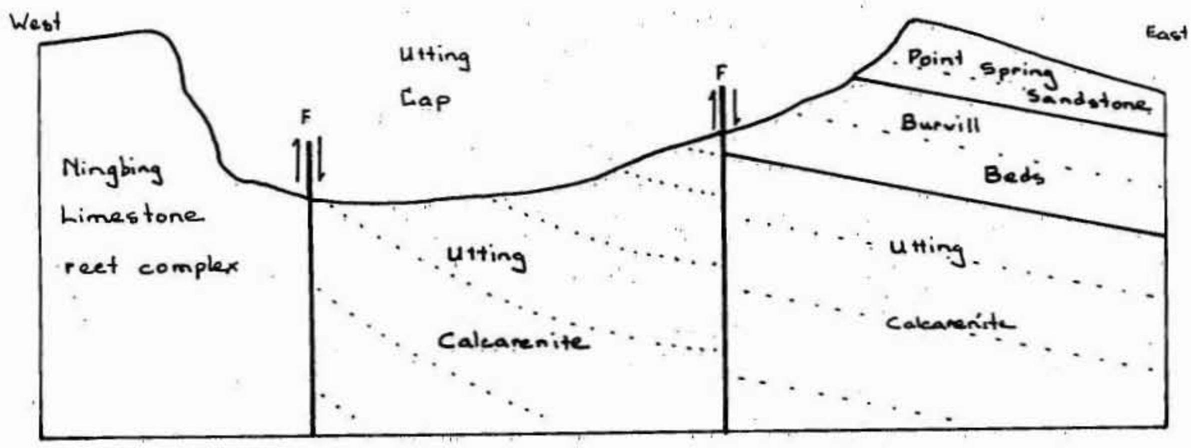
John Roberts
24.11.65
28.3.66
5.5.66

Fig. 48

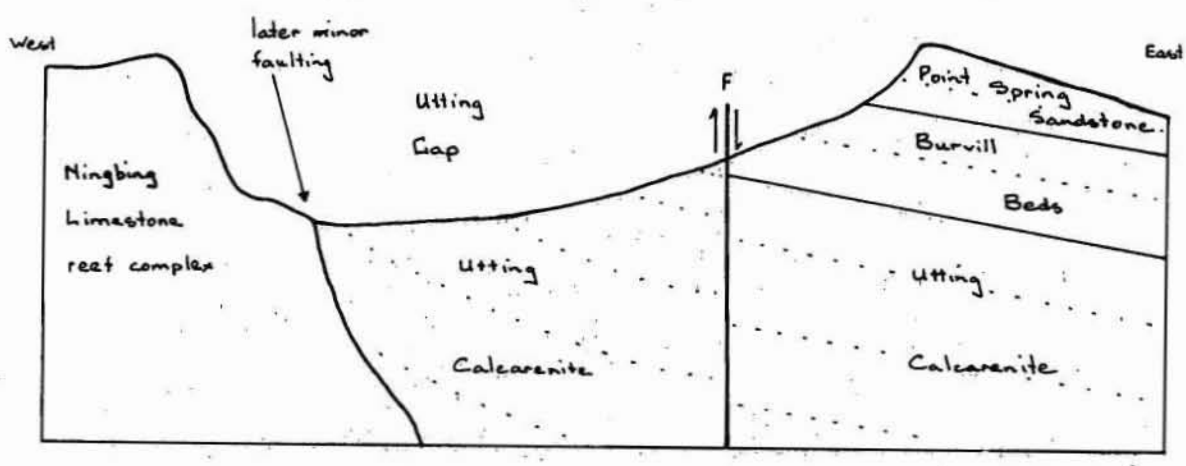
Fig 49

Diagramatic cross sections showing the possible relationships between the Utting Calcarenite and the Ningbing Limestone at Utting Gap.

A Faulted



B Abutment



John Roberts
20.3.66
3.5.66

Fig. 49

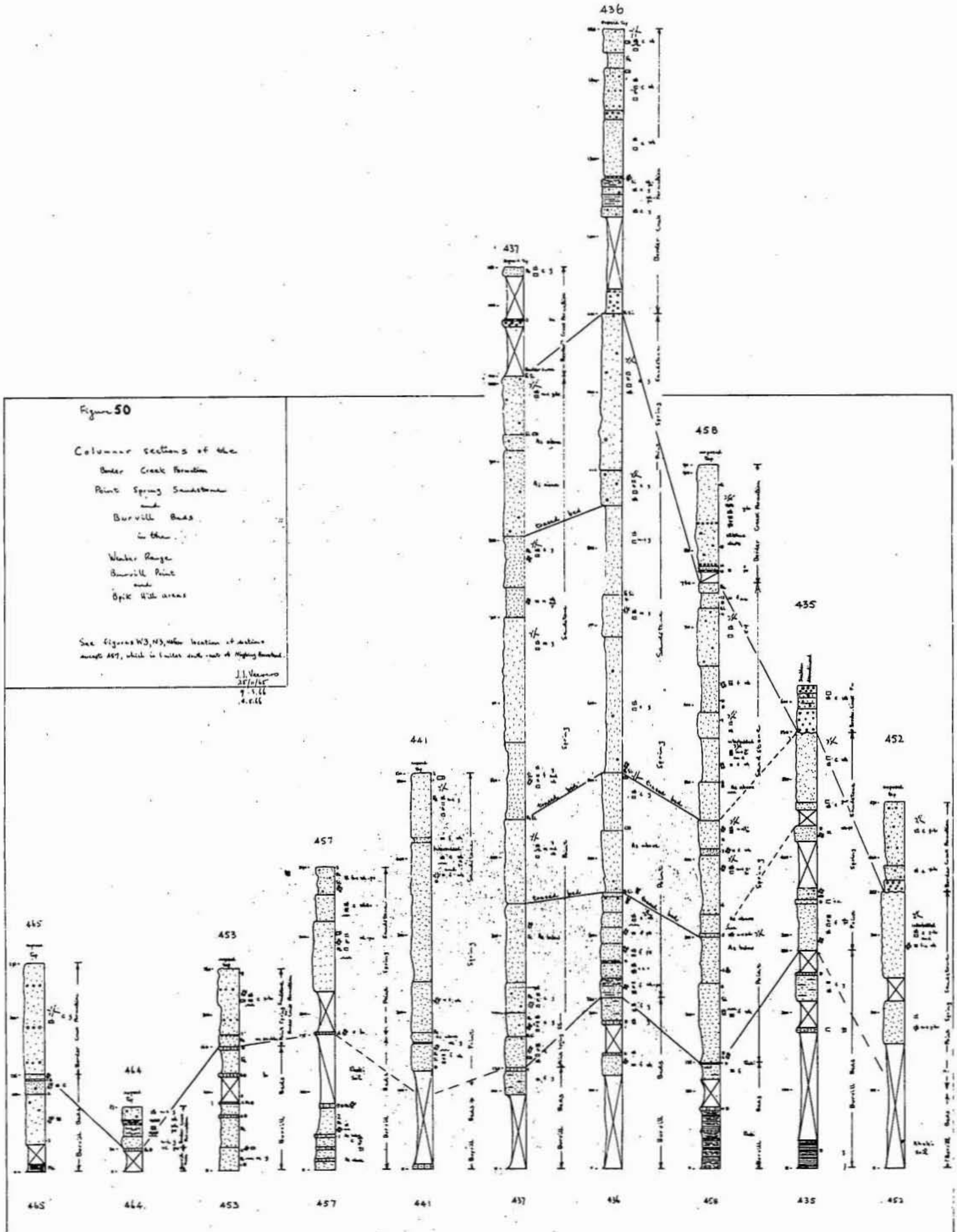


Figure 50
Columnar sections of the
Border Creek Formation
Point Spring Sandstone
and
Burvill Beds
in the
Walter Range
Burvill Point
and
Öpik Hill areas
See figures W3, N3, for location of sections except 457, which is 5 miles south-east of Mt. ...
J.J. Veevers
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436
437
458
435
441
452
457
465
464
453

Figure 50

which is dated as lower to middle Visean ($CuII_{\delta}$ - $CuIII_{\alpha}$).

UTTING CALCARENITE (new name)

Utting Calcarenite is the name given to the carbonate cropping out at the head of the velley between the Ningbing Range and the northern extension of the Weaber Range (Fig.48). It is also found at an isolated outcrop 3 miles to the south near Tanmurra Creek (see Plate 1). In the type area (Fig.48) the formation is probably faulted against the Devonian Ningbing Limestone; the lower part of the formation is exposed as isolated ribs of carbonate, and the upper part crops out as benches beneath the Burvill Beds and Point Spring Sandstone, and has a faintly layered pattern on the air photographs.

The formation is named after Utting Gap (Fig.48), a divide between drainage running north on to mud flats and that running into tidal channels at the false mouths of the Ord River in Cambridge Gulf.

E.P.Utting (pers.comm.) was the first to examine the calcarenite and sent a collection of fossils for identification to G.A.Thomas. Thomas (1965b) reported that the fauna was younger than that in the Septimus Limestone, but older than that in the Point Spring Sandstone (the lower and most fossiliferous part of which is divided off and is now called the Burvill Beds).

Type section

The type section, section 108, is measured across Utting Gap from the edge of the Ningbing Limestone to the western scarp of a small butte (Fig.48). The geographic co-ordinates of the base of the section are Lat.14°58'S, Long.128°56'E. The lowermost beds in the section are thought to be faulted against the Ningbing Limestone because the contact between the formations is oblique to the strike and is slightly ferruginised; the dip of the calcarenite steepens towards the contact. Additional evidence to support faulting against the Ningbing Limestone is found south of the type section, where the beds near the Ningbing Range are drag folded.

It is possible, however, that the gross relationship between the Utting Calcarenite and the Ningbing Limestone is an abutment unconformity (Fig.49) and that the faulting is a later and rather minor adjustment feature of a major fault along the eastern side of the Ningbing Range.

The Utting Calcarenite is a coarse to medium-grained grey, yellow-brown and fawn, skeletal sandy calcarenite. It is usually thin to medium-bedded, is sometimes cross-bedded or laminated, and contains abundant silicified fossils.

In section 108 the overlying Burvill Beds are faulted against the calcarenite, but to the southeast of the section line the contact seems to be conformable. The throw on the fault has been accounted for in the columnar section (Fig.48).

Fossils indicate that the rocks in section 107, half a mile to the south, are slightly older than those in the type section. The two sections cannot be linked because of transverse faults and drag folds in the intervening area. The rocks in section 107 are thin-bedded, yellow, brown or grey, sandy calcarenite, and crop out as isolated ribs; between the ribs are probably softer beds of shaley carbonate.

The thickness of the type section is 200 feet, and that of the formation is estimated as more than 400 feet.

Age

Thomas (1965b) described a new species, Delepinea uttingi, from the Utting Calcarenite and concluded that it was closest to two species from the early Visean in Belgium, Britain and Ireland. He regarded the fauna associated with D. uttingi as indicative of the early Visean.

Conodonts have confirmed Thomas' determination and date the calcarenite as lower to middle Visean (CuII γ to CuIIIα).

Environment

The Utting Calcarenite was deposited on a shallow shelf area on the western side of the deeper central part of the basin in an environment similar to that of the Septimus Limestone. Terrigenous sediments deposited on the shelf presumably came from the west or southwestern margins of the basin and were sandy, and in one place pebbly. The shelf supported a rich fauna of brachiopods, tabulate and rugose corals, the latter up to 3 inches across and 9 inches long, foraminifers, ostracods, conodonts and sharks. The sharks have been identified by J.G.Tomlinson as Psammodus sp. and ?Ctenacanthus sp.

SUCCESSION IN THE WEABER RANGE

Traves (1955, p.78) defined the Point Spring Sandstone as the 'sandstone and other sediments which crop out in the Weaber Range'. Later work has shown that Traves' Point Spring Sandstone is composite and consists of three stratigraphical units, which, in descending order, are:

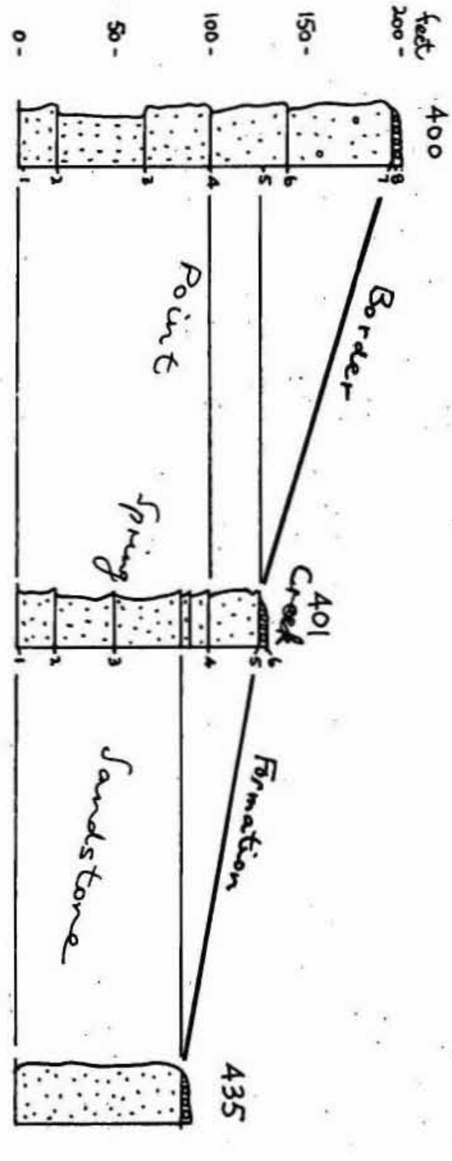
Border Creek Formation
Point Spring Sandstone
Burvill Beds

The Burvill Beds and Point Spring Sandstone are conformable, and the Border Creek Formation disconformably overlies the Point Spring Sandstone and the Burvill Beds. The Point Spring Sandstone is the only one of these units that is completely exposed; the base of the Burvill Beds is covered, and the top of the Border Creek Formation is covered or eroded. The Burvill Beds are exposed in the scarp of the Weaber Range, which is a cuesta, and the Point Spring Sandstone and the Border Creek Formation are exposed in the dissected dip slope. The Burvill Beds and the Point Spring Sandstone are fossiliferous and their age is known. The Border Creek Formation is barren except for poorly preserved plants, and its age is known only by reference to superposition.

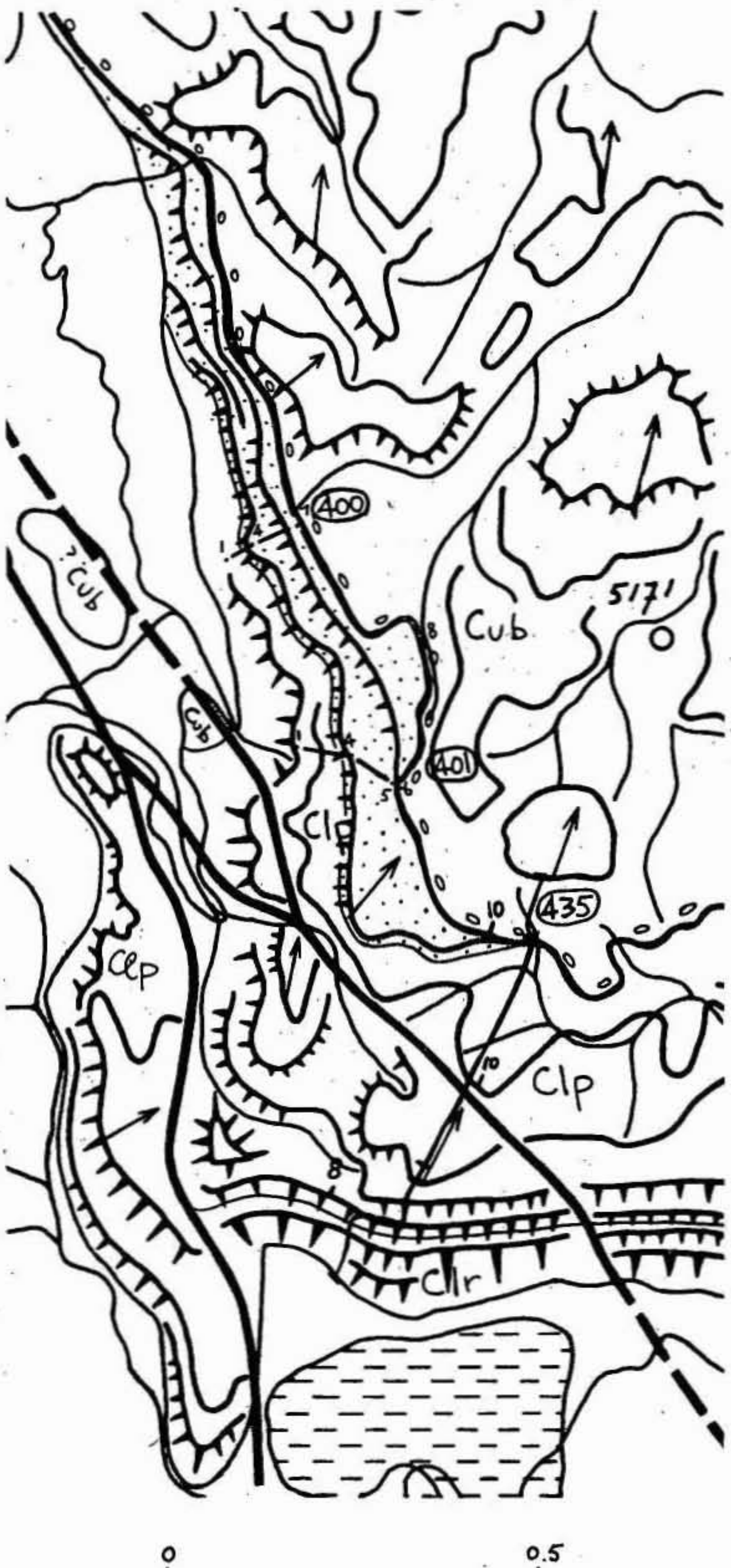
BURVILL BEDS (new name)

The Burvill Beds are defined as the sequence of sandstone, shale, and interbedded sandy limestone that is conformably overlain by the Point Spring Sandstone or disconformably overlain by the Border Creek Formation in the Weaber Range. The interval 0-160 feet in section 453 (Fig.50) at Point Burvill, one mile east of Ningbing Homestead, is designated type. The co-ordinates of its base are Lat.15°15½'S, Long.128°41'E. The Burvill

Figure 51



B. Columnar sections showing stratigraphic relationships.



Cub – Border Creek Formation

Clp – Point Spring Sandstone

Clr – Burvill Beds

A. Geological map of part of the Weaber Range. See Figure 52 for location.
Adapted from air-photo interpretation of KRS Run 5 No. 5171 by R. Richard (I.F.P.).
Stippling indicates that part of Clp locally overlapped by Cub.

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Figure 51

Beds extend in discontinuous outcrop along the scarp of the Weaber Range from Utting Gap to the state border (section 452). The only outcrops of the Burvill Beds known outside the Weaber Range are at Milligans Hills. The interval 0-280 feet in section 435 is the thickest measured section of the Burvill Beds.

The type section (interval 0-160 feet of section 453) consists dominantly of coarse-grained ferruginous quartz sandstone with minor interbedded sandy limestone, locally ferruginized. Part if not all of the covered interval between 87 and 120 feet consists of shale, as indicated by patches of loamy soil. Pelecypods, brachiopods, gastropods, and trace fossils are common. The overlying Point Spring Sandstone or Border CreekFormation is locally ferruginized, and contains a bed of conglomeratic sandstone overlain by cross-bedded pebbly sandstone with trace fossils.

Sequences of the Burvill Beds like the type are found in section 465, near Öpik Hill, which contains a ferruginous shale at its base, and in section 457, 5 miles south-east of Burvill Point. East of PointSpring, the coarse sandstone of the Burvill Beds is replaced by poorly exposed calcareous shale which weathers khaki, and fine-grained calcareous sandstone, best seen at the base of section 458 (Fig.52), 3½ miles east-north-east of Point Spring. The distinctive feature of the Burvill Beds, regardless of whether its dominant component is coarse sandstone or shale, is its sandy limestone. Grey where fresh and red-brown where ferruginized, this limestone contains abundant sub-rounded very coarse sand grains or granules of lustrous quartz which impart a distinctive 'porphyritic' texture to the limestone. The limestone 'groundmass' consists of finer angular quartz grains and broken fossils cemented by recrystallized, partly dolomitic, limestone. In the field, this rock was called calcareous grit.

Among the abundant fossils in the Burvill Beds, brachiopods and trace fossils are widespread, and pelecypods are almost restricted to the coarse sandstone at the north-western part of the outcroppingBurvill Beds. Conodonts were found in section 435.

The only outcrops of Burvill Beds found in front of the Weaber Range are locality 5/2 (Fig.26), 1 mile south of Ningbing Homestead, and locality 306, ½-mile east of Ningbing. Locality 5/2 is a low isolated outcrop, discovered by E.P.Utting (pers.comm.), of very coarse calcareous sandstone which contains abundant rugose corals and bryozoans as well as brachiopods. At locality 305, 1½ miles north-east of Ningbing, a similar outcrop with the same fossils is overlain by Point Spring Sandstone. At locality 306, ½ mile east of Ningbing Homestead, ferruginized limestone with pelecypods and brachiopods, and sandstone apparently lie beneath section 453. As mentioned above in the description of the Ningbing Limestone, locality 5/2 lies only a few hundred yards east of the eastern edge of the outcropping Ningbing Limestone, but erratic dips in this area obscure the relationships between the Burvill Beds and the Ningbing Limestone. The correlation of the Burvill Beds with the basal pebbly sand of the Waggon Creek Breccia indicate that the Burvill Beds are a basal transgressive deposit that unconformably overlies the Ningbing Limestone.

At Milligans Hills the Burvill Beds consist of brown, coarse-grained, (gritty) calcareous sandstone and sandy limestone (Fig.46). Section 147, measured on the westernmost hill (Fig.31), consists of 75 feet of fossiliferous calcareous sandstone and limestone (Burvill Beds) overlain by sandstone and conglomerate of the Border Creek Formation. Section 148, measured on the easternmost hill, contains fine to medium-grained sandstone at the base overlain by fossiliferous limestone and calcareous sandstone, in turn overlain by ferruginised limestone and sandstone. Section 148 appears to be continuous with that in Milligans No.1 Bore, drilled only a quarter of a mile from the 148 section line.

Fauna and age

The Burvill Beds contain a rich fauna of brachiopods and gastropods as well as ostracods and conodonts.

G.A.Thomas (1962, p.731) listed a fauna from Point Spring and Milligans Hills and suggested it was Visean to Namurian. At this time (1962) the Burvill Beds were not separated from the Point Spring Sandstone and it is likely that the plants listed by Thomas came from the Point Spring Sandstone (sensu stricto). The remainder of the fossils in his list from near Point Spring probably came from the rocks we now callBurvill Beds. The fossils from Milligans Hills are in the Burvill Beds.

Conodonts from the Weaber Range (section 435) indicate an age of not older than upper Viséan ($CuIII_{\beta}$) and possibly as young as Namurian.

Correlation

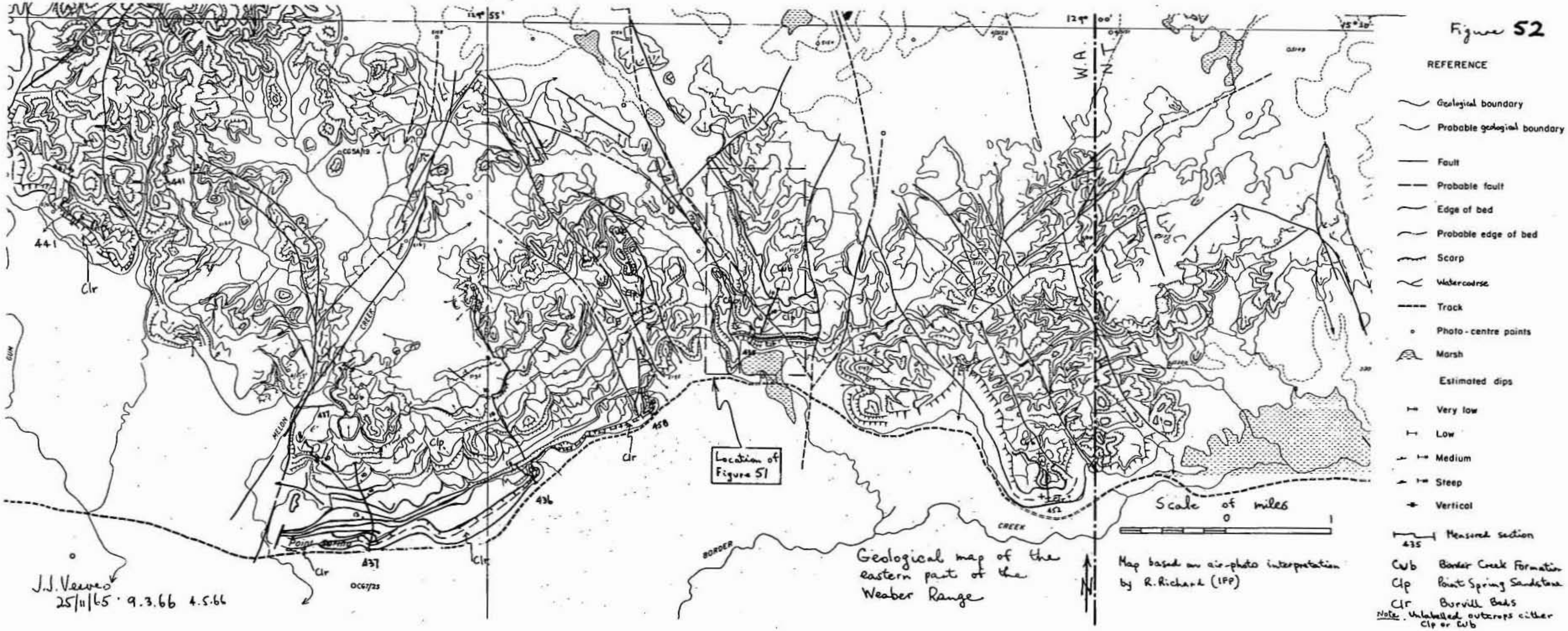
According to these determinations the Burvill Beds are equivalent to the lower part of the Tanmurra Formation in Bonaparte No.1 Well (Fig.32); as yet no correlation based on common species can be made between the two formations.

POINT SPRING SANDSTONE

Noakes et al. (1952, p.101) introduced the name Point Spring Sandstone for the sandstone at Point Spring, divided it into lower marine beds with brachiopods, overlain by upper lacustrine beds with plants, and regarded it as Permian. As noted already, Traves (1955, pp.78, 79) defined the Point Spring Sandstone as the 'sandstone and other sediments which crop out in the Weaber Range'. He quoted descriptions of two sections from an unpublished report by F.Reeves. We identify the interval 0-235 feet of Reeves' measured section east of Ningbing as Burvill Beds, and the overlying interval from 235-355 feet as Point Spring Sandstone. Reeves' other section, 4 miles north-west of the state boundary, corresponds with our section 435; the interval 0-250 feet in Reeves' section is identified as Burvill Beds, 250-400 feet as Point Spring Sandstone, and 400-450 feet (top of the section) as Border Creek Formation. With some reservations, Traves also regarded the Point SpringSandstone as Lower Carboniferous, probably Visean or Namurian, and this we have confirmed.

The Point Spring Sandstone is re-defined as the sheet of quartz sandstone that conformably overlies the Burvill Beds and is disconformably

Figure 52



Geological map of the eastern part of the Weaber Range overlain by the Border CreekFormation in the Weaber Range. The type section, not hitherto designated, is the interval 135-760 feet in section 458 (Fig.50), 4 miles north-east of Point Spring (Fig.52). The co-ordinates of the base of the type section are Lat.15°$23\frac{1}{2}$'S, Long.128°$56\frac{1}{2}$'E. The interval 220-1100 feet (890 feet) in section 436 is the thickest known Point Spring Sandstone.

The type section and other sections of the Point Spring Sandstone consist of an alternation of jointed and cross-bedded medium to coarse yellow to white quartz sandstone and laminated to thin-bedded fine quartz sandstone with abundant trace fossils. In many parts of the Weaber Range, in particular in the type area, the jointed and cross-bedded sandstone, like similar sandstone in the Cockatoo Formation, is etched into characteristic castle-like outcrops which on the ground and in the air photographs are readily distinguished from the associated thin-bedded sandstone. The regular alternation of these contrasting sandstones limits the scope of air-photo interpretation in the Weaber Range; where continuity of outcrop is broken by faults or by cover, as in the type area, the absence of reliable markers in the Point Spring Sandstone rules out positive identification. The best link between sections is the boundary between the Burvill Beds and the Point Spring Sandstone, and in many places this boundary is obscure in the air photographs. Moreover, even in a small area, most beds are hard to trace because of rapid lateral change, as shown in sections 437, 436, and 458 (Fig.50). Some beds are traceable between these sections, but many beds do not persist from one section to another.

The jointed and cross-bedded sandstone is coarse, with rare pebbles of quartz and quartzite. Like similar sandstone in the Cockatoo Formation, it is friable. The thin-bedded sandstone is firmer, and contains numerous silicified or ferruginized 'hard-grounds', which, because of their good exposure, are valuable local markers.

The Point Spring Sandstone abounds in minor sedimentary structures. Of the inorganic ones, cross-bedding is the commonest, followed by ripple-mark, and contorted bedding. Organic structures (trace fossils) are abundant in the thin-bedded sandstone.

Fossils (brachiopods, pelecypods, and plants) are most abundant near the base of the Point Spring Sandstone, but, as shown by the type section, extend almost to the top, showing that much if not all of it is marine.

Fauna and age

The Point Spring Sandstone contains brachiopods, pelecypods and plants. Two distinct brachiopod faunas have been collected: at the base of the formation the fauna is more or less the same as that in the underlying Burvill Beds and is thought to be uppermost Visean to lowermost Namurian in age; the upper fauna, from locality 458/12 at the top of the sandstone, is probably Namurian.

Correlation

According to these determinations the Point Spring Sandstone is equivalent to the upper part of the Tanmurra Formation in Bonaparte No.1 Well (Fig.32); as yet no correlation based on common species can be made between the two formations.

The Border CreekFormation, originally named by E.P.Utting in an unpublished report, is defined as the sequence of quartz sandstone, pebbly quartz sandstone, conglomerate, and siltstone that disconformably overlies the Point Spring Sandstone and Burvill Beds in the Weaber Range. The top of the Formation is eroded or covered. Theinterval 1100-1465 feet of section 436 (Fig.50) is designated type; it is the thickest measured section. The co-ordinates of the base are Lat.$15^{o}23\frac{1}{2}'$S, Long.$128^{o}55'$E. The Border Creek Formation in the Burt Range Syncline is described elsewhere, and this description applies to the Weaber Range only.

The type section contains three beds of poorly exposed conglomerate with rounded pebbles and cobbles of vein quartz and quartzite, and rare fragments of siltstone and sandstone. White or purple siltstone is a minor but distinctive part of the Border CreekFormation forming a curious association with the conglomerate. In section 458, siltstone is the basal bed of the Border Creek Formation, and much of it was later eroded to form fragments up to 6 inches long in the overlying conglomerate and sandstone. The siltstone and siltstone breccia of the Border Creek Formation are its most distinctive components. The jointed and cross-bedded coarse quartz sandstone of the Border CreekFormation is indistinguishable from that of the Point Spring Sandstone.

Silicified fine white and purple silty sandstone contains Phyllotheca-like plants at 1275 feet in section 436. This is the only fossil found in the Border CreekFormation in the Weaber Range.

The top of the Point Spring Sandstone is locally channelled to a depth of several feet and filled with the basal conglomerate of the Border CreekFormation. Between section 436, which contains 890 feet of Point Spring Sandstone and section 435, which contains 280 feet, the relief of the disconformity is 610 feet in a distance of $2\frac{1}{2}$ miles. In the Öpik Hill area of the north-west Weaber Range, the entire Point Spring Sandstone is thought to have been eroded, and the Border Creek Formation overlies the Burvill Beds.

An isolated outcrop of claystone and conglomerate of locality 72, 9 inches south of Bonaparte No.1 Well, is identified as Border Creek Formation.

Age and relationships

As mentioned above, the only fossil known from the Border Creek Formation is a Phyllotheca-like plant which probably indicates Carboniferous or Permian. Because it disconformably overlies the Visean Point Spring Sandstone, the Border Creek Formation is younger than Visean; and, as described below, because the Border Creek Formation is overlain by the Lower Permian Keep Inlet Beds, it is older than Permian; hence its age is Upper Carboniferous.

Occurrences of the Burvill Beds, Point Spring Sandstone, and Border Creek Formation outside the Weaber Range

The Burvill Beds and the Point Spring Sandstone, on the one hand, are distinctive units which can be readily identified in outcrops

Geological sketch maps and sections of offshore islands

Figure 53

Cub – Border Creek Formation

J.J. Veevers 26.11.65 9.3.66 4.5.66

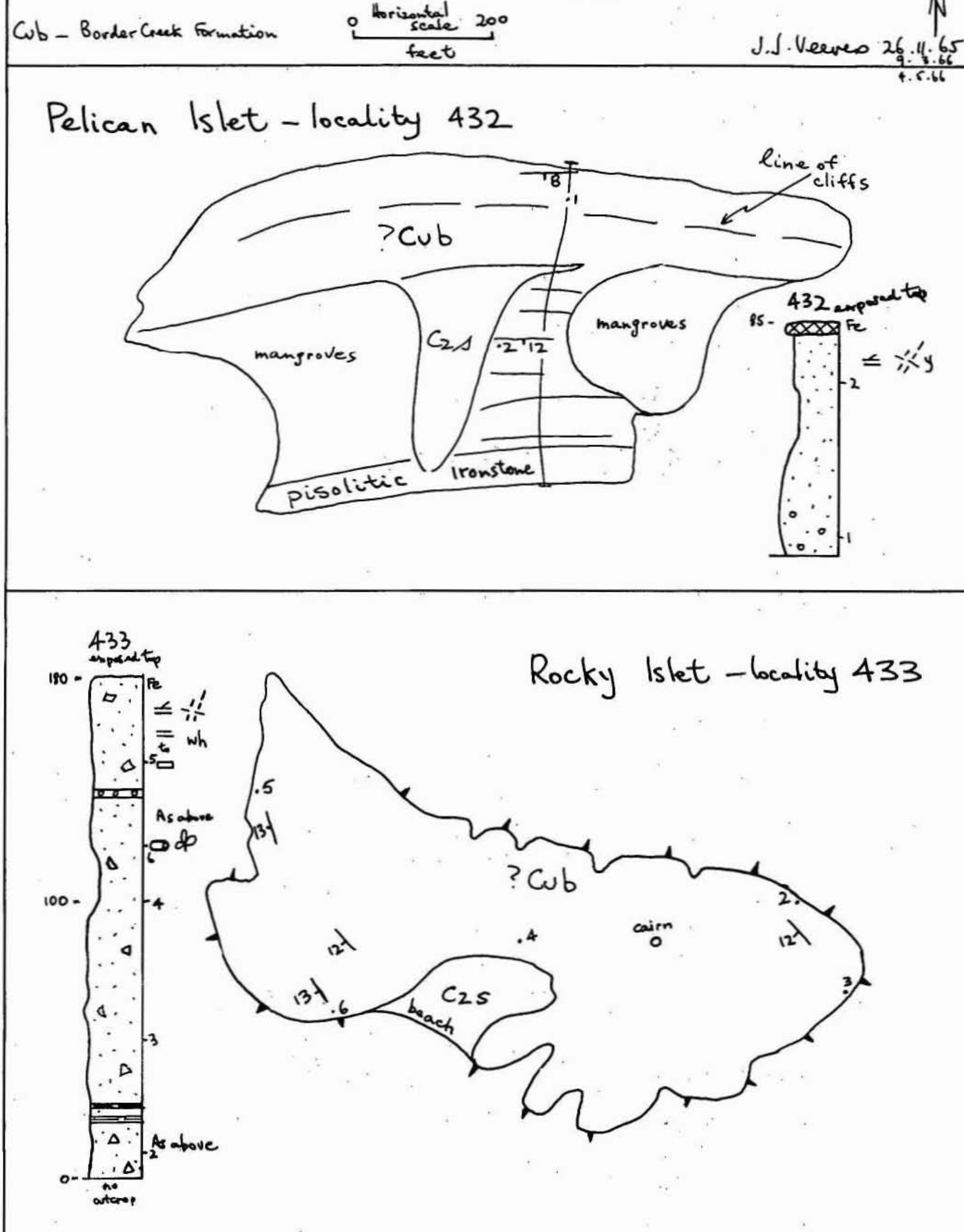


Fig. 53

outside the Weaber Range. On the other hand, the Border Creek Formation, lying disconformably above older units and having its top eroded or covered, is less positively identified in other areas. All these occurrences are in the Burt Range Syncline, and are described on pp. 72 - 74.

The offshore islets contain a sequence similar to that of the Border Creek Formation and are appropriately described here. This of course is not meant to imply that the two sequences are equivalent.

Offshore islets (Fig.53)

Rocky Islet (Lat.14°43½'S, Long.128°38'E) and Pelican Islet (Lat.14°46½'S, Long.128°47'E) are situated in the southern part of Joseph Bonaparte Gulf 5 miles from the shore. As a guest of Anacapa Oil Corporation, Veevers accompanied W.Jauncey on a brief visit by boat to the islets in July 1965.

Rocky Islet

A south-westward dipping sequence roughly 180 feet thick was measured across Rocky Islet, and consists dominantly of cross-bedded silicified micaceous silty quartz sandstone commonly with fragments of white siliceous siltstone ranging in size from a fraction of a millimetre to platy breccia fragments exceptionally 20 inches long. Sandstone near the exposed base contains blocks of banded siltstone 3 feet long and 18 inches wide. White siltstone is interbedded with the sandstone 25 feet above the base. A thin bed of conglomerate, with pebbles of quartzite, crops out at 140 feet. Phyllotheca-like plants, probably indicating Carboniferous or Permian, were found at locality 433/6, and this is the only fossil known from the islets.

Pelican Islet

A south-dipping sequence roughly 85 feet thick was measured across Pelican Islet, and consists of cross-bedded yellow micaceous silty quartz sandstone with pebble bands at the exposed base. The sequence, like that on Rocky Islet, is deeply weathered, and is capped by 5 feet of pisolitic ironstone.

The relationships of the sequences in Rocky and Pelican Islets to each other and to the rest of the Bonaparte Gulf Basin are unknown. Within the interval Carboniferous to Permian the islet sequences resemble parts of the Border Creek Formation and parts of the Permian sequence of the Port Keats area. The resemblance between the Rocky Islet sequence and the Border Creek Formation is strengthened by the occurrence in both of Phyllotheca-like plants. Further evidence provided by structure is discussed below.

Outliers of barren sandstone in the Pretlove Hills and Ningbing Range

At locality 67/1, on the north-eastern edge of the Pretlove Hills, 4 miles west of the Jeremiah Hills, 70 feet of horizontal barren medium-bedded buff silicified quartz sandstone unconformably overlie tilted quartz sandstone of the Cockatoo Formation. Conical outcrops of silicified sandstone at the foot of the north-eastern part of the Pretlove Hills and an outcrop south-east of No.8 Tank are probably the same unit.

An outcrop of white silicified sandstone that unconformably overlies the Ningbing Limestone at locality 17/3, south of Tanmurra Creek (Fig.28), is also probably the same unit. This outcrop consists of tumbled blocks only and its unconformable relations with the underlying limestone are indicated by its occupying a depression in the limestone.

All these outcrops are mapped tentatively as Point Spring Sandstone. A second possibility is that they are a non-calcareous part of the Burvill Beds.

BORDER CREEK FORMATION IN THE BURT RANGE SYNCLINE

The Border Creek Formation is the youngest rock unit in the Burt Range Syncline and comprises the sandstone, siltstone and conglomerate capping the Central Burt Range, Mt.Septimus, Milligans Hills and the western part of Spirit Hill. An isolated outcrop of Border Creek Formation has been mapped at the southern margin of the Burt Range Amphitheatre (Fig.31).

In the Burt Range Syncline theBorder Creek Formation is expressed as high cliffs of jointed sandstone and conglomerate separated by deep undercuts exposing soft siltstone. In the air photographs the formation is well layered, and in the southern part ofthe Central Burt Range and the western part of Spirit Hill the sandstone exhibits a strong system of joints and is weathered into beehive-shaped turrets.

Border Creek Disconformity

The Border Creek disconformity is recognised throughout the Burt Range Syncline; the Border Creek Formation disconformably overlies the Burvill Beds, the Milligans Beds, the Septimus Limestone, the Zimmermann Sandstone and the Enga Sandstone (Fig.55). Figure 55 shows that erosion was greater on the flanks, particularly the eastern flank, than in the central part of the syncline, where part of the Zimmermann Sandstone was preserved. In the Weaber Range the greatest thickness of Point Spring Sandstone, which underlies the Border CreekFormation, is in the middle of the range and may also mark the axis of a syncline (Fig.55).

Erosion before the deposition of the Border Creek Formation in the southern Central Burt Range deeply channelled the Zimmermann Sandstone and completely stripped the formation from the northern part of the range, exposing the Septimus Limestone. The northernmost part of the Zimmermann Sandstone appears to have been truncated by a channel in the erosion surface, which was later filled by the basal sandstone of the Border Creek Formation (Fig.43). The contact between the Zimmermann Sandstone and the Border Creek Formation in the channel is obscured by talus. Figure 43 shows the jointed sandstone bed overlying the thinly bedded Zimmermann Sandstone rapidly thickening so that the sandstone of the Border Creek Formation rests against the eroded side of the Zimmermann Sandstone. This could be interpreted as a lateral change from a deposit of well-sorted, fossiliferous, fine-grained sandstone to a contemporaneous channel deposit of poorly sorted, barren, coarse-grained sandstone. However, because the

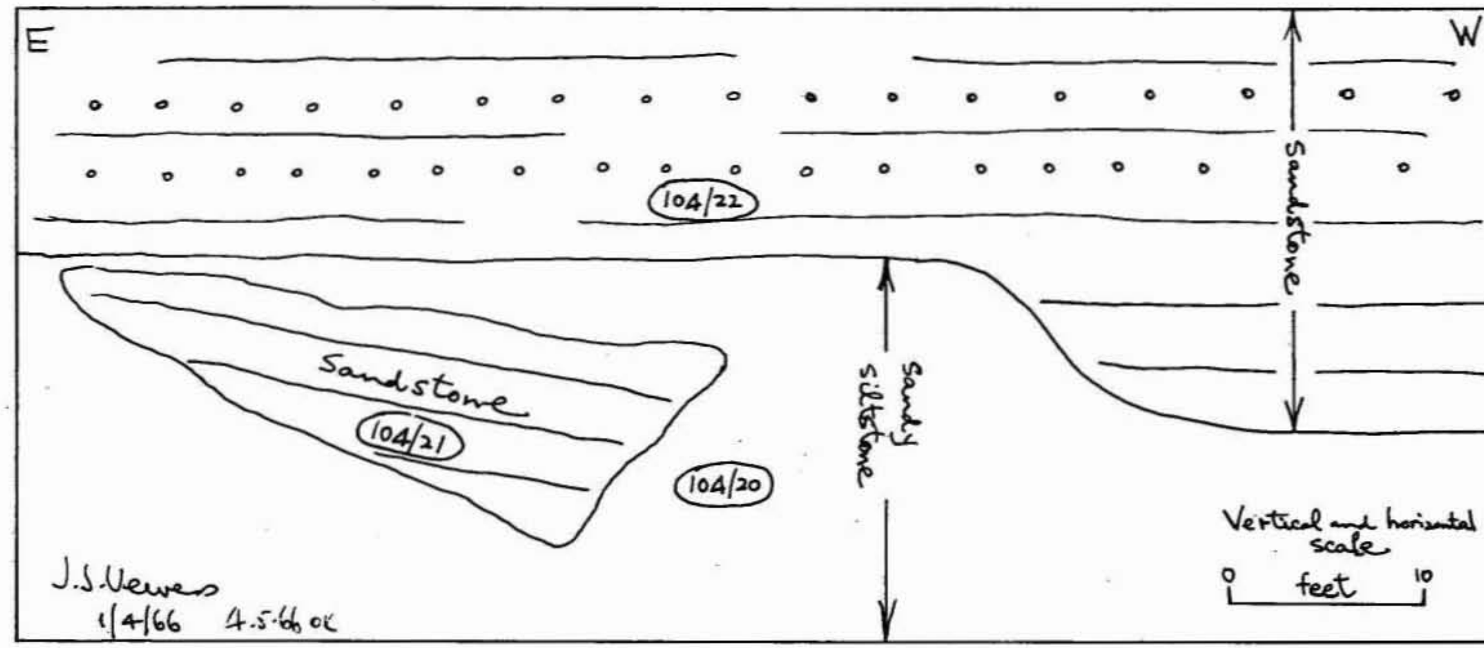


Fig. **54** — Sketch section at locality 104/20-22, Mount Septimus, showing cut-and-fill sandstone structures in sandy siltstone of the Border Creek Formation.

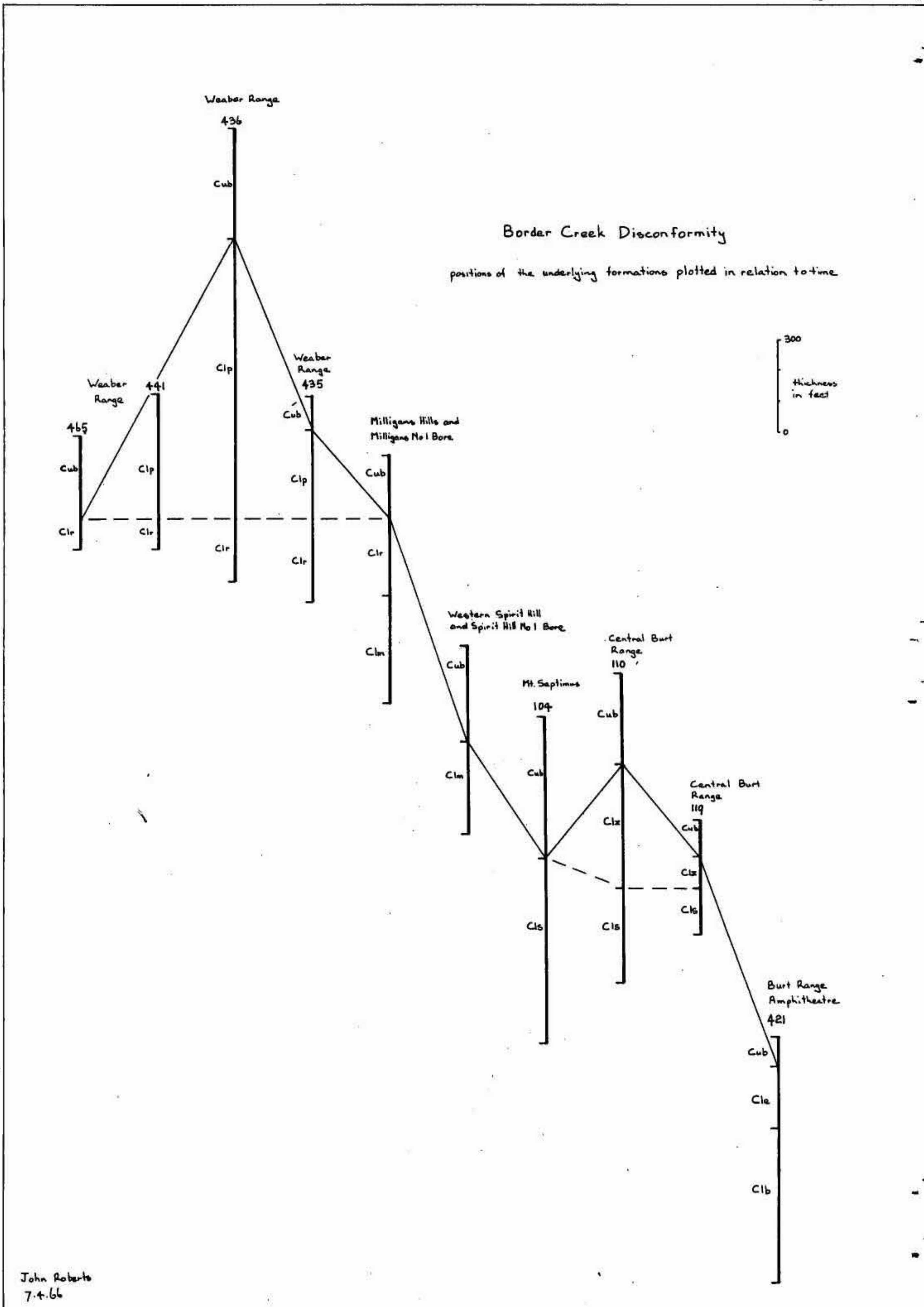

Border Creek Disconformity
positions of the underlying formations plotted in relation to time
300
thickness in feet
0
Weaber Range
436
Cub
Clp
Clr
Weaber Range
441
Clp
Clr
465
Cub
Clr
Weaber Range
435
Cub
Clp
Clr
Milligans Hills and Milligans No 1 Bore
Cub
Clr
Clm
Western Spirit Hill and Spirit Hill No 1 Bore
Cub
Clm
Mt. Septimus
104
Cub
Cls
Central Burt Range
110
Cub
Clz
Cls
Central Burt Range
119
Cub
Clz
Cls
Burt Range Amphitheatre
421
Cub
Cle
Clb
John Roberts
7.4.66

Fig. 55

sandstone in the channel is part of the same bed which overlies the Zimmermann Sandstone we consider it is Border CreekFormation.

Sections

In section 110, measured on the western scarp of the Central Burt Range, the Border Creek Formation crops out from 835 to 1,120 feet stratigraphically above the base, and overlies the type section of the Zimmermann Sandstone (Fig.41). The base of the Border Creek Formation is taken at the first conglomerate in the scarp; the top is eroded.

The formation comprises interbedded sandstone, siltstone and conglomerate. The sandstone is moderately to poorly sorted, medium to coarse-grained, feldspathic quartz sandstone having a clay cement. It is usually laminated in thick beds and is locally cross-bedded. The sandstone is white to brown near the base of the formation and becomes ferruginised towards the top of the range.

The siltstone is frequently laminated, white when freshly exposed and yellow, purple or red when weathered.

The conglomerate contains pebbles of rounded to sub-rounded quartzite averaging 2 inches in diameter and ranging up to 6 inches in diameter, fewer laths of Precambrian siltstone, and mud pellets set in a poorly sorted, coarse-grained quartz sandstone matrix, and is locally cross-bedded. The conglomerates usually overlie eroded surfaces and wedge out over short distances. When traced southwards from section 110 the basal conglomerate fills a deep channel cut into the underlying Zimmermann Sandstone (Fig.44). The channel, immediately east of Langfield Point, is about three-tenths of a mile wide, up to 75 feet deep at the centre, U-shaped in cross section, and is expressed topographically as a hollow in the southern part of the range. The clasts in the conglomerate of the channel are mainly rounded to sub-rounded quartzite boulders averaging 4 inches in diameter and up to 1 foot in diameter, with minor clasts of quartz sandstone and large blocks of siltstone having a size of up to 15 by 8 feet. The conglomerate lenses out to the north of section 110 and in less than two miles is replaced by sandstone.

At Mt.Septimus, the Septimus Limestone is overlain by medium to coarse-grained, buff to white, feldspathic quartz sandstone, siltstone and conglomerate. A conglomerate, 65 feet thick, in section 150 at the southern end of the mountain, wedges within one mile to a pebble band in section 104. A second conglomerate in section 104 fills channels in the top of a siltstone but is also present as lenses within the siltstone (Fig.54), suggesting closely associated deposition in a stream or lake.

At Milligans Hills the Border Creek Formation overlies coarse, brown calcareous sandstone of the Burvill Beds. In section 147, in the westernmost hill (Fig.46), the Burvill Beds are overlain by 15 feet of barren, medium-grained, grey-brown quartz sandstone identified as Border Creek Formation. The sandstone is overlain by a conglomerate containing rounded to well-rounded quartzite pebbles averaging 2 to 4 inches and up to 1 foot in diameter in a coarse-grained ferruginous sandstone matrix.

A conglomerate of similar appearance and 35 feet thick crops out in the northernmost hill (section 155, Fig.46) and is overlain by 100 feet of thick-bedded coarse to medium-grained, brown feldspathic quartz sandstone and 10 feet of pebbly sandstone which crop out as steep cone-shaped turrets.

The Border Creek Formation in the western part of Spirit Hill is dealt with in the description of the Spirit Hill area.

SPIRIT HILL

Spirit Hill is the name given to a group of hills rising about 600 feet above a tree-covered plain fourteen miles north of the Central Burt Range and eight miles east of the Pincombe Range. The hills are close to the eastern margin of the basin (Plate 1).

Traves (1955) assigned all of the rocks in the Spirit Hill area to the Weaber Group. He proposed the name Spirit Hill Limestone for the sandy limestone and calcareous sandstone on the southeastern part of the hill, and considered them to be Permian. He also described scattered outcrops of Spirit Hill Limestone between Spirit Hill and the Legune track crossing at Sandy Creek.

Thomas (1962) identified fossils from a limestone near Spirit Hill and reported that the species were Carboniferous and indicated a correlation with the upper part of the Septimus Limestone.

The unpublished work of various private company geologists has been summarized by Drummond (1963, unpublished). All of these workers considered the isolated outcrop of Septimus Limestone, mentioned above, to belong to the main limestone mass at Spirit Hill, and thus identified the entire limestone sequence as Septimus Limestone. This led to a misinterpretation of the geology and of the sequence in Spirit Hill No.1 Well (see Drummond, 1963, figure 7), drilled about one mile north of Spirit Hill. Palaeontological work, outlined below, shows that with one exception the carbonates at Spirit Hill and in Spirit Hill No.1 Well between 826 and 2,000 feet correlate with part of the Burt Range Formation. The term Spirit Hill Limestone is thus a junior synonym of the Burt Range Formation and is discarded.

Outline of the geology of Spirit Hill

The distribution of the formations exposed at Spirit Hill is shown in Figure 40. A total of six formations has been recognised from outcrop, and these in ascending stratigraphic order are the Cockatoo Formation, the Burt Range Formation, an unnamed limestone equivalent to the basal part of the Enga Sandstone, the Septimus Limestone, the Milligans Beds, and the Border Creek Formation. Three of these formations are present in Spirit Hill No.1 Well, drilled to a depth of 3,003 feet, about one mile north of the hill (Fig.39).

Spirit Hill can be divided into three topographical units: a complex series of hills and amphitheatres in the southeastern part; lower, more rounded, grass-covered hills in the northeastern and central regions; and blocky hills, many deeply dissected, to the west. These units have different outcrop patterns on the air photographs and correspond to the main formations cropping out on Spirit Hill (Fig.40), illustrating the control of geology on the present topography. The Burt Range Formation, on the southeastern corner, has a well-layered pattern which contrasts with the smooth appearance of the Milligans Beds in the northeastern and central part of Spirit Hill. To the west, sandstone in the Border Creek Formation has a regular joint system.

Small outcrops identified as Cockatoo Formation on the southeastern part of Spirit Hill are overlain, probably unconformably, by the Burt Range Formation. The Cockatoo Formation consists of coarse-grained quartz sandstone containing pelecypods and plant remains; the sandstone probably belongs to the Cecil Member.

The Burt Range Formation consists dominantly of calcareous and dolomitic sandstone with minor quartz sandstone and sandy limestone. It has been subdivided into three informal stratigraphic units for the purpose of discussing the unconformities within the formation in southeastern Spirit Hill (see below). The rocks are sandier and more dolomitic than their equivalents in the type section and are lithologically similar to those in the Burt Range Amphitheatre. Their stratigraphic relationships with other sections measured through the Burt Range Formation are shown in Figure 35.

An unnamed grey, crinoidal sandy limestone equivalent to the basal part of the Enga Sandstone unconformably overlies the Burt Range Formation in section 116 (Fig.40).

Elsewhere, the Burt Range Formation is unconformably overlain by a poorly exposed sequence of shale, sandstone, calcareous sandstone, and conglomerate referred to the Milligans Beds. The best outcrops are at locality 118 (Fig.40) in northeastern Spirit Hill, and at locality 73 on the southern margin of the hill, where grey silty shale is interbedded with sandstone. The shale is not well exposed elsewhere.

The Border CreekFormation crops out over the whole of the western part of Spirit Hill and extends as tongues and outliers into the eastern part of the hill where it unconformably overlies the Milligans Beds and the Burt Range Formation.

The Septimus Limestone is known from a single isolated outcrop at locality 272, just east of Spirit Hill. The Septimus Limestone has not been found in the main mass of the hill, and so its exact stratigraphic relationship with the other formations at Spirit Hill is not clear.

Structure

A detailed study of the structure of Spirit Hill was not undertaken in the present investigation. However, an air photograph interpretation of the area by R.Richard (Fig.35) shows that it is extensively faulted in the east and that some of the larger faults have extended westwards into the Border Creek Formation. A cross section (Figure 58) through Spirit Hill shows that it is a faulted anticline. The axis of the anticline, in the southeastern part of Spirit Hill, trends N 25^{O}E and pitches towards the northeast. Folding may have initially taken place as early as the lower or middle Tournaisian. The anticline can be seen in Figure 59, a panorama of southeastern Spirit Hill.

Traves (1955) mapped an anticline and syncline at Spirit Hill. We could not recognise these folds. The anticlinal axis on our map is essentially the same as that recognised by Allen (1956, unpublished; a copy of Allen's map is given in figure 5 by Drummond, 1963, unpublished).

The major fault between the Precambrian and Palaeozoic sediments, east of Spirit Hill, has a throw of more than 4,000 feet; it does not crop out and its position on the cross section (Fig.58) is inferred. Major faulting took place after the deposition of the Border Creek Formation, i.e. after the upper Carboniferous. Figure 40 shows that most of the smaller faults affect the Devonian and lower Carboniferous formations in the eastern part of Spirit Hill, but not the upper Carboniferous Border Creek Formation in the western part of Spirit Hill, From this we infer that most of the minor faulting took place after the deposition of the Milligans Beds, i.e. after the upper Visean (Fig.60). Faulting probably took place before this time, however, when the Spirit Hill area was folded, an d may have been responsible for a number of the unconformities in the area. Downfaulting in the late Tournaisian or early Visean was probably responsible for the preservation of the Septimus Limestone at locality 272, immediately east of Spirit Hill.

Large crystals of dolomite and galena are frequently in vughs within the fault zones. Allen (1956, unpublished) reported a ferruginous gossan and the minerals galena, cerussite, psilomelane and rhodochrosite in fault zones cutting carbonate rocks.

Stratigraphy

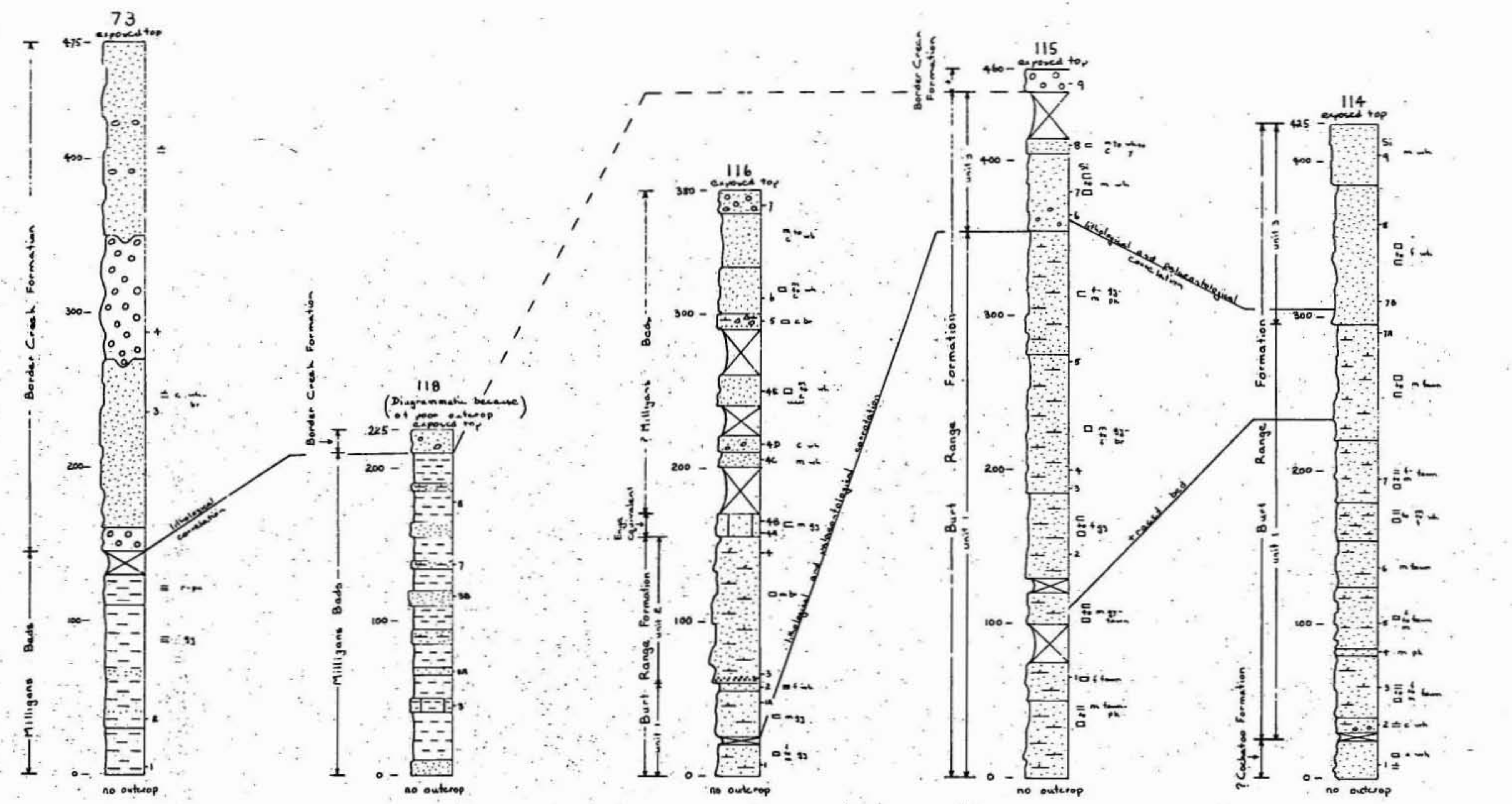
For the purposes of discussing the stratigraphy, Spirit Hill is divided into three parts; southeastern, northeastern and western Spirit Hill.

Southeastern Spirit Hill

Three sections have been measured in southeastern Spirit Hill; sections 114, 115 and 116 (Fig.40). Columnar sections are given in Figure 56 and Figure 39 gives the stratigraphic relationships between the sections and the sequence in Spirit Hill No.1 Well; it also shows five unconformities in the southeastern Spirit Hill area.

The lowermost unconformity separates probable Cockatoo Formation and the Burt Range Formation; the second is within the Burt Range Formation; the third separates the Burt Range Formation and an unnamed limestone equivalent to the base of the Enga Sandstone; the fourth occurs between the Burt Range Formation and the Border Creek Formation; and there is probably a fifth between the Burt Range Formation and the Milligans Beds (Fig.40). The hiatus at each break is illustrated diagrammatically in Figure 39.

At the base of section 114, 25 feet of barren, thick-bedded, coarse-grained, white quartz sandstone is tentatively identified as Upper Devonian Cockatoo Formation. A similar sandstone, half a mile south of the section line at locality 266, contains logs of Leptophloeum australe (McCoy) and pelecypods; the pelecypod fauna is close to that in interbedded sandstone and limestone, mapped as Buttons Beds, at locality 146/4 near Eight Mile Creek (Fig.31).



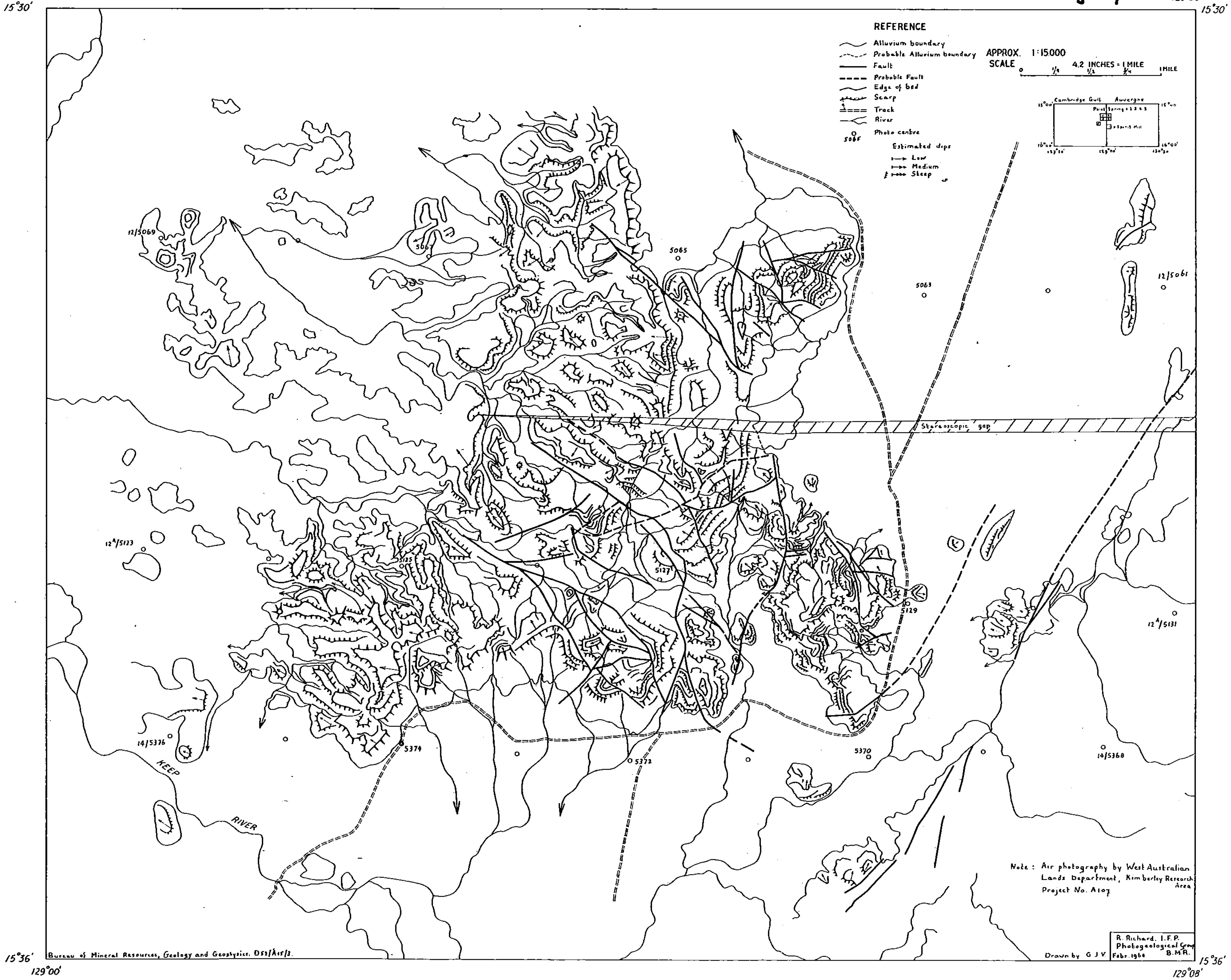
Columnar Sections at Spirit Hill

See figure B6 for locations

John Roberts
12.4.65
14.3.66
24.3.66

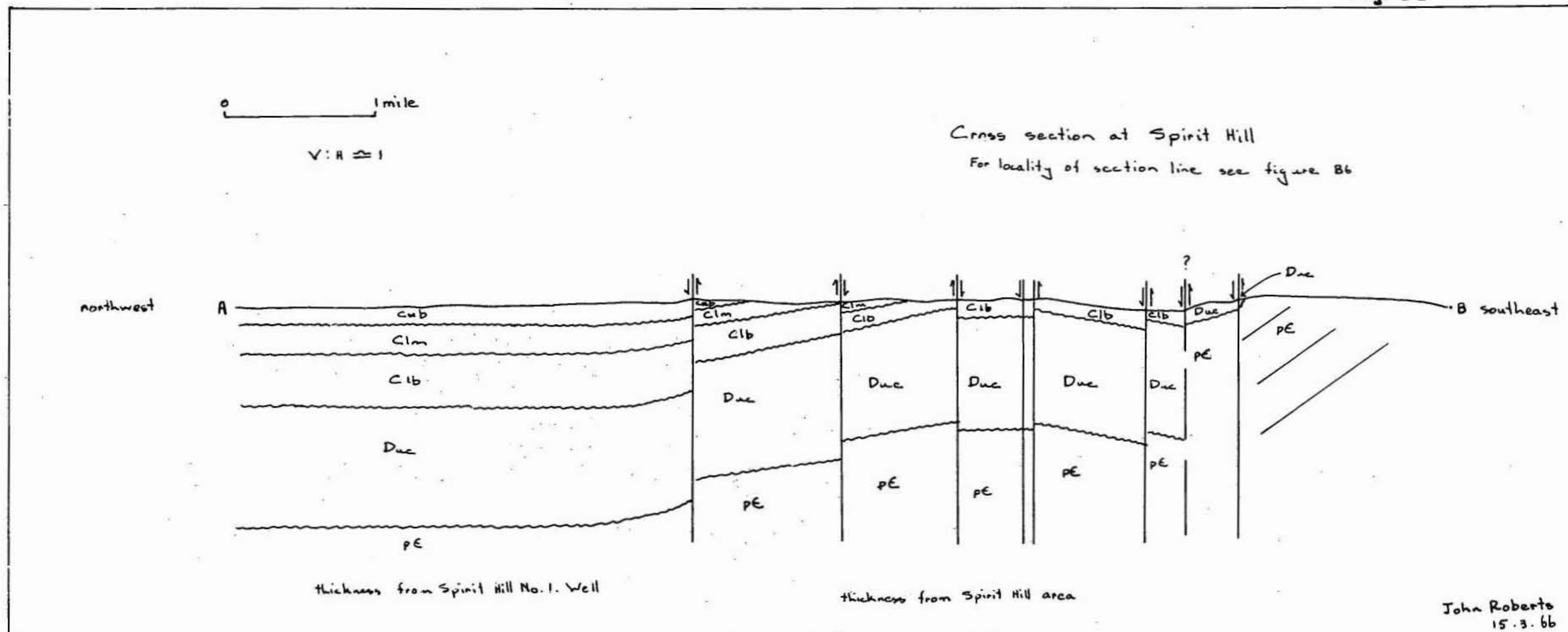
SPIRIT HILL – AIR PHOTO INTERPRETATION.

Fig. 57



A B C

Fig. 58



John Roberts
15.3.66
20.6.66

Overlying the sandstone in section 114, probably unconformably, are 265 feet of fine to medium-grained, fawn dolomitic and calcareous sandstone belonging to the Burt Range Formation.

In southeastern Spirit Hill three informal rock units have been recognised in the Burt Range Formation. They are virtually the units mapped by Allen (1956, unpublished) whose geological map of Spirit Hill has been reproduced by Drummond (1963, unpublished). The units are described in ascending stratigraphic order.

Unit 1 consists of medium to thick-bedded, fine to medium-grained, grey to fawn dolomitic and calcareous sandstone. It crops out in alternating hard and soft bands and in places forms small cliffs. Fossils are common in the upper parts of the unit, for example at localities 114/7A and 115/4, and indicate equivalance with the middle part of the Burt Range Formation in the type area, probably with the interval between 800 and 900 feet.

Unit 2 is a dark brown dolomitic and calcareous sandstone having a pebble bed at the base; the pebbles are rounded quartzite and milky quartz which range from 1 to 2 inches in diameter, with a few reaching a size of about 5 inches. The brown calcareous sandstone is medium-grained and thickly bedded, and forms prominent cliffs. Its best exposures are in section 116 and on the northern part of the hill containing the114 and 115 sections (Fig.40). Fossils are very poorly preserved (locality 116/3), but like those of unit 1 indicate equivalence with the middle part of the Burt Range Formation.

Unit 3 is a medium to thickly bedded, medium to fine-grained, white quartz sandstone which is sometimes silicified. Rounded pebbles of quartzite up to 2 inches in diameter are present at the base of the unit in section 115. Fossils from unit 3 (localities 114/7B and 115/7) indicate the same age as those from units one and two.

In southeastern Spirit Hill in sections 114 and 115 the grey to fawn calcareous sandstone (unit 1) is unconformably overlain by white quartz sandstone (unit 3). By tracing a bed between the two sections it can be shown that the uppermost 180 feet of calcareous sandstone in section 115 is missing in 114, indicating that a greater amount of erosion took place in section 114 before the deposition of the white quartz sandstone. The disconformity can be seen on the southern part of the hill where white sandstone occupies a position on the same level as calcareous sandstone in the north of the hill (Fig.59). The possibility that the southernmost sandstone outcrop is a lateral equivalent of part of the calcareous sandstone is rejected because of an angular difference between units 1 and 3 in section 114. In this section the calcareous sandstone dips at 5° towards 65° and the white sandstone is horizontal; no angular difference was seen in section 115. This particular disconformity affected only the western and southern parts of the hill containing sections 114 and 115 (Fig.40). In the north, the grey to fawn calcareous sandstone (unit 1) is overlain, apparently conformably, by a dark brown calcareous sandstone (unit 2). The latter is in turn overlain, again apparently conformably, by white quartz sandstone (unit 3).

The faunas from above and below the disconformity are short ranging and are restricted to the 800 to 900 foot interval in the type section of the Burt Range Formation, which suggests that there was only a short hiatus.

In section 116 dark brown calcareous sandstone (unit 2) is unconformably overlain by a thin, unnamed, grey sandy limestone which, from faunal evidence, is equivalent to the basal part of the Enga Sandstone.

Overlying the unnamed limestone is a succession of quartz sandstone, calcareous sandstone and conglomerate. The sandstone is a white, medium to coarse-grained quartz sandstone and contains a few pectenid pelecypods from locality 136/2, near the base (Fig.40). At 300 feet in section 116 there is a very coarse-grained, brown calcareous sandstone and conglomerate. The conglomerate has rounded pebbles of quartzite ranging from ½ to 3 inches in diameter, sub-angular blocks of limestone up to 6 inches long, and laths of Precambrian siltstone set in a matrix of coarse-grained brown calcareous sandstone. Loose yellow-marl observed in the intervals of no outcrop in section 116 is thought to indicate shale interbeds; similar marl has been collected from shaley parts of the 118 section in northeastern Spirit Hill.

This succession is tentatively identified as Milligans Beds because it has the same outcrop pattern and contains the same rock-types as that identified as Milligans Beds in northeastern Spirit Hill. However, because of the age of the underlying limestone (basal Enga Sandstone) the succession could be a lateral equivalent of the Enga Sandstone. The fossils from locality 136/2 are not sufficiently diagnostic to provide a correlation.

A conglomerate at the top of section 115, identified as Border Creek Formation, rests unconformably on the Burt Range Formation (unit 3).

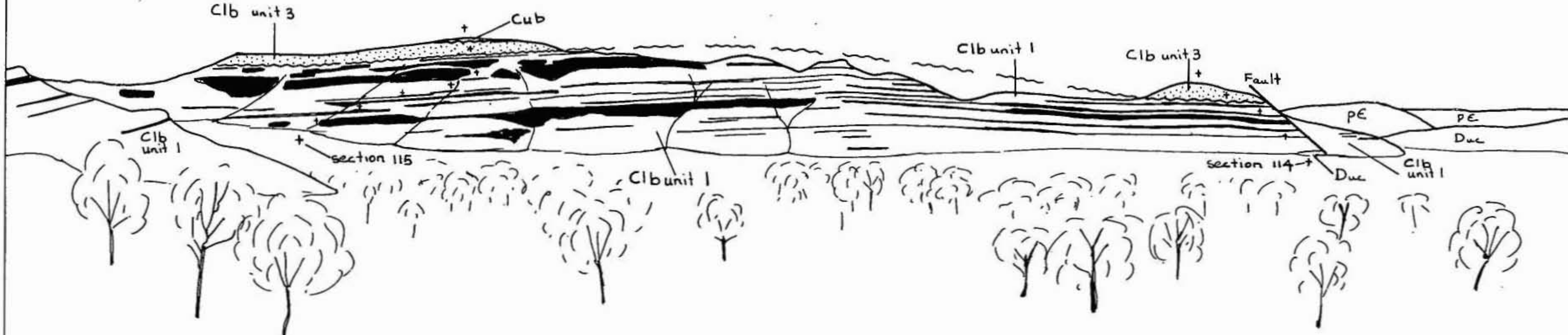
Northeastern Spirit Hill

In the northeastern part of Spirit Hill the Burt Range Formation is overlain, probably unconformably, by rocks identified as Milligans Beds. The latter are in turn unconformably overlain by a thin capping of Border Creek Formation. An isolated outcrop of Septimus Limestone is mapped at locality 272 (Fig.40).

Outcrops of the Milligans Beds consist mainly of tumbled blocks of sandstone and soft interbedded shale. One reasonably well exposed section in a gully at locality 118 (Fig.40) has a succession of grey silty shale containing beds of marl, sandstone and calcareous sandstone. A diagrammatic representation of this section is given in Figure 56. The sandstone is generally a well sorted, medium-grained, white quartz sandstone which has probably been leached. It is frequently ripple-marked, exhibits sole marks and flute casts, and contains mud pellets. Some poorly preserved brachiopods and gastropods have been found in a sandstone at locality 118/3, mid-way up the section, and fragments of fossil wood have been collected from throughout the section.

The Septimus Limestone at locality 272 consists of a low mount of fossiliferous, grey calcarenite. Thomas (1962) has shown that the brachiopod fauna from this locality is equivalent in age to his 'assemblage a' at the top of the Septimus Limestone.

Fig. 59



Uncontormities in southeastern Spirit Hill.

Drawn from a panorama photograph looking northeast from Spirit Hill Cave

Cub Border Creek Formation

Clb Burt Range Formation — cliffs

Duc Cockatoo Formation

pЄ Precambrian

unconformity

John Roberts
22.3.66
28.5.66

Western Spirit Hill

On the southern margin of western Spirit Hill at locality 73 (Fig.40) shales of the Milligans Beds are unconformably overlain by the Border CreekFormation. The Milligans Beds are fissile blue-grey shales containing occasional resistant silty bands and beds of fontainebleau sandstone, overlain by red to purple shales. Brachiopods collected from the harder silty beds at locality 73/2 indicate a lower Visean age. The shales are probably the same as those, dated as Visean (Jones in Thomas, 1962), in the Milligans Hills No.1 and 2 bores near Milligans Lagoon (Fig.31).

The Border CreekFormation is exposed in high turreted cliffs along southwestern and western Spirit Hill and extends as scattered outcrops to Milligans Hills, three miles to the southwest. The basal beds in section 73 (Fig.56) consist of a boulder and cobble conglomerate with poorly rounded quartzite, sandstone and possible crystalline fragments up to 1½ feet in diameter set in a coarse feldspathic quartz sandstone matrix. The basal conglomerate is overlain by a coarse-grained, cross-bedded, white to fawn feldspathic quartz sandstone containing several layers of pebbles and boulders. Channels up to a foot deep have been cut into the top of this sandstone and filled by the overlying conglomerate. The conglomerate contains fragments of quartzite, sandstone and white siltstone averaging 5 inches in diameter, with the largest about three feet across. The matrix is lithologically similar to the underlying sandstone. Allen (1956, unpublished) recorded angular blocks of purple to grey indurated mudstone up to 6 feet long lying parellel with the bedding planes of the same conglomerate in the southwestern part of Spirit Hill. At the top the conglomerate has also been channelled and filled with coarse feldspathic quartz sandstone containing pebble bands. Both sandstone units in the conglomerate are cut by intersecting vertical joint systems and are weathered into high beehive-shaped turrets.

Spirit Hill No.1Well

Spirit Hill No.1 Well, a continuously cored subsidised diamond drill hole, was drilled in 1959 and 1960 to a depth of 3,003 feet for Westralian Oil Limited and Oil Development N.L. at a locality about one mile north of Spirit Hill, (Fig.40). A completion report on this well by R.Hare et al. (1961) was later revised by G.A.Thomas (1961, unpublished). Drummond (1963 unpublished) re-examined the Spirit Hill No.1 core, gave detailed lithological descriptions (Drummond, appendix 5) and showed various stratigraphic interpretations of the well (Drummond, fig.7). A slightly modified columnar section, taking into account the information from the completion report and the later work of Drummond, is given in Figure 39. This section shows lithologies, a break in sequence, and the formations to which the rocks have been assigned.

A brief summary of the sequence in Spirit Hill No.1 Well is given below. Beneath a thin cover of surface material the well penetrated the following strata: grey to black silty shale with several beds of sandstone, dolomitic sandstone and thin conglomerate to a depth of 826 feet; from 826 to 2,000 feet, grey dolomite, limestone and sandy dolomite, with minor dolomitic siltstone and sandstone; from 2,000 to 2,500 feet, dolomitic sandstone, with minor siltstones and dolomites; and from 2,500 to 3,003 feet, sandstone with minor shale and dolomitic sandstone. The well intersects a possible fault at a depth of 2,469 feet.

The shale to a depth of 826 feet is identified as Milligans Beds. P.J.Jones (pers.comm.) has correlated an ostracod assemblage from 50 feet with a similar one towards the base of Milligans No.1 Bore, drilled to a depth of 510 feet at the southeastern corner of Milligans Hills (Fig.31).

Balme (1961), in the revised completion report of Spirit Hill No.1 Well, identified spores from several samples of shale and found the assemblage to be closely comparable with that from the Milligans No.1 Bore; he suggested that the shales in both bores could be correlated.

P.J.Jones (pers.comm.) has dated the shales in Spirit Hill No.1 Well and Milligans No.1 and No.2 Bores as Visean.

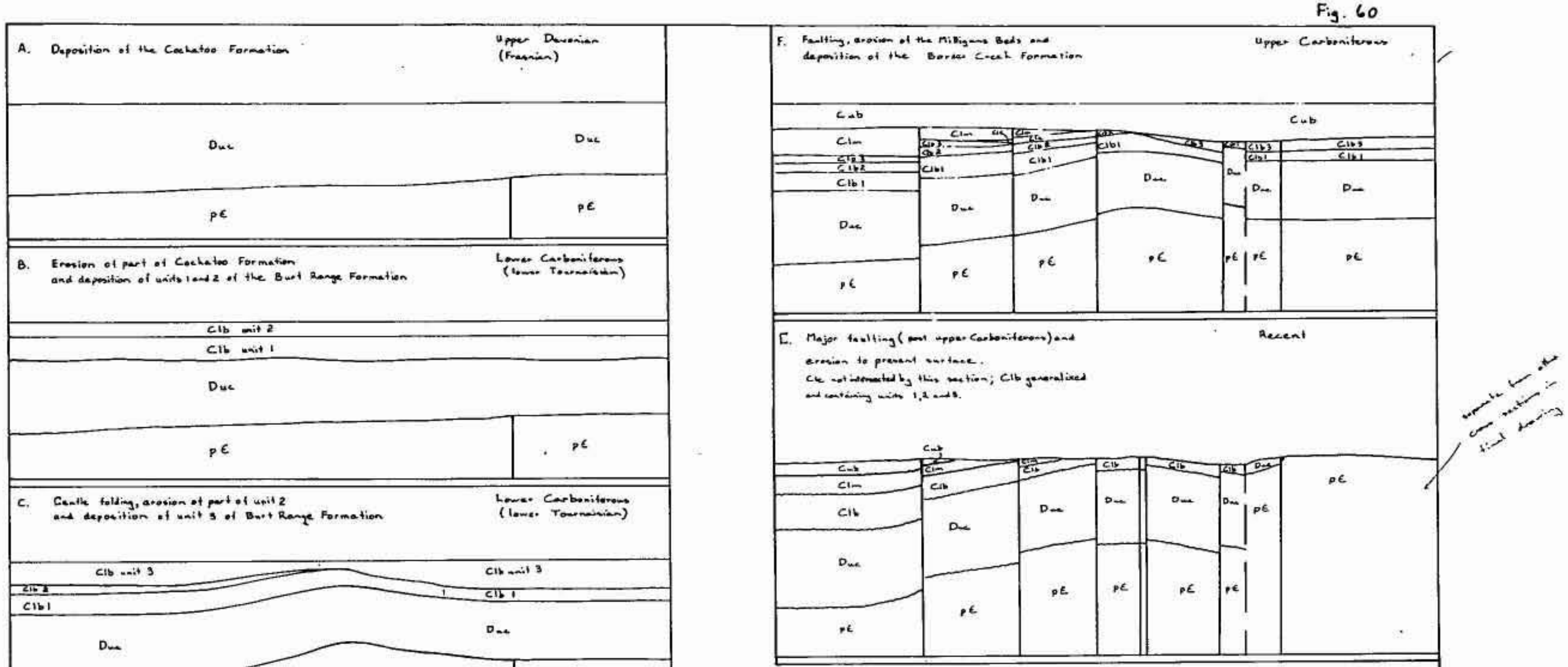
The sequence between 826 and 2,000 feet is identified as Burt Range Formation. Both brachiopods (J.Roberts) and conodonts (E.C.Druce) show that the top of the Burt Range Formation in the well can be correlated with the interval between 800 and 900 feet in the type section dated as lower to middle Tournaisian (Jones and Druce, 1966). Together with the presence of a pebbly conglomerate at the base of the Milligans Beds, this indicates that there is a hiatus between the Milligans Beds and the Burt Range Formation in Spirit Hill No.1 Well.

The section between 826 and 1300 feet in the well can be correlated with the top of unit 1, and units 2 and 3 of the Burt Range Formation in southeastern Spirit Hill.

The base of the Burt Range Formation in the well is drawn at a depth of 2,000 feet because conodonts from 1907 feet indicate a correlation with locality 100/6A (E.C.Druce, pers.comm.), from just above the base of the formation in the type section (Fig.33); ostracods from 1907 feet suggest a slightly higher equivalent, 300 feet above the base of the Burt Range Formation. Few brachiopods have been found between the depths of 1,400 and 2,000 feet in the well. Those from 1413 feet correlate with a similar assemblage between 400 and 500 feet above the base of the type section.

The rocks beneath 2,000 feet are mainly sandstone and dolomitic sandstone and are tentatively assigned a Devonian age; possibly equivalent to part of the Cockatoo Formation or the Ningbing Limestone. G.A.Thomas (1961, in Hare et al.) has identified a specimen of <u>Leptophloeum australe</u> (McCoy) from a depth of 2,161 feet and a 'cosmoid' fish scale from a depth of 2,564 feet. Both fossils are common in the Upper Devonian but are also known in the Lower Carboniferous. No other palaeontological evidence is available.

Fig. 60



Geological evolution of Spirit Hill

Cub Border Creek Formation
Clm = Milligans Beds
Cls Septimus Limestone
Cle Enga Sandstone equivalent
Clb Burt Range Formation
units 1, 2 and 3
Duc Cockatoo Formation (undifferentiated)
pЄ Precambrian

There probably was minor faulting (not shown in figures C, D and E) during the Tournaisian and Viséan.

The Septimus Limestone, shown as having been completely eroded in figure E, crops out immediately east of Spirit Hill (see figure 56).

John Roberts
27.3.66
20.4.66

Fig. 60

Geological History

The geological history of the Spirit Hill area is summarized in Figure 60. The figure shows the following events:

A. Deposition of Cockatoo Formation over Precambrian basement.

B. Erosion of part of the Cockatoo Formation and then deposition of units 1 and 2 of the Burt Range Formation.

C. Gentle folding, erosion of unit 2 of the Burt Range Formation, especially from the eastern limb of the anticline, followed by the deposition of unit 3 of the Burt Range Formation.

D. Erosion of unit 3 of the Burt Range Formation followed by the deposition of a carbonate equivalent of the Enga Sandstone, and the Septimus Limestone.

E. Erosion of the Septimus Limestone and most of the Enga Sandstone equivalent followed by the deposition of the Milligans Beds.

F. Faulting, erosion of the Milligans Beds and the deposition of the Border Creek Formation.

G. Major faulting (post upper Carboniferous) and erosion to the present day.

The breaks between or within the formations are shown in Figure 39. They were probably caused by gentle folding and possible minor faulting in the Spirit Hill area. Faulting is not shown until the figure portraying the middle to upper Visean at Spirit Hill because there is little evidence on which the faults could be based. Downfaulting was probably responsible for the preservation of the Septimus Limestone at locality 272, immediately east of Spirit Hill (Fig.40).

POST-CARBONIFEROUS

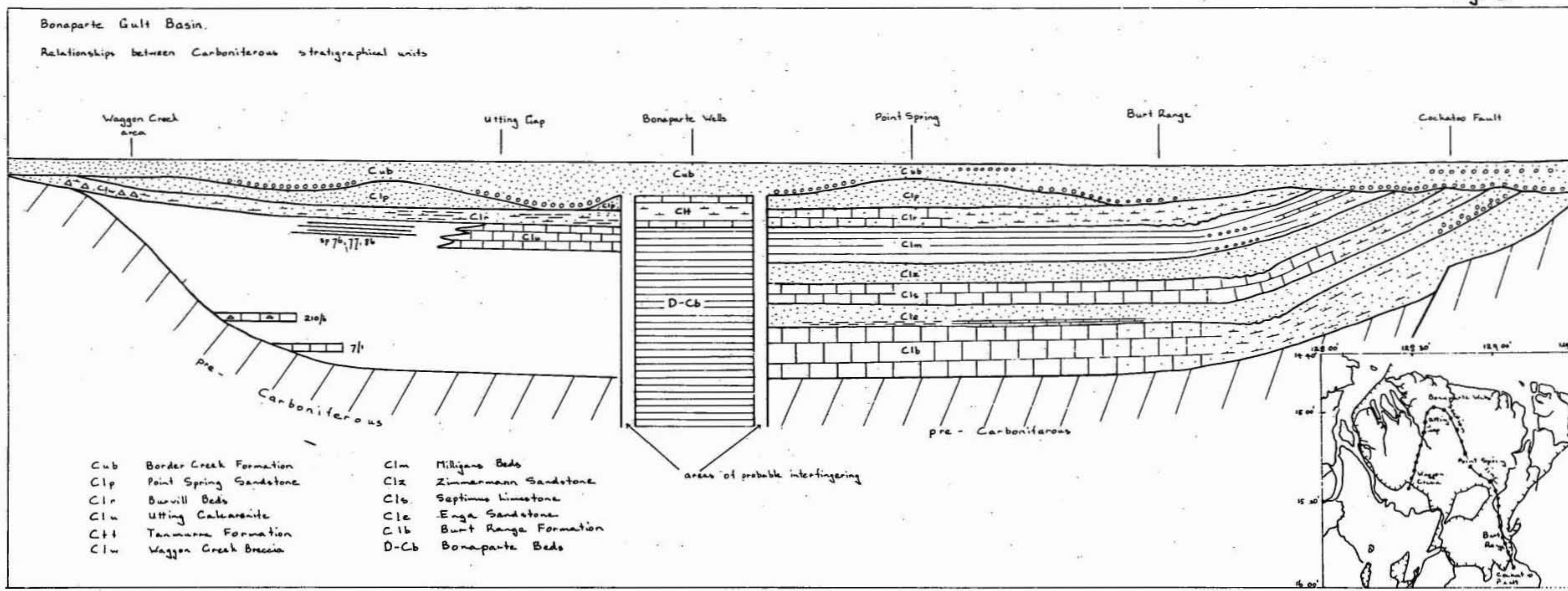
KEEP INLET BEDS (new name)

Glover et al. (unpublished) proposed the name Keep Inlet Beds for the Permian glacial sediments in the Keep Inlet area. Outcrop in this area (Fig.62) is extremely poor, and the field relations between the Keep Inlet Beds, which are the only outcropping consolidated rocks, and other Palaeozoic units are not visible.

All the known outcrops of the Keep Inlet Beds lie north of Cleanskin Bore at or slightly above the level of the highest or 'king' tides, which once or twice a year bring the sea across broad salt-encrusted mud flats to the edge of the sand plain of the Moogarooga Creek area. Calcareous feldspathic and lithic quartz sandstone, locally pebbly, is the commonest rock in situ, and is found at localities 22/1, 3, 4, and 6. At locality 22/6, designated the type (co-ordinates Lat.15°03'S, Long.128°58'E), the calcareous sandstone is lustre-mottled, and contains pellets of green mud in which Glover et al. found a brachiopod which D.Hill determined as an immature Strophalosia, indicating Permo-Carboniferous, probably Lower Permian. A subsequent search for fossils at this spot yielded only a reworked Ordovician conodont (P.J.Jones, pers.comm.). Rare glauconite was found in samples from localities 22/3 and 22/6.

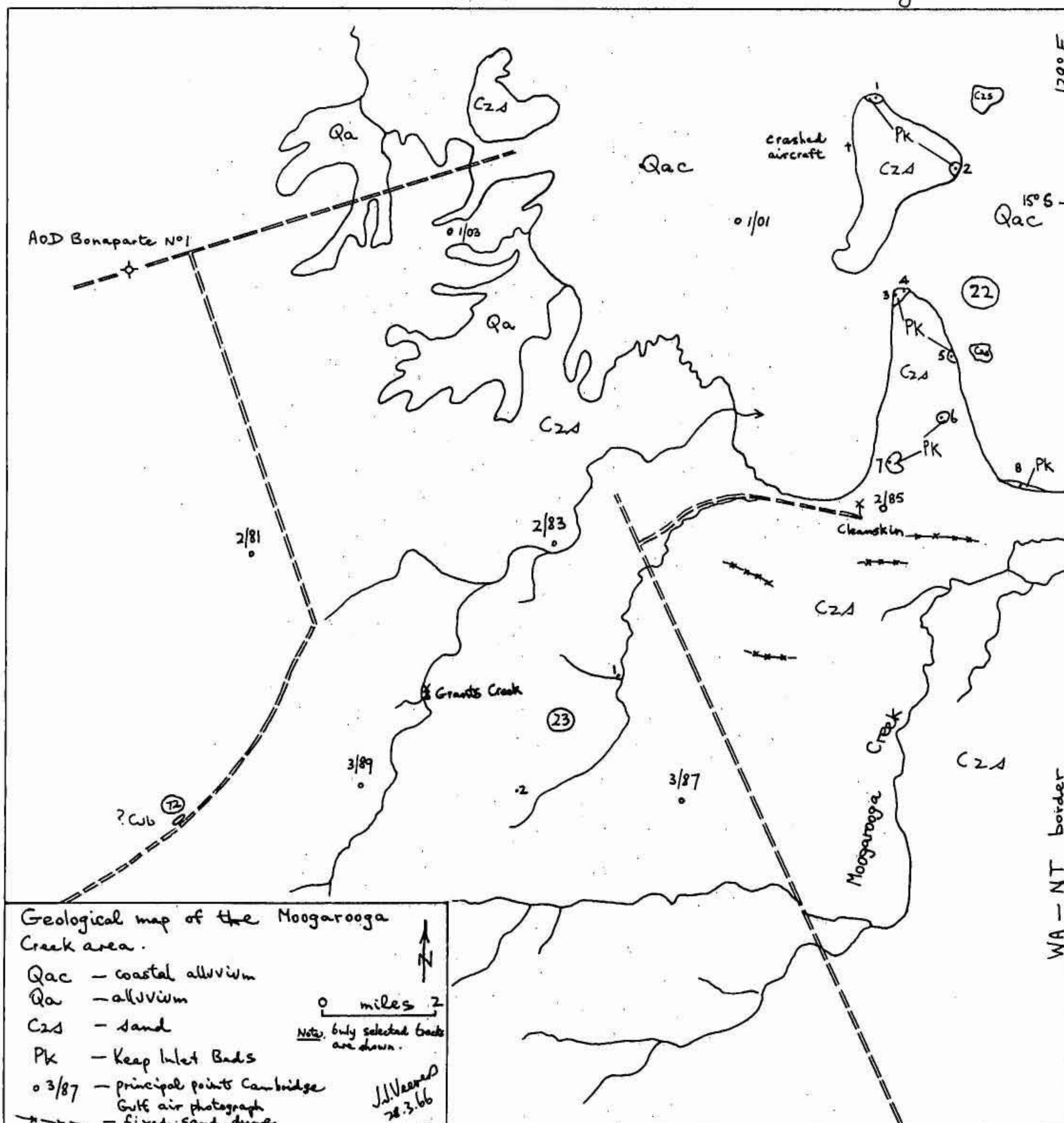
The other chief component of the Keep Inlet Beds is a heterogenous suite of rock fragments, ranging from pebbles to blocks 3 feet across, best seen at locality 22/8. Pink orthoquartzite is the commonest type of fragment. I.Gemuts (formerly W.A.Geological Survey) briefly examined our collection of fragments, and identified several types of granite, granodiorite, porphyry, schist, and sub-greywacke, all of which are common in the Precambrian successions of the Kimberleys. Glover et al. additionally list a massive light-grey quartzite, a boulder of which contains a poorly preserved indeterminate plant stem 8 inches long and 1 inch wide, and a Cambrian glauconitic limestone with Biconulites. The relationships between these fragments and the calcareous sandstone are not clear, but an outcrop of pebbly fontainebleau sandstone at locality 22/8 near the occurrence of numerous blocks probably indicates that the calcareous sandstone enclosed the fragments. Glover et al. remarked that because of the large size of the biggest blocks and because of their heterogenous lithology, age, and

Fig. 61



Bonaparte Gulf Basin.
Relationships between Carboniferous stratigraphical units
Waggon Creek area
Utting Gap
Bonaparte Wells
Point Spring
Burt Range
Cockatoo Fault
Cub
Clp
Clr
Clu
Clw
Ctt
Clm
Clz
Cls
Cle
Clb
D-Cb
210/1
7/1
pre-Carboniferous
pre - Carboniferous
areas of probable interfingering
Cub Border Creek Formation
Clp Point Spring Sandstone
Clr Burvill Beds
Clu Utting Calcarenite
Ctt Tanmurra Formation
Clw Waggon Creek Breccia
Clm Milligans Beds
Clz Zimmermann Sandstone
Cls Septimus Limestone
Cle Enga Sandstone
Clb Burt Range Formation
D-Cb Bonaparte Beds

Fig. 62



Qa
Cz s
Qac
crashed aircraft
Pk
Cz s
15° S
Qac
129° E
AOD Bonaparte No1
o 1/03
o 1/01
Qa
22
Pk
Cz s
Pk
8 Pk
Cz s
2/85
Cleanskin
2/83
2/81
Cz s
Grants Creek
23
Moogarooga Creek
Cz s
3/89
3/87
? Cub
72
WA – NT border
Geological map of the Moogarooga Creek area.
Qac – coastal alluvium
Qa – alluvium
Czs – sand
Pk – Keep Inlet Beds
o 3/87 – principal points Cambridge Gulf air photograph
– fixed sand dune
N
0 miles 2
Note, only selected tracks are shown.
J.J.Veevers 28.3.66
OK .4.5.66

Fig. 62

J.J. Veevers
27/3/66
OK 4/5/66

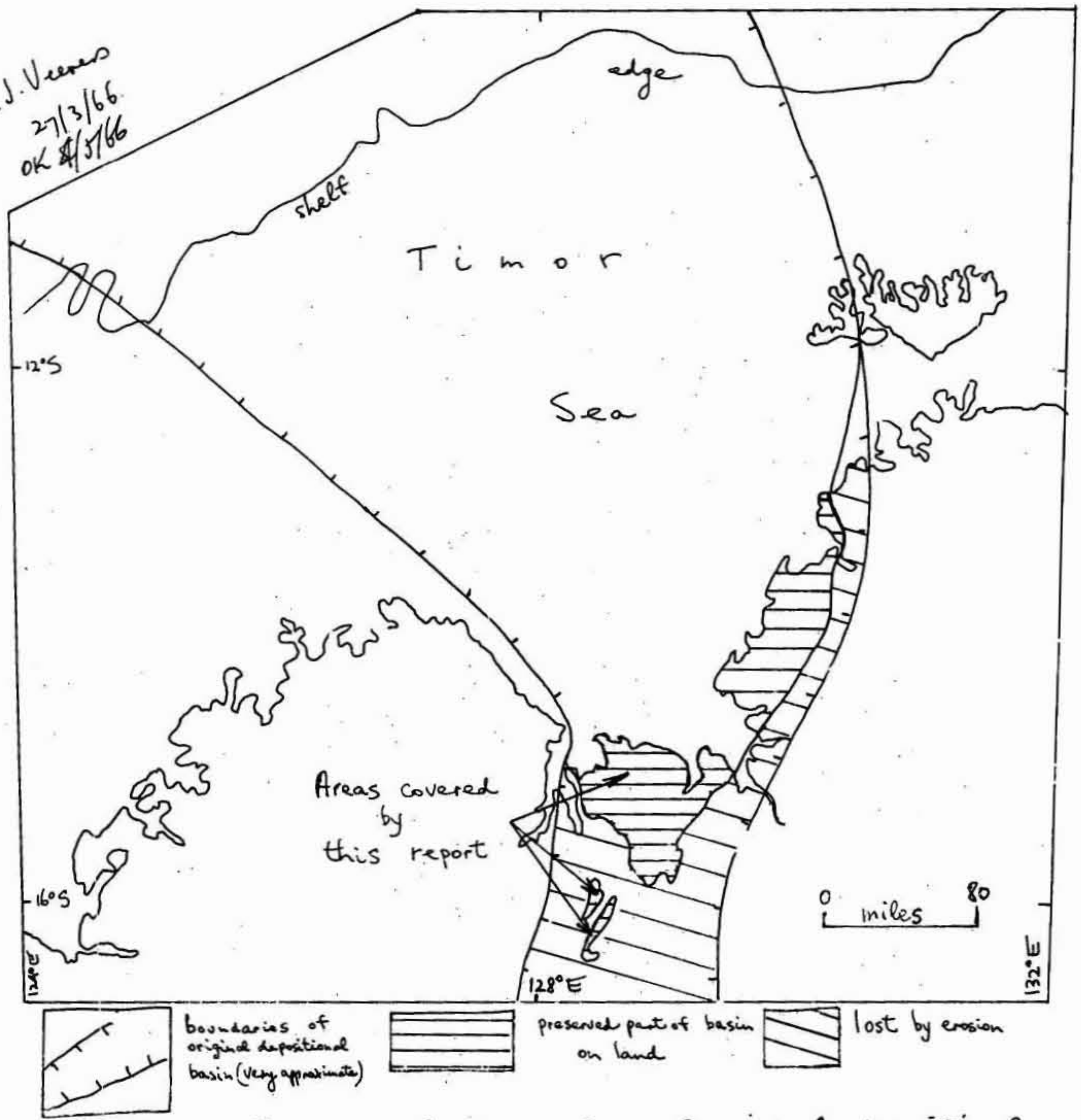


Fig. **63** — Sketch map showing outlines of original depositional basin, the part subsequently lost by erosion, the preserved part of the basin on land, and the areas covered by this report.

size, the rock fragments are glacial erratics, and we have no cause to question this.

At locality 23/1, 5 miles south-west of Cleanskin Bore (Fig.62), a loose block of cross-bedded quartzite measuring 6 x 4 x 3 feet, and at locality 23/2, 2 miles south-westward, a similar block of quartzite, 3 x 3 feet, were found in sandy areas strewn with rounded cobbles and boulders of quartzite. No other type of rock was found. If, as their size suggests, these blocks belong to the Keep Inlet Beds, their association with quartzite gravel, devoid of any of the other types found in the Keep Inlet Beds, is puzzling. The quartzite gravels are closely related to the conglomerate of the Border Creek Formation. An explanation of this puzzle, offered in the field by Dr.G.A.Thomas, is that with the lowering of the land surface by erosion these resistant blocks have slowly dropped down into the elluvium of the Border Creek Formation. Alternatively, the quartzite gravel may be derived from a quartzite-rich part of the Keep Inlet Beds from which the chemically unstable rock fragments have been lost. Whichever explanation is accepted, the conclusion seems inescapable that the Permian Keep Inlet Beds overlie the Border Creek Formation of the Weaber Range, and thus mark the upper age limit of the Border Creek Formation.

Blue-grey and red claystone overlain by a conglomerate of quartzite cobbles in a sand matrix are exposed in a road cutting at locality 72, 9 miles south of Bonaparte No.1 Well, and are identified as Border Creek Formation.

The interval 60 to 638 feet in AOD Bonaparte No.1 Well (Le Blanc, 1964)(Fig.47) consists of coarse-grained quartz sand and sandstone except for micaceous silty shale from 250 to 295 feet. P.R.Evans (pers.comm.) found Lower Permian spores in this shale. Between 295 and 390 feet, poorly cemented sandstone contains '20 per cent of coloured quartz grains and lithic fragments'. We identify the interval 60 to 638 feet as Keep Inlet Beds on the basis of the Lower Permian age of the shale, and thelithology of lithic sandstone. The kaolinitic sandstone beneath 390 feet may also be interpreted as Border Creek Formation or Point Spring Sandstone.

STRUCTURE

Noakes et al. (1952) pointed out that 'the Bonaparte Gulf Basin as a structural unit probably extends north-westerly from the present coast line to the edge of the continental shelf', and this extrapolation has been confirmed by recent geophysical surveys. Noakes et al. illustrated their point by saying that the Bonaparte Gulf Basin is roughly comparable in size to the Canning Basin, with the difference that the Bonaparte Gulf Basin is largely submerged. The present report islimited to the southern, landward part of the Bonaparte Gulf Basin and its outliers (Fig.63). This part of the basin, in turn, is only a small, but not insignificant, part of the original depositional basin. For brevity, and following established custom, we refer to this area of Palaeozoic sedimentary rocks as the Bonaparte Gulf Basin, bearing in mind that this is merely the southern landward part of the entire basin.

To reiterate this important point: the original Palaeozoic depositional basin in the Bonaparte Gulf area was disrupted by subsequent earth movements, and, at least near the southern margins, much of the original basin removed by erosion. In late geological time, the greater part of the preserved basin was submerged, leaving only a small part on land. It is this small preserved landward part of the original basin which has come to be called the Bonaparte Gulf Basin, and this report deals with the southern part of this outcrop. The outliers of the Ragged Range, Dillon Spring, and Mount Rob, part of the original depositional basin, are now detached from the Bonaparte Gulf Basin sensu stricto, whose limits are shown in Figure 64.

The Bonaparte Gulf Basin lies discordantly on the Precambrian Kimberley Block, and is bounded on the east by the Precambrian Halls Creek Mobile Zone (Traves, 1955, fig.33*). The geology of the Kimberley Block, part of which the Bonaparte Gulf Basin discordantly overlies, is now being studied by geologists of the Bureau and W.A.Geological Survey, and discussion of the regional structural setting is deferred until this work is completed.

Major structural subdivisions

The chief structural elements of the Bonaparte Gulf Basin are faults, probably normal faults, along which the major earth movements have been effected. The southern parts of the basin and the outliers are bounded by faults, and other parts of the basin, in particular the Pretlove Hills and the area northward, are strike-faulted. Folds are rare. A 22-mile long inlier of Precambrian rocks in the Pincombe Range, the Pincombe Inlier, divides the Bonaparte Gulf Basin into two areas which Traves (1955, p.9) called the Carlton Basin in the west and, following Matheson & Teichert (1948, p175), the Burt Range Basin in the east. We amend the term Burt Range Basin to the Burt Range Syncline, and the term Carlton Basin is replaced by several, more specific, terms.

The Burt Range Syncline (Fig.65) is a broad asymmetrical syncline with a northerly axis which almost coincides with the state border; the syncline extends northward from Cockatoo Spring to a line joining Sorby Hills and Alpha Hill, is bounded on the east by the Cockatoo Fault System, on the south-west by the Ivanhoe Fault, and on the north-west by the Pincombe Inlier. The pitch is probably horizontal throughout except in the area south of the Central Burt Range where it pitches northward from 10 to 20 degrees. The Burt Range Syncline is distinguished from a homocline only by the reversal of dip, probably due to drag, along the east-bounding Cockatoo Fault System. The easternmost part of the syncline is the Amphitheatre Anticline, which is bounded by faults of the Cockatoo System, and contains an estimated 6,000 feet of Upper Devonian and Lower Carboniferous sediments, the youngest of which is the Enga Sandstone. The northern part of the syncline is poorly known due to scanty outcrop on the western limb. According to our interpretation (Fig.66), which is confirmed by seismic surveys (Bigg-Wither, 1963, Pl.22), the syncline is bounded on the east by the Cockatoo Fault System, and its eastern part is represented by the faulted Spirit Hill Anticline, which corresponds with

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* Traves' Figure 33 must now be amended to show a broader expanse of 'Middle Palaeozoic' (Upper Devonian and Lower Carboniferous) sediments, bounded on the east by the Halls Creek Mobile Zone.

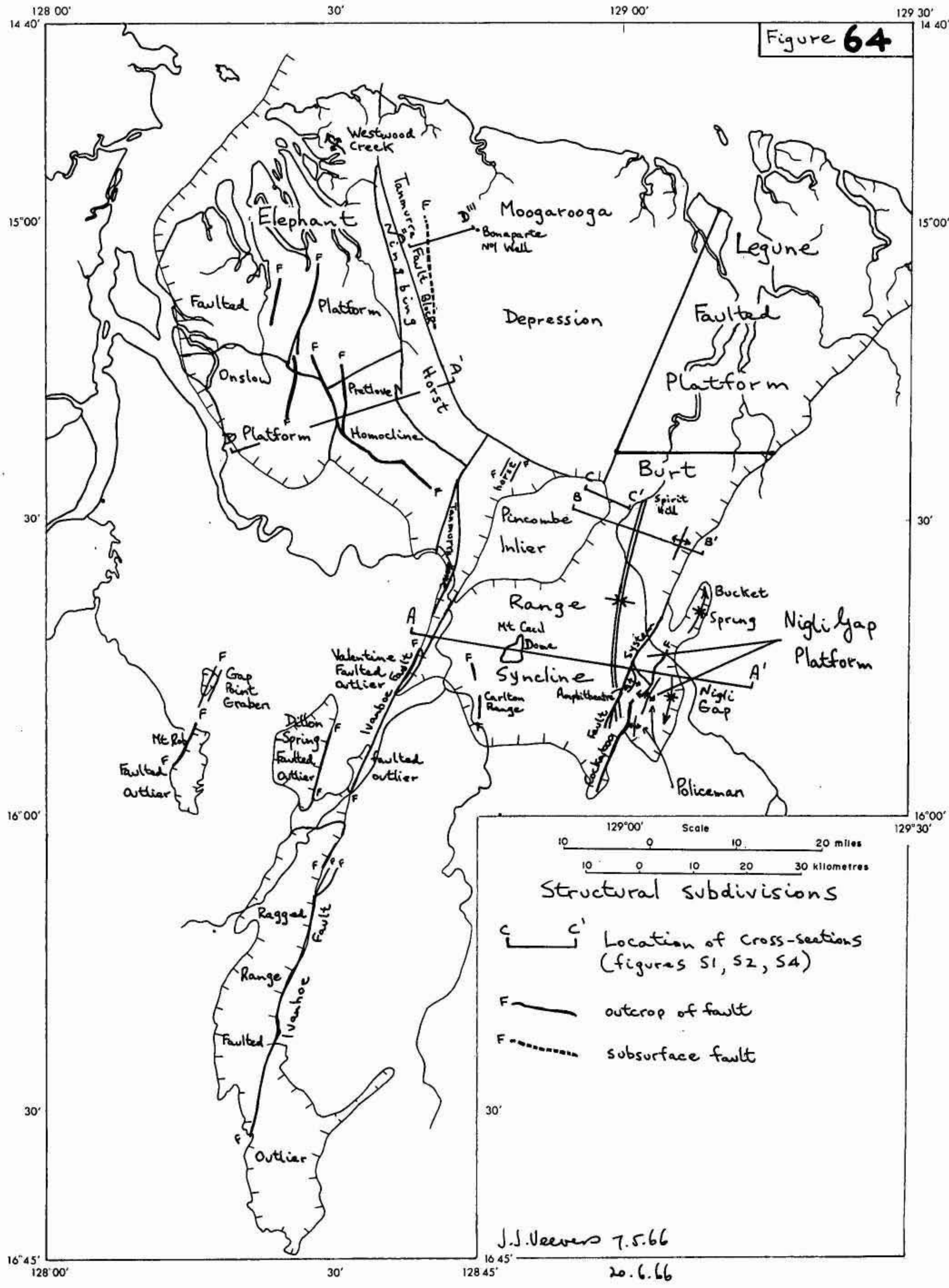
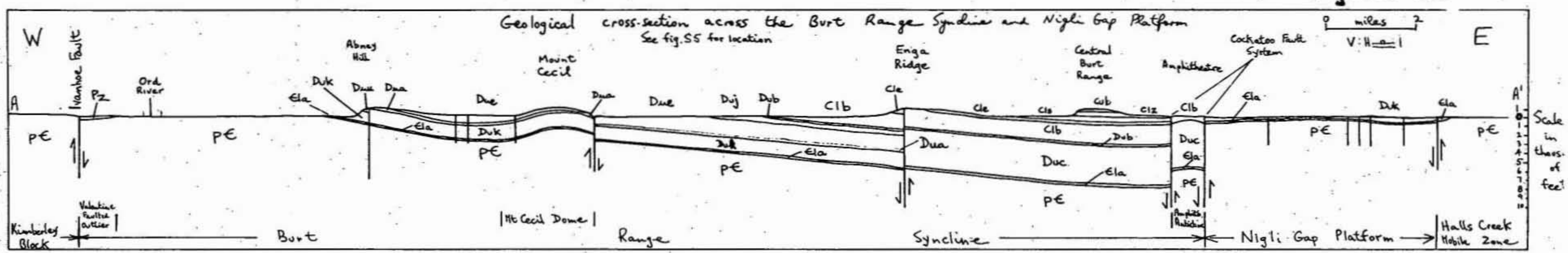


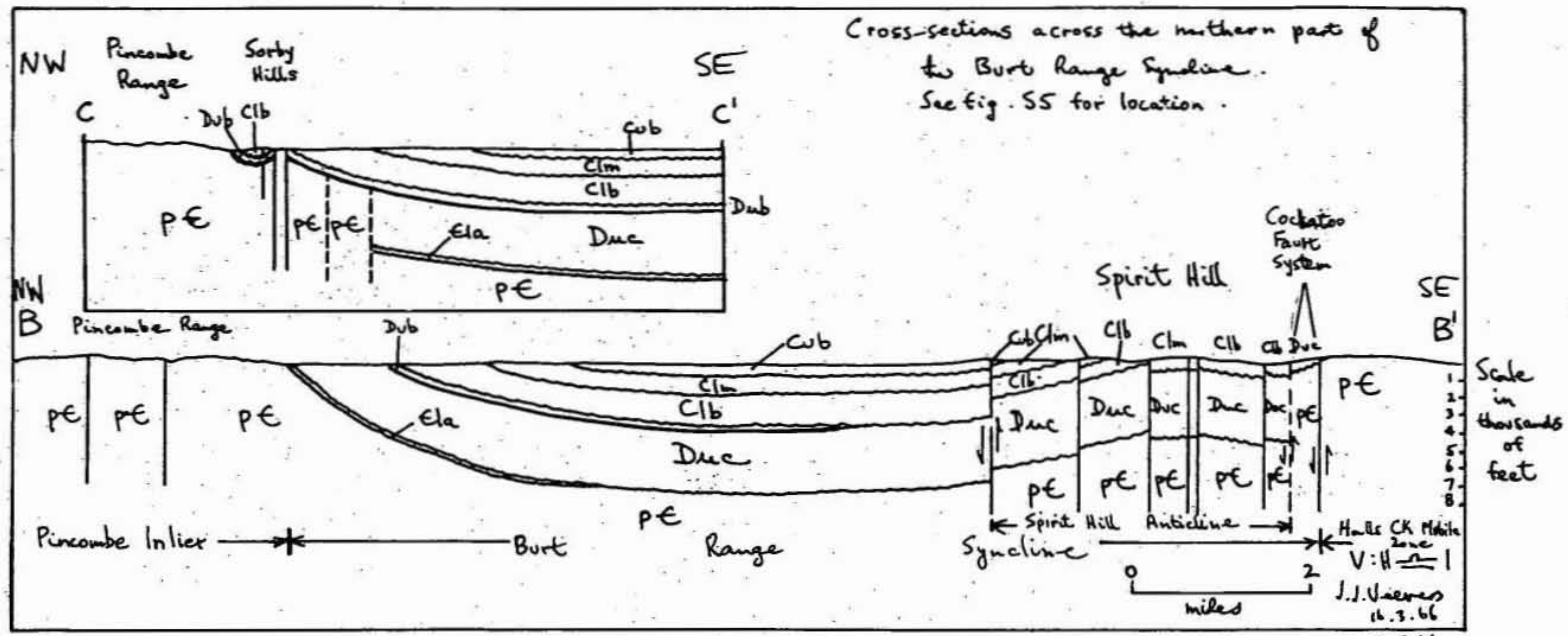
Figure 64
128 00'
30'
129 00'
129 30'
14 40'
15°00'
30'
16°00'
16°45'
128 45'
16 45'
Westwood Creek
Elephant
Faulted
Platform
Onslow
Platform
Pretlove
Homocline
Tanmurra Fault Block
Ningbing
Horst
D'''
Moogarooga
Bonaparte No1 Well
Depression
A'
Legune
Faulted
Platform
Burt
C
C'
B
B'
Spirit Well
Pincombe
Inlier
Range
Mt Cecil Dome
Syncline
A
A'
Bucket Spring
Nigli Gap
Platform
Nigli Gap
Amphitheatre
Policeman
Carlton Range
Valentine Faulted Outlier
Gap Point Graben
Mt Rob
Faulted outlier
Dillon Spring Faulted Outlier
faulted outlier
Ivanhoe
Ragged
Range
Faulted
Outlier
Ivanhoe Fault
F
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Structural subdivisions
C C'
Location of cross-sections (figures 51, 52, 54)
outcrop of fault
subsurface fault
J.J. Veevers 7.5.66
20.6.66

Figure 65



J.J. Veevers
27.3.66
4.5.66

Figure 66


Cross-sections across the northern part of the Burt Range Syncline.
See fig. 55 for location.
NW
Pincombe Range
Sorby Hills
SE
C
C'
Dub
Clb
Cub
Clm
Clb
Dub
pЄ
pЄ
pЄ
Єla
Duc
pЄ
NW
B
Pincombe Range
Dub
Cub
Clm
Clb
Єla
Duc
pЄ
Spirit Hill
Cockatoo Fault System
SE
B'
Clb
Clm
Clb
Clm
Clb
Clb
Duc
Duc
Duc
Duc
Duc
Duc
pЄ
Scale in thousands of feet
1
2
3
4
5
6
7
8
Pincombe Inlier
Burt
Range
Syncline
Spirit Hill Anticline
Halls Ck Mobile Zone
V:H = 1
0
2
miles
J.J. Veevers
16.3.66
4.5.66

the Amphitheatre Anticline to the south. Other secondary structures distinguished within the Burt Range Syncline are the Mount Cecil Dome and the Valentine Faulted Outlier.

The Mount Cecil Dome (see also Fig.8) is morphologically a dissected dome with a surface of silicified sandstone of the Cecil Member of the Cockatoo Formation, and a core of Abney Member. The Valentine Faulted Outlier, named after the nearby Valentine Creek, contains fossiliferous Cambrian dolomite, and barren quartz sandstone, part of it identified as the Cockatoo Formation. The Outlier is bounded on the west by the Ivanhoe Fault, and presumably rests on Precambrian rocks to the east. The Spirit Hill Anticline is a faulted anticline; it is described on p. 75.

The Carlton Range Fault (Matheson & Teichert, 1948, p.82, 83, Fig.10) is a north-trending vertical fault along which Kellys Knob Member is juxtaposed against Antrim Plateau Volcanics on the west.

The Nigli Gap Platform is a sheet, 1,000 feet thick, of Cambrian Antrim Plateau Volcanics and Devonian Cockatoo Formation (Ragged Range and Kellys Knob Members) that lies between the Burt Range Syncline on the west and the Halls Creek Mobile Zone on the east. Secondary structures within the platform are the Nigli Gap Syncline, Bucket Spring Syncline, and Policeman Anticline.

The Nigli Gap Syncline is a south-pitching syncline south of Nigli Gap; it is faulted, and is bounded by faults. The Policeman Anticline lies south-south-west of Policeman Waterhole, and is also faulted and bounded by faults. The Ragged Range Member is probably exposed in the core in the south, and Kellys Knob Member elsewhere. Dips are very low. The Bucket Spring Syncline pitches north-north-eastward, and except for its southern part is known from air-photo interpretation only.

Our mapping shows that the Ivanhoe Graben, first described by Matheson & Teichert (1948, p.78, pl.11), may be extended north-north-eastward from the Ord River to the track from Carlton to Point Spring, and is paralleled on its western side by a horst, the Tarrara Horst. As shown in Figure 16, the southern part of the Ivanhoe Graben is bounded by covered inferred faults each with an inferred throw exceeding 3,000 feet. The trends of these faults are not known except that they lie within the north-east quadrant. Northward, the eastern edge of the graben is marked by the Pincombe Inlier, and the western edge by a fault which lies 1 mile east of Tarrara Bar. The faulted Ningbing Limestone of the Jeremiah Hills and to the east is included in the Ivanhoe Graben because of its high stratigraphical position compared with strata on either side and because the main faults through it trend north-north-east. The outcropping Cambrian Clark Sandstone (Fig.19) within this area of limestone is probably a horst.

The Pretlove Homocline includes the exposed Cambrian, Ordovician, and Devonian rocks of the Pretlove Hills and the exposed Devonian sediments of the Hargreaves Hills, all of which dip 10 to 30 degrees north-eastward. Figure 3 of Kaulback & Veevers (1967) is a cross-section through the Pretlove Hills, and part of Figure 67 shows a cross-section of the Hargreaves Hills. The homocline is strike-faulted;

the Pretlove Hills consist of blocks faulted down toward the south-west and horsts; the Hargreaves Hills are a sequence of blocks uniformly faulted down towards the west-south-west, in an opposite direction to the dip.

The Onslow Platform consists of exposed low-dipping Cambrian rocks, with a single graben of Cockatoo Formation (Kaulback & Veevers, 1967). The Platform is cut by a fault which trends northward to Bald Hill. A south-east trending branch of this fault marks the eastern edge of the Onslow Platform, and continues south-eastward to join the main fault in the Pretlove Hills.

The outcrop of the Ningbing Horst coincides with the Ningbing Range. The bounding faults of the horst are covered except at the south-west tip of the Ningbing Range, and are inferred from stratigraphical relationships at the margins. The outcropping Ningbing Limestone is crossed by small-throw faults and is broadly folded into basins and domes (Fig.26).

The Elephant Faulted Platform, named after Elephant Hill, is poorly exposed. Faults are apparently the dominant structural element, and along faults in the Leichhardt Spring andBald Hill areas the Cockatoo Formation is brought against Cambrian Skewthorpe Formation and Clark Sandstone. At Westwood Creek, a faulted anticline (Fig.22) of the Cockatoo Formation pitches north-westward. In the Shakespeare Hill area, faults cut the Cockatoo Formation into numerous blocks.

The Tanmurra Fault Block of the north-west Weaber Range is bounded by the fault along the eastern edge of the Ningbing Horst and by a subsurface fault revealed by seismic surveys (Petty Geophysical, 1964).

The Moogarooga Depression is bounded on the west by this subsurface fault and on the south-east by the Legune Faulted Platform. As shown by the Bonaparte No.1 Well, the thickness of Upper Devonian and Lower Carboniferous sediments in the Depression is at least 10,000 feet.

The Legune Faulted Platform is a north-west sloping platform crossed by north-trending faults. According to seismic surveys, it possibly contains 5,000 feet of Palaeozoic sediments near the coast.

The offshore islets consist of strata that dip southward to south-westward.

The Ragged Range Faulted Outlier is crossed by the Ivanhoe Fault which marks the eastern edge of the northern half of the Outlier and the western edge of the southern half (Fig.14 of Kaulback & Veevers, 1967).

The Dillon Spring Faulted Outlier is a well-exposed half-basin of Cambrian volcanics and sediments and Cockatoo Formation bounded on the east by an unnamed fault. A similar smaller structure 4 miles east of the Dillon Outlier is truncated by the Ivanhoe Fault.

Figure 67

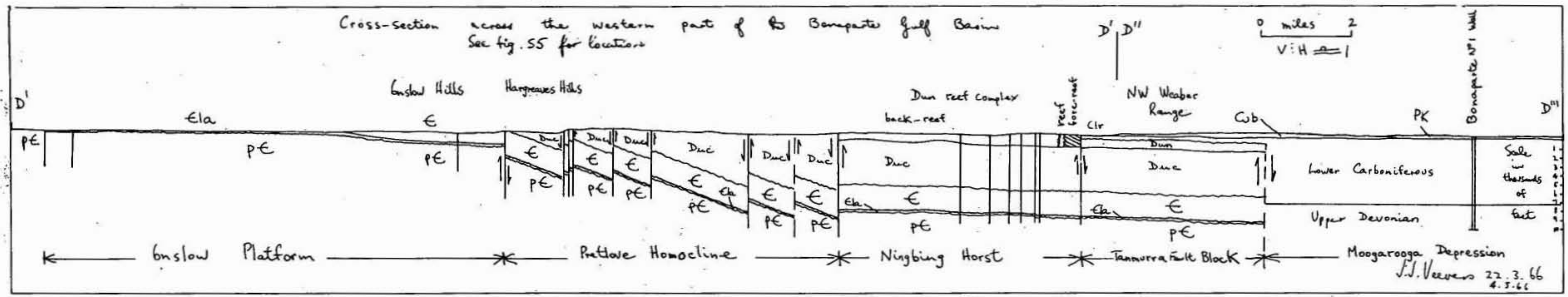

Cross-section across the western part of the Bonaparte Gulf Basin
See fig. 55 for location
D'
D''
0 miles 2
V:H = 1
Onslow Hills
Hargreaves Hills
Dun reef complex
back-reef
reef
fore-reef
NW Weaber Range
Bonaparte No 1 Well
Ɛla
Ɛ
pƐ
Duc
Dun
Clr
Cib
PK
Lower Carboniferous
Upper Devonian
Scale in thousands of feet
Onslow Platform
Pretlove Homocline
Ningbing Horst
Tanmurra Fault Block
Moogarooga Depression
J.J. Veevers 22.3.66
4.5.66

TABLE 1

PHANEROZOIC STRUCTURAL HISTORY

Age \ Area		Legune Faulted Platform	Moogarooga Depression	Tanmurra Fault Block	Ningbing Horst	Elephant Faulted Platform	Onslow Platform	Pretlove Homocline	Tarrara Horst	Ivanhoe Graben	Pincombe Inlier	Burt Range Syncline	Nigli Gap Platform	Gap Pt. Graben, Faulted Outliers of Mt. Rob and Dillon Spring	Ragged Range Faulted Outlier
Quaternary			uplift and erosion. Quaternary eustatic sea-level changes												
Miocene							? SUBSIDENCE								
Tertiary															
Cretaceous															
Jurassic															
Triassic															
Upper Permian			Faulting									Faulting			
Lower Permian															
Upper Carboniferous			Subsidence									Sub-sidence			
Namurian			Uplift and erosion									Uplift and erosion			
Visean	late		Subsidence	Sub-sidence				?Sub-sidence							
	mid		Subsidence		Uplift and erosion			Subsidence				Sub-sidence with inter-mittent faulting and uplift			
	early		Subsidence		Uplift and erosion			Uplift and erosion				Sub-sidence with inter-mittent faulting and uplift			
Tournaisian	late	Sub-sidence	Subsidence, non-deposition or erosion	Subsidence				Subsidence			Subsidence				
	mid		Subsidence, non-deposition or erosion	Subsidence				Tilting, faulting, uplift and erosion				Uplift and erosion			
	early														
Famennian			subsidence			Subsidence				Sub-sidence	Land	Subsidence			
Frasnian		Faulting & subsidence	?Subsidence	Subsidence							Uplift & erosion	Faulting and subsidence			
Middle Devonian to Middle Ordovician			UPLIFT AND EROSION												
Lower Ordovician Upper Cambrian Middle Cambrian				?Subsidence					?Subsidence					Sub-sidence at Gap Point	?Sub-sidence
						SUBSIDENCE								Sub-sidence	
Lower Cambrian	Late					erosion									Sub-sidence
	Early					uplift and erosion									
						extrusion of basalt and deposition of associated sediments									
epi-Proterozoic		Land				LAND					LAND				

NOTE: The blank parts of the table are those for which no relevant information is available.

Upper Permian: faulting
Miocene: possibly subsidence
Post-Miocene: uplift and erosion

The chief of these events are:

a) the late Lower or early Middle Cambrian subsidence that preceded Cambrian marine deposition.
b) Middle Ordovician to Middle Devonian uplift and erosion.
c) early Frasnian differential movements initiating Upper Devonian to Lower Carboniferous marine deposition.
d) early to middle Tournaisian faulting, uplift, and erosion, most intense in the south-western part of the basin.
e) Namurian uplift and erosion.
f) later Upper Carboniferous to Lower Permian: subsidence initiating deposition of Upper Carboniferous - Lower Triassic sequence.
g) Upper Permian: faulting

The final episode of faulting is naturally the one whose age is least precisely known. It probably immediately predates the Upper Permian unconformity in the Port Keats area.

Some of these events more or less correspond in time with allegedly widespread earth movements, such as event (c) with the epi-Middle Devonian Tabberabberan Orogeny of eastern Australia. According to recent work, the Tabberabaran Orogeny is possibly older (epi-Lower Devonian) than hitherto determined, so that event (c) would be much younger than the Tabberabaran Orogeny. However, a glance at Table 1 shows that most of the events are limited to a few areas within the Bonaparte Gulf Basin itself, and, at least during the Upper Devonian and Lower Carboniferous, span an almost continuous range of time, so that, with the exception of the initial early Upper Devonian event, none of these events can be singled out as a major widespread earth movement.

<u>Explanatory notes to Table 1</u>

These notes refer to points not already covered in the text.

The Cambrian and Ordovician history is based on information given in Kaulback & Veevers (1967), which should be consulted for details.

The possible subsidence in the Miocene refers to a widespread marine transgression at this time, described by Lloyd (1967).

Van Andel & Veevers (1967) outline the Quaternary, in particular the Holocene, eustatic sea-level changes in this area.

GEOLOGICAL HISTORY

Hitherto in this report, we have concentrated on descriptive geology, and eschewed the genetic. This is because further laboratory work remains to be done to complete this project; this should barely affect the foregoing description of the field geology but the interpretation of this geology will we hope be much improved. Accordingly, this chapter on geological history is preliminary, and some of the interpretations given below will probably have to be revised in the light of laboratory work.

This revision, together with what we hope will be a deeper analysis of the determining factors of the geological history of the Bonaparte Gulf Basin, will appear in our concluding bulletin.

This account of the Upper Devonian and Carboniferous geological history of the southern part of the Bonaparte Gulf Basin is presented in a series of regional reconstructions accompanied by a brief commentary.

A reconstruction of the solid geology of the area immediately before the deposition of the Cockatoo Formation is shown in Figure 68. In broad terms, this surface consisted of Precambrian rocks on the east and south-east, and passed through Lower Cambrian volcanics and sediments to Upper Cambrian and Lower Ordovician sediments in the north-west. Except in a few places, the Cambrian and Ordovician sediments were sub-horizontal. Because the thickness of the Cambrian and Ordovician sedimentary sequence exceeds 4,000 feet, structure dominated over morphology in determining this distribution. Whether the regional structure was a homocline with low west dip, or a fault structure, or a combination of both, is not known.

A marine invasion accompanied the earth movements which affected the area in the early Upper Devonian (Fig.69). Conglomerate and red sandstone were deposited at the foot of high ground that marked the eastern margin of the basin, and at the foot of the southern side of the Pincombe Inlier. The conglomerate passed basinward into white sandstone, which, in turn, possibly passed laterally into dark siltstone and shale. A low shore-line in the north-western part of the area is postulated to account for the deposits of thick sandstone (Kellys Knob Sandstone Member) in this part of the basin. The land to the west shed sand and probably also mud but no gravel. The exact position of the postulated shore-line is unknown: the best estimated position is shown in Figure 69. The southern continuation of the postulated shore-line is also unknown. The basal sandstone of the Cockatoo Formation in the outliers of Gap Point and Dillon Spring is close enough to the eastern margin of the basin to have come originally from this side so that the shore-line may have lain a considerable distance westward.

Islands were dotted along the north-east coast-line. The Pincombe Inlier was a small island with a high south coast (as shown in Figure 69) or with south-flowing drainage. Conglomerate was deposited along the southern shore, and quartz sandstone to the north and north-east.

The postulated deposition of dark shale and siltstone in the centre of the basin anticipated Famennian and Lower Carboniferous depositional patterns.

A waning supply of coarse sand later in the Frasnian (Fig.70) was accompanied by the spread of calcareous deposits over the area previously covered by sand so that coarse terrigenous detritus was deposited along only the eastern shore. The postulated western shore intermittently yielded sand, and, in a period of abated sand deposition, incipient reefs were deposited at least in the Westwood Creek area. We postulate continued deposition of shale and siltstone in the centre of the basin.

Following this phase of deposition, the surrounding land was uplifted and a thick layer of sand (Cecil Sandstone Member) was deposited over the area except in the central part where postulated shale and siltstone

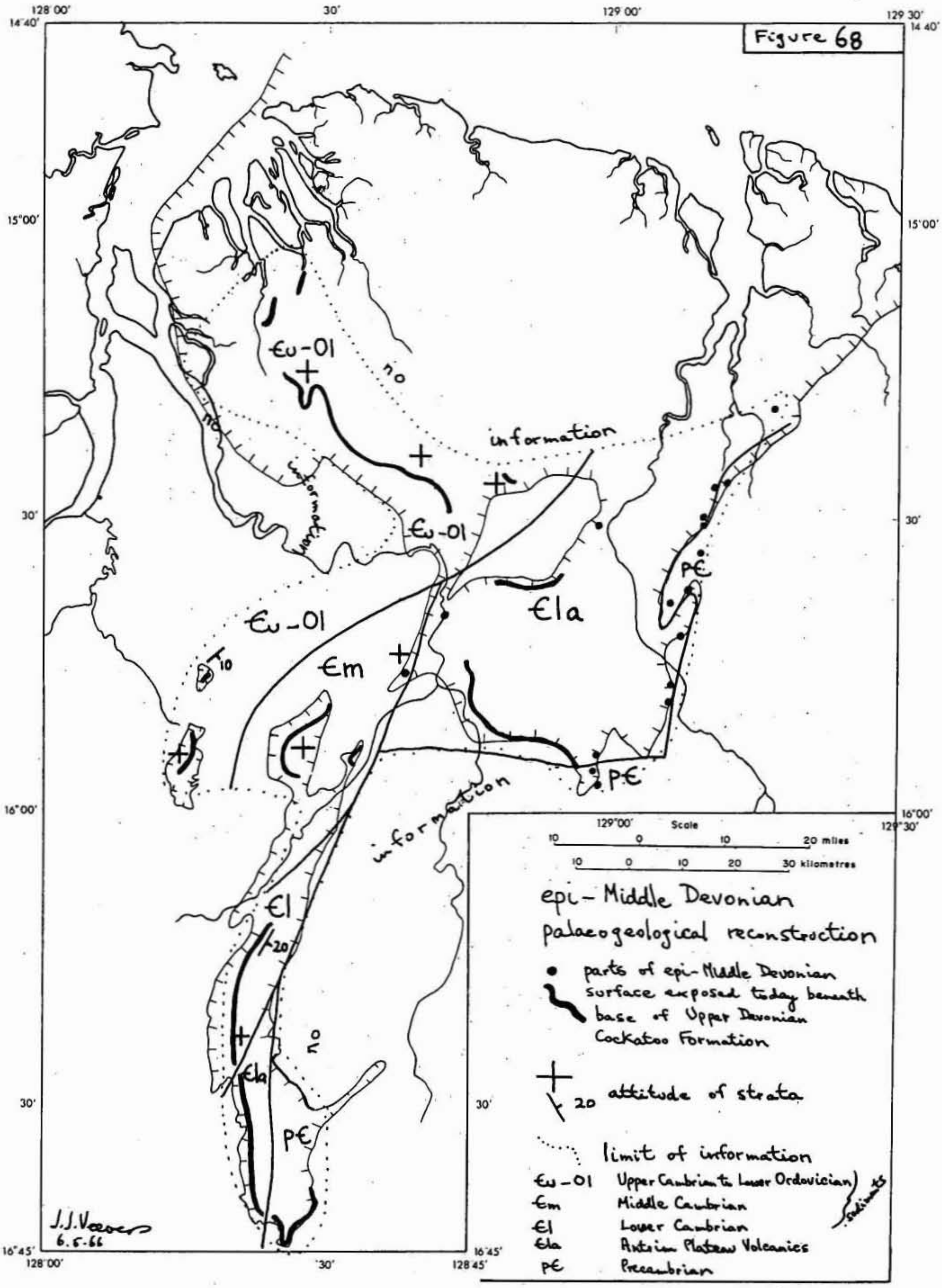
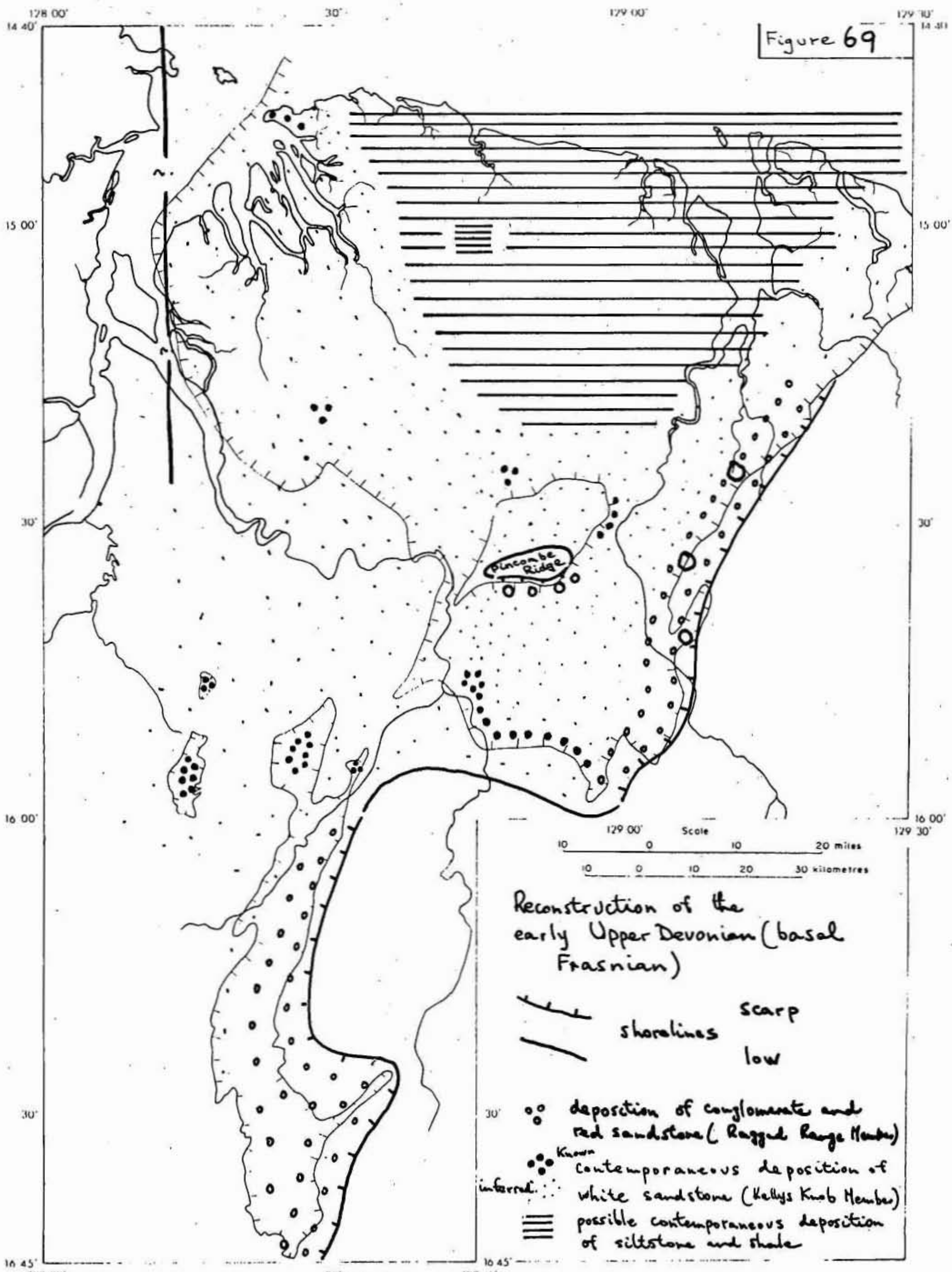
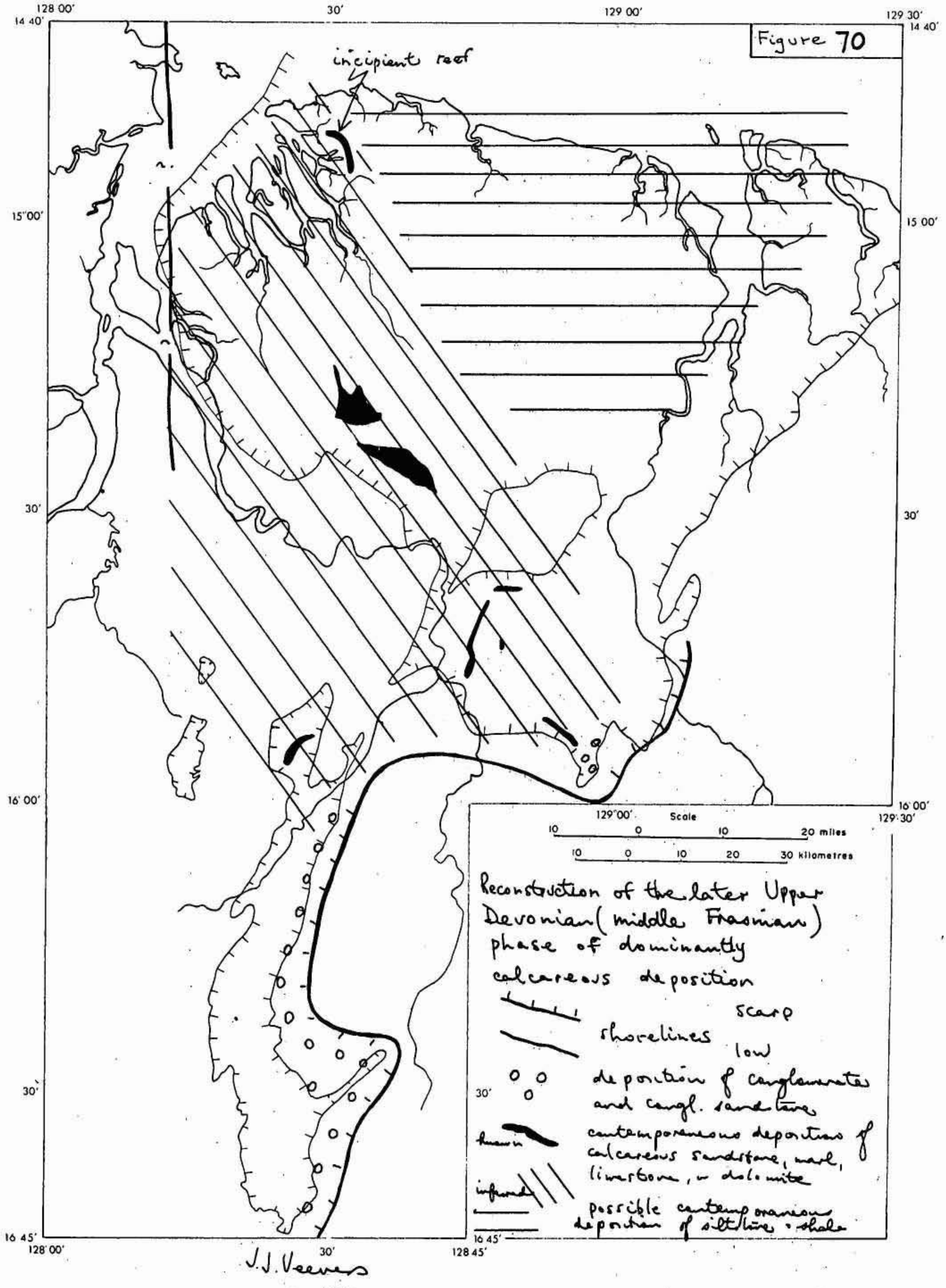


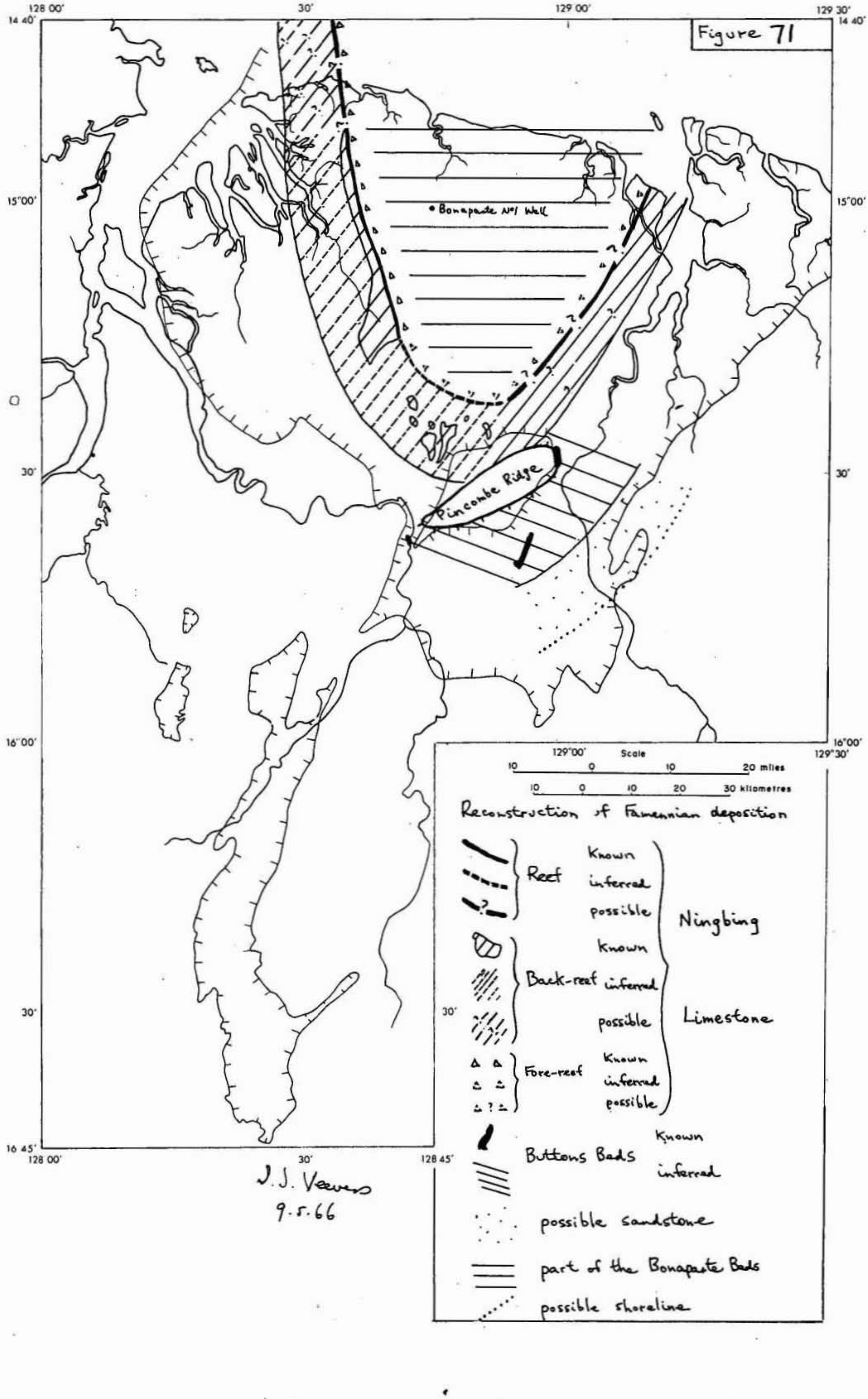
Figure 68
128°00'
30'
129°00'
129°30'
14°40'
15°00'
30'
16°00'
16°45'
128°45'
Єu-01
Єm
Єla
Єl
pЄ
no information
10
20
epi-Middle Devonian
palaeogeological reconstruction
parts of epi-Middle Devonian surface exposed today beneath base of Upper Devonian Cockatoo Formation
attitude of strata
limit of information
Єu-01 Upper Cambrian to Lower Ordovician
Єm Middle Cambrian
Єl Lower Cambrian
Єla Antrim Plateau Volcanics
pЄ Precambrian
sediments
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
J.J. Veevers
6.5.66



J.J. Veevers 9.5.66



J.J. Veevers
9.5-66



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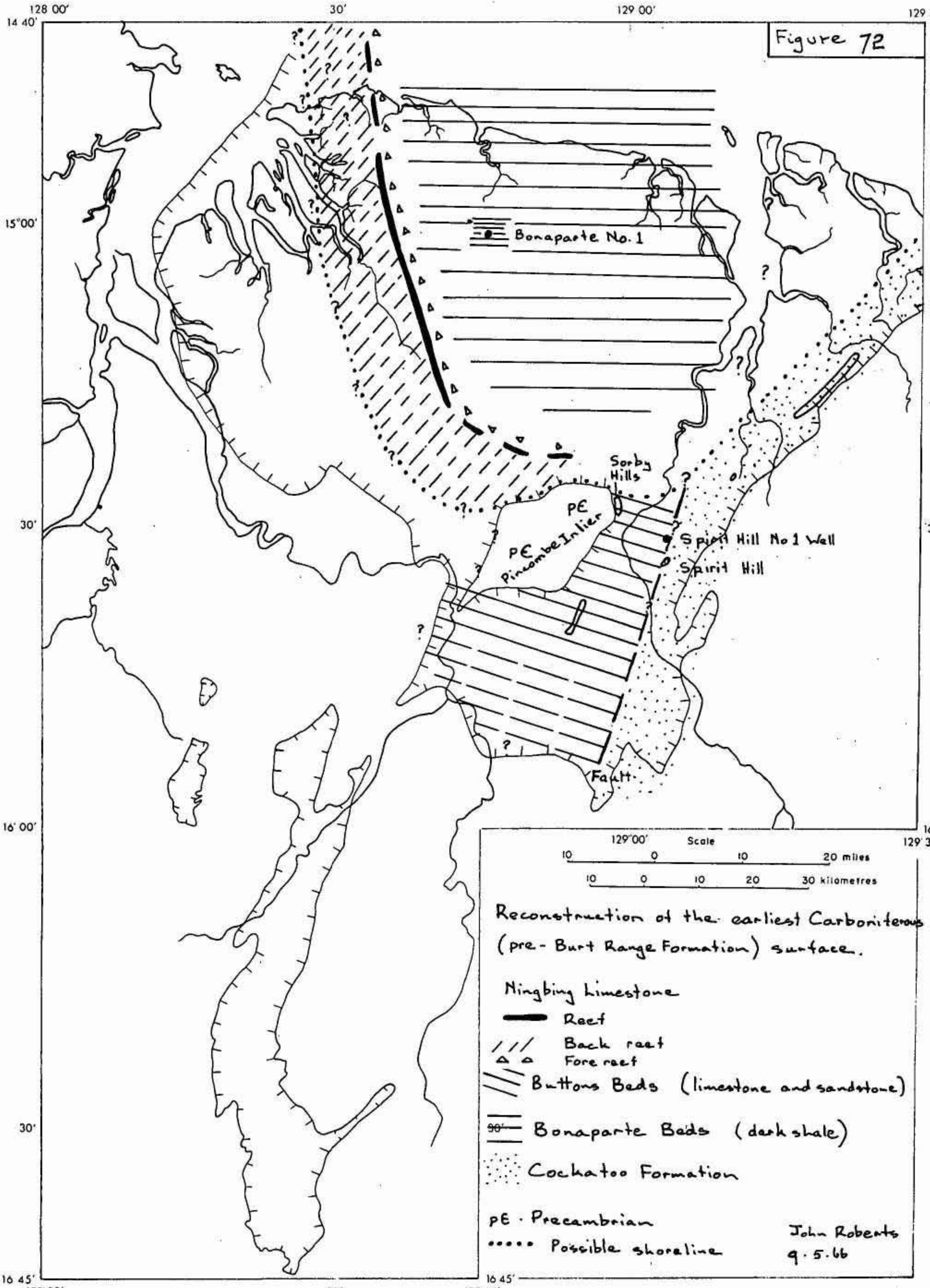
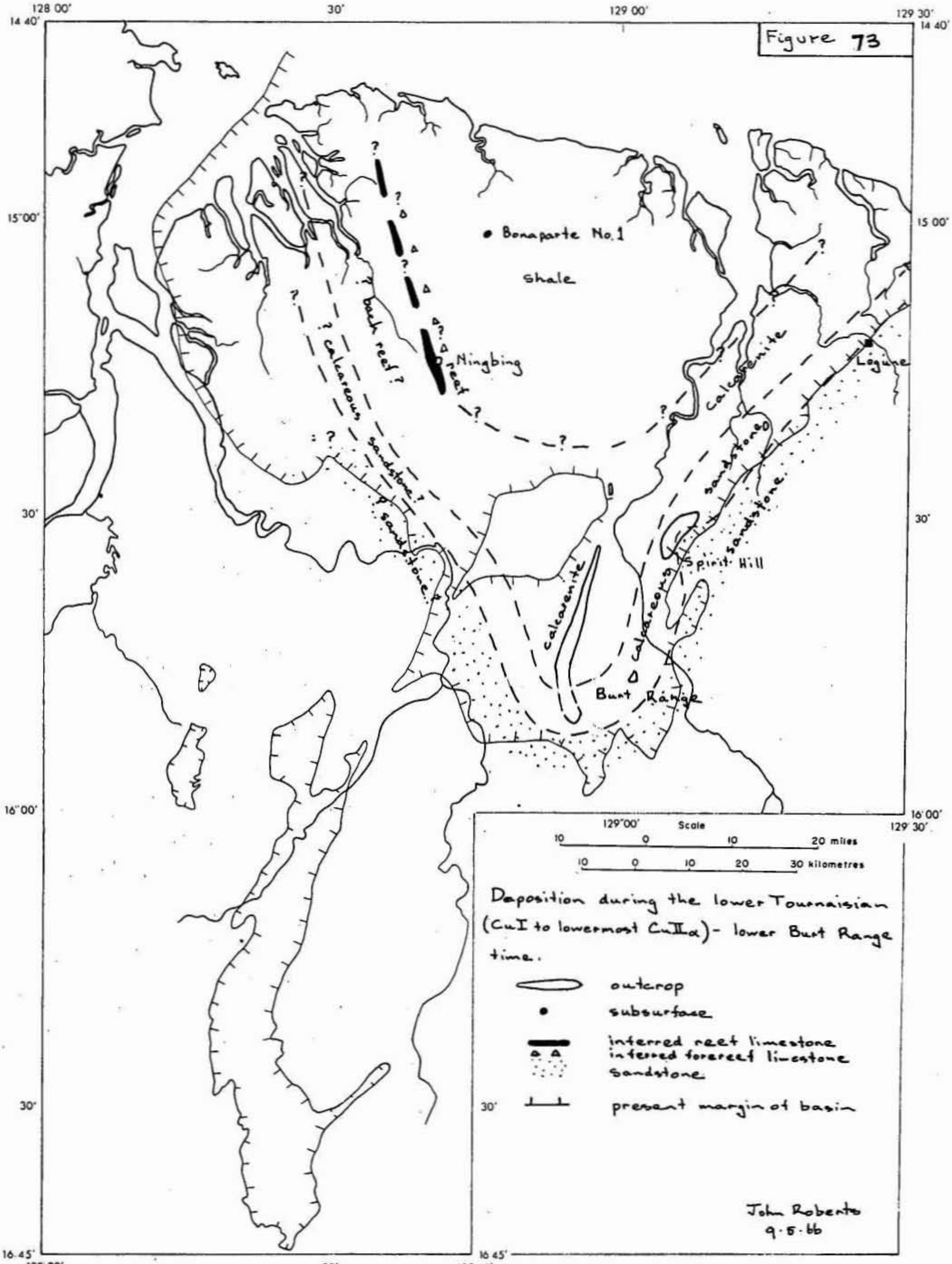


Figure 72
128 00'
30'
129 00'
129 30'
14 40'
15°00'
15 00'
30'
16'00'
16 45'
128 45'
Bonaparte No. 1
Sorby Hills
PЄ
PЄ Pincombe Inlier
Spirit Hill No 1 Well
Spirit Hill
Fault
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Reconstruction of the earliest Carboniferous (pre-Burt Range Formation) surface.
Ningbing Limestone
Reef
Back reef
Fore reef
Buttons Beds (limestone and sandstone)
Bonaparte Beds (dark shale)
Cockatoo Formation
PЄ · Precambrian
Possible shoreline
John Roberts
9 · 5 · 66



Deposition during the lower Tournaisian (CuI to lowermost CuIIα) - lower Burt Range time.

were deposited.

A second phase of carbonate deposition took place during the Famennian (Fig.71), probably due in part to the reduced supply of terrigenous detritus. Sediments were deposited in four belts: dark siltstone and shale (Bonaparte Beds) were deposited in the central part of the basin; a carbonate reef complex (Ningbing Limestone) was deposited on the western side of the basin and possibly also on the eastern side; sandy and silty limestone (Buttons Beds) was deposited on the landward side of the reef; and a belt of postulated quartz sandstone was deposited along the shore. At least in one place - the north-east tip of the emergent Pincombe Inlier - the Buttons Beds were deposited along the shore.

Late in the Devonian or early in the Carboniferous the eastern and southern parts of the basin were uplifted and eroded, and the sea withdrew to north of the emergent Pincombe Inlier (Fig.72). The fault shown in Figure 72 suggests that the rocks have been stepped upwards towards the east; it was postulated because the Burt Range Formation overlies Buttons Beds to the west of the fault line and Cockatoo Formation to the east and northeast of the line; strata in these areas were flat lying.

Despite the migration of the shoreline, the reef complex appears to have continued growing along the western margin. No limestone of this age (Famennian to VI) is known south of Ningbing and the reefs shown near the Pincombe Inlier are only postulated. Fore-reef limestone probably passed eastwards into dark shale and siltstone.

In the lower Tournaisian the sea returned to the eastern and southern parts of the basin, apparently covering the Pincombe Inlier as well as the eroded Buttons Beds and Cockatoo Formation (Fig.73). The basal lower Tournaisian rocks are free of any debris incorporated from the sandier Devonian rocks, which suggests that the sea moved rapidly into the area.

Our knowledge of deposition in the lower Tournaisian is mainly confined to the southern and eastern parts of the basin. Marine sandstone, deposited close to the shore, passed seawards into calcareous sandstone which in turn passed into calcarenite (all Burt Range Formation) and finally into shale in the central part of the basin. An exception to this general statement is the lower Tournaisian sandstone in the Sorby Hills, at the tip of the Pincombe Range. This sand could have been derived from the Pincombe Inlier, but we maintain, because calcarenite in the Burt Range is close to the Pincombe Inlier, that it is more likely to have come from the eastern edge of the basin near Spirit Hill. At this time at Spirit Hill there were at least two periods of erosion followed by the deposition of quartz sandstone containing scattered pebbles and boulders. The lower Tournaisian shore intermittently crossed the Spirit Hill area but is not shown in Figure 73. It was probably only a short distance from the marine sands because, as mentioned above, some of these contain coarse clastic material.

Reef limestone grew near the western margin of the basin near Ningbing and probably extended northwards along the trend of the Famennian reefs. There is no evidence of other rocks of this age in the western part of the basin and so we postulate back-reef and fore-reef limestone, with the back-reef presumably passing into calcareous sandstone and sandstone towards the shore. The fore-reef limestone probably passed laterally into dark shale and siltstone towards the centre of the basin.

In the middle Tournaisian (CuIIα or upper Burt Range time) the western part of the basin was profoundly faulted, tilted and uplifted (Fig.74). Rapid erosion of the Precambrian, Cambrian, Ordovician and Devonian rocks (mainly sandstone, with some dolomite and basic volcanics) supplied a vast quantity of detritus which, we postulate, was deposited at the mouth of the ancient Waggon Creek Valley, south of Ningbing. The valley may have been a gap in the reefs as early as the Devonian or may have been formed by the erosion in the middle Tournaisian. A barrier formed by the reef complex to the north probably prevented detritus from reaching the coast, and caused most of it to be funnelled through the Waggon Creek Valley. The calcareous sand and calcarenite 'facies' shown along the western side of the basin (Fig.74) are conjectural. They are thought to pass laterally into dark shale.

The faulting and uplift of the western side of the basin may be reflected by the possible dipmeter unconformity between 7,472 and 7,520 feet in the shale in Bonaparte No.1 Well.

There was uninterrupted deposition in the Burt Range area, but movement on faults or upwarping to the east and northeast caused uplift and erosion, particularly at Spirit Hill and at the northern end of the Burt Range Amphitheatre. The shore was thus west of these localities (Fig.74); the position of the shore on the southwestern margin of the basin is conjectural.

Slightly later in the middle Tournaisian (basal Enga time) the area between the Burt Range Amphitheatre and Spirit Hill and probably the whole eastern margin of the basin sank beneath the sea and the various facies - sand, calcarenite and sandy limestone, and shale-shifted short distances towards the east and south (Fig.75). The sand became coarser towards the shore and at one locality immediately north of the Keep River contains quartzite boulders. Carbonate was less important than earlier in the Tournaisian, as reflected by the narrower band of sandy limestone and calcarenite. The rocks passed basinwards into marl and shale, such as those at locality 102/4 on the northern end of Enga Ridge, which are postulated as being continuous with the dark shale in the central part of the basin.

At Waggon Creek the sea lapped on to cliffs of dolomite and sandstone (Cockatoo Formation) and deposited a dolomite breccia. This marks a firm point on the western shore, which we continue northwards along the eastern margin of the Famennian and lower Tournaisian reef complex. We have no knowledge of the sediments deposited along this shore.

Sedimentation continued in the Burt Range area and along the southeastern margin of the basin until the late Tournaisian or early Visean, with the deposition of alternating sand and calcarenite (i.e. the remainder of the Enga Sandstone, the Septimus Limestone and the Zimmermann Sandstone). Deposition of the different rock types was probably controlled by the availability of sediment.

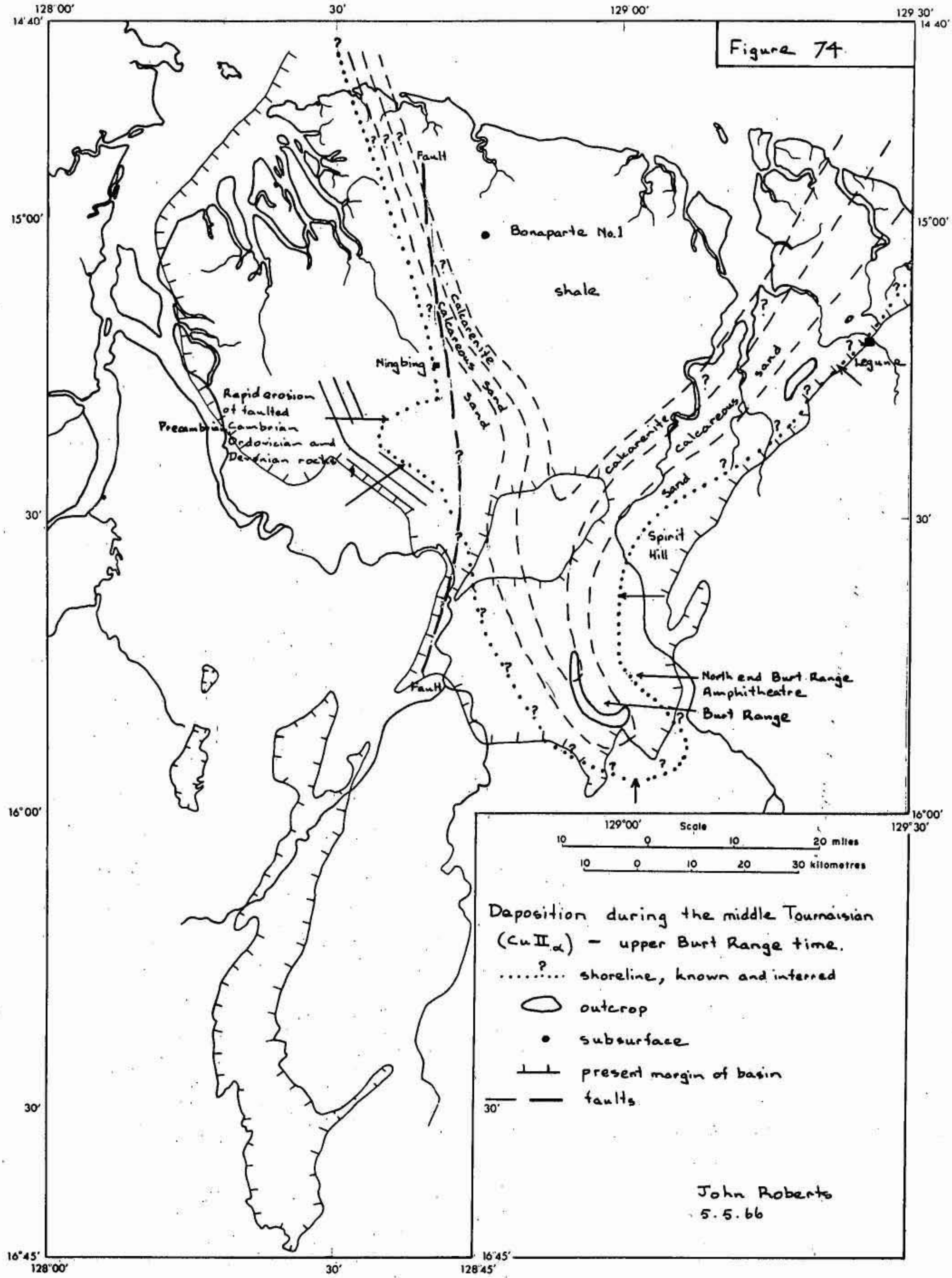


Figure 74
Fault
Bonaparte No.1
shale
Calcarenite
Calcareous sand
Ningbing
sand
Rapid erosion of faulted Cambrian Ordovician and Devonian rocks
Precambrian
Calcarenite
Calcareous sand
sand
Legune
Spirit Hill
North end Burt Range Amphitheatre
Burt Range
Fault
Scale
20 miles
30 kilometres
Deposition during the middle Tournaisian (Cu II α) – upper Burt Range time.
shoreline, known and inferred
outcrop
subsurface
present margin of basin
faults
John Roberts
5.5.66

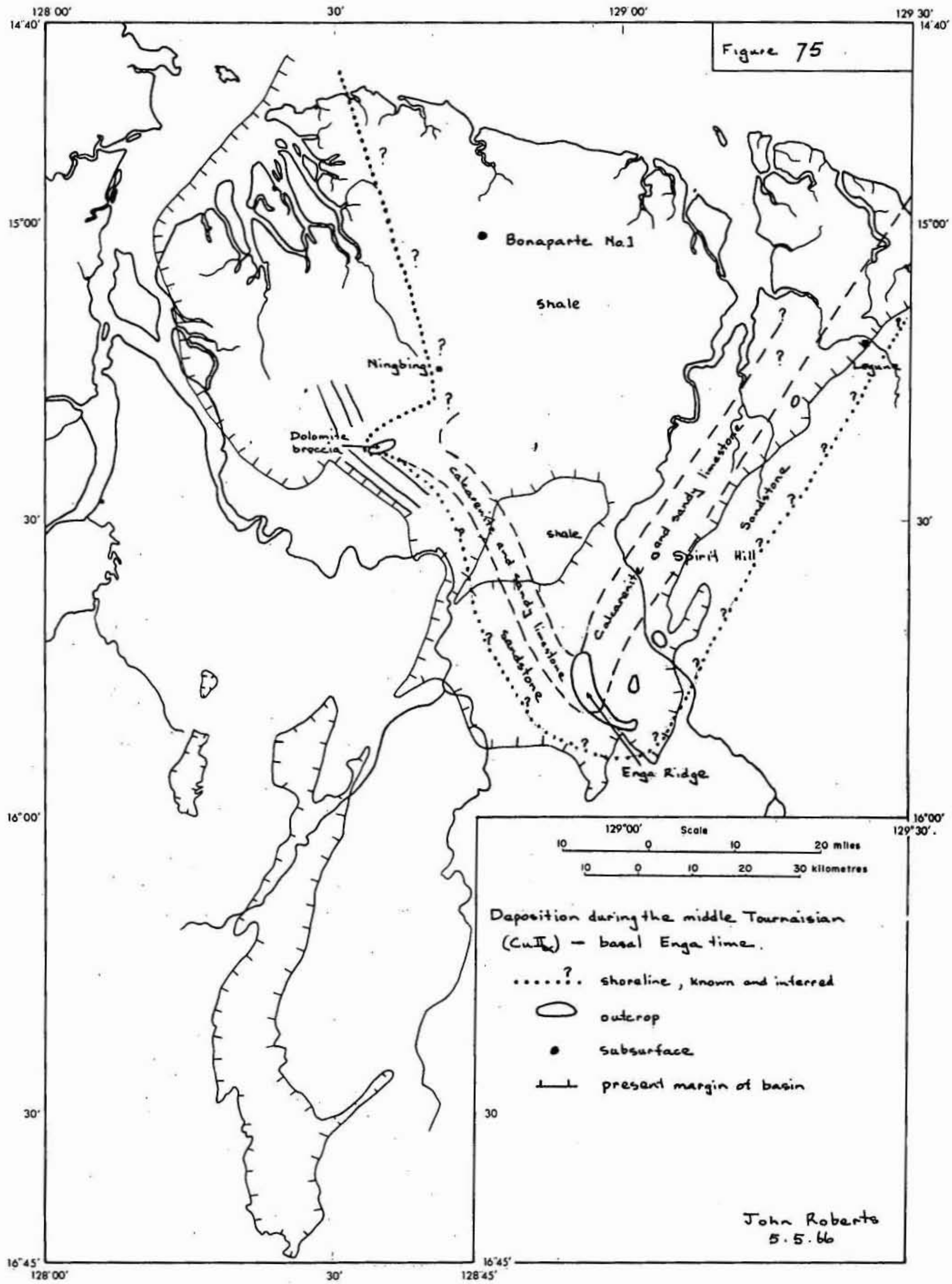


Figure 75
128°00'
30'
129°00'
129°30'
14°40'
15°00'
16°00'
16°45'
128°45'
Bonaparte No.1
Shale
Ningbing
Dolomite breccia
Calcarenite and sandy limestone
Sandstone
Shale
Spirit Hill
Calcarenite and sandy limestone
Sandstone
Legune
Enga Ridge
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Deposition during the middle Tournaisian
(CuII) – basal Enga time.
shoreline, known and inferred
outcrop
subsurface
present margin of basin
John Roberts
5.5.66

Early in the Visean the southern and eastern part of the basin, in particular the area around Spirit Hill, emerged and was eroded. We do not know whether the Burt Range area was land, but it seems likely that it was not eroded to the same extent as the Spirit Hill area which was stripped of the Septimus Limestone and most of the Enga Sandstone (Fig.60). We have no knowledge of lower Visean rocks except for the dark shale deposited in the centre of the basin.

In the middle and upper Visean the sea spread across the Spirit Hill area and also re-entered the Waggon Creek Valley (Fig.76). Dark shale with minor sandstone and conglomerate (Milligans Beds) were deposited between Milligans Hills and Spirit Hill. Shale from Spirit Hill No.1 Well contains a high percentage of the mineral kaolinite which suggests that the shale was deposited close to the margin of the basin (Loughnan, Appendix 1). This shale has thus been termed nearshore shale (Fig.76). Loughnan has not examined shale from Waggon Creek Valley but because it was deposited close to the margin of the basin it too is classed as nearshore shale.

The dark shale in Bonaparte No.1 and No.2 Wells (Bonaparte Beds) contains a higher percentage of the mineral illite and, according to Loughnan (Appendix 1), was deposited away from the influence of land; it is termed an offshore shale (Fig.76).

It is not known whether the nearshore and offshore shales belong to a single shale body or whether the onshore shales accumulated as separate bodies in a restricted environment. The interpretation in Figure 60 is that they belong to a single body and that the onshore shales are merely tongues projecting from the central mass.

Because the nearshore shales are close to the coastline it seems likely that the widespread distribution of shale resulted from the absence of coarse detritus from the deeply eroded source area, rather than from a widespread marine transgression in which the shoreline would have moved landward many tens of miles.

In the northwestern part of the basin calcarenite (Utting Calcarenite) accumulated on a shallow platform close to the shore. Some beds in the calcarenite contain coarse sand and conglomerate pebbles which must have been derived from the land area to the west. The calcarenite is thought to pass basinwards into dark shale.

In the upper Visean the sea regressed and coarse alluvial sand was deposited in a wide belt running parallel with the western and southwestern shores. With the return of the sea a short time afterwards these coarse sands were reworked and incorporated into beach deposits (Burvill Beds). Sea level probably fluctuated during this time and Figure 77 gives an indication of the narrowest and widest extent of the sea. As the sea moved into the Waggon Creek Valley it incorporated the alluvial sediments into a basal pebbly sandstone, which was consolidated as beach rock, and then attacked the nearby cliffs of dolomite and sandstone (Cockatoo Formation). The sandstone was friable and easily eroded, leaving exposed cliffs and stacks of dolomite. These were undermined, collapsed into a jumbled mass of blocks, and were mixed with boulders of quartzite and coarse sand brought down and dumped in the piedmont valleys along the hills surrounding the valley. These deposits (Waggon Creek Breccia) are described in detail by Veevers and Roberts (1967).

The movement of the sea into the Waggon Creek Valley was probably caused by subsidence in that area rather than by a widespread marine transgression. There does not seem to have been a rise in sea level throughout the basin, and from the nature of the sediments in Bonaparte No.1 and No.2 Wells (dolomite and dolomitic sandstone) it seems likely that there was actually a regression of facies so that, for the first time in the Devonian and Carboniferous, the dark shale in the centre of the basin was covered by rocks characterising the marginal deposits. We assume that the dark shale moved further out into the basin.

In the latest Visean or earliest Namurian the source area provided a supply of quartz sand (Point Spring Sandstone) which was deposited in more or less the same areas as the upper Visean calcareous grit and breccia. The sandstone appears to be a regressive deposit and contains marine beds as well as coarse, cross-bedded barren beds which could be non-marine.

Between the early Namurian and the Upper Carboniferous the basin was uplifted and eroded. The deepest erosion was in the south, particularly in the Burt Range (Fig.55) which suggests that the uplift was caused by upwarping or upfaulting in the south. These or later movements also rejuvenated the source area and coarse clastic sediments accumulated in alluvial deposits (Border Creek Formation) across a large part of the basin (Fig.78). These rocks were later overlain by Permian glacial deposits (Keep Inlet Beds).

The Lower Carboniferous depositional provinces, at least the marginal and inner provinces, are not so clear cut as those of the Upper Devonian. The outer province is still clearly distinguished by deposits of dark siltstone and shale but the marginal and middle provinces overlap each other and, where distinguishable, the marginal province is very narrow.

In describing the Carboniferous depositional history we therefore refer to areas rather than to depositional provinces (Fig.61). The areas are the Keep River area extending from the southern part of the Burt Range to Spirit Hill; the Central area around the Bonaparte No.1 and No.2 Wells which corresponds to the Upper Devonian outer province; and the Surprise Valley area extending from Utting Gap to Ningbing Station and into the Waggon Creek Valley.

The stratigraphic relationships between the Carboniferous formations are shown in Figure 61, a diagrammatic cross section extending northwestwards across the Keep River area into the Central area, and then turning southwestwards into the Surprise Valley area. The time relationships of the formations (i.e. correlation with the Carboniferous goniatite zones of Germany) are shown in Figure 32. Detailed relationships between individual sections in the Burt Range Formation are shown in Figure 35, between the formations in the Central Burt Range in Figure 42, and the Border Creek disconformity in Figure 55.

The diagrammatic section (Fig.61) shows that the Lower Carboniferous formations are sandy or conglomeratic near the margins of the basin, calcareous or finer grained away from the margin, and interfinger with

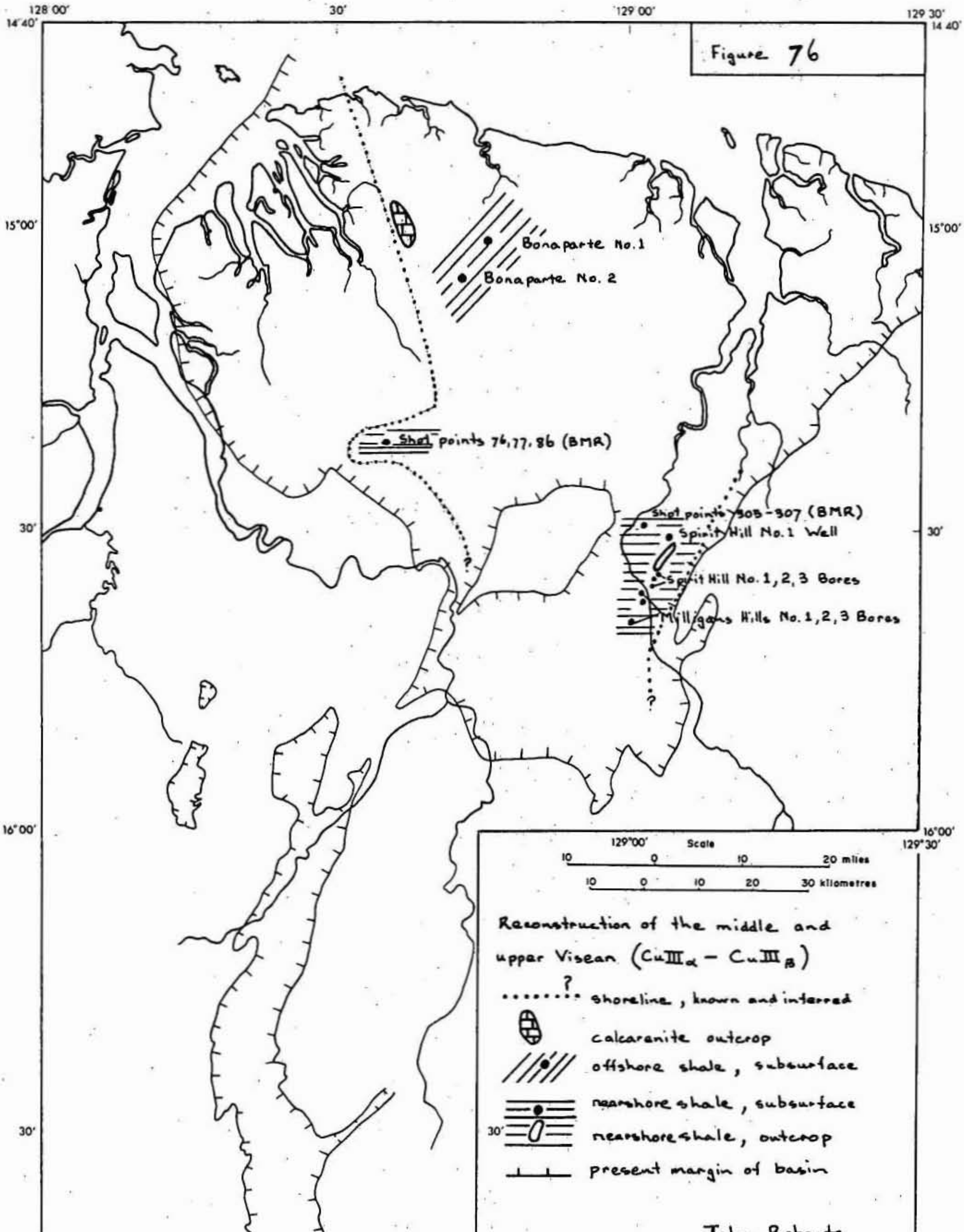
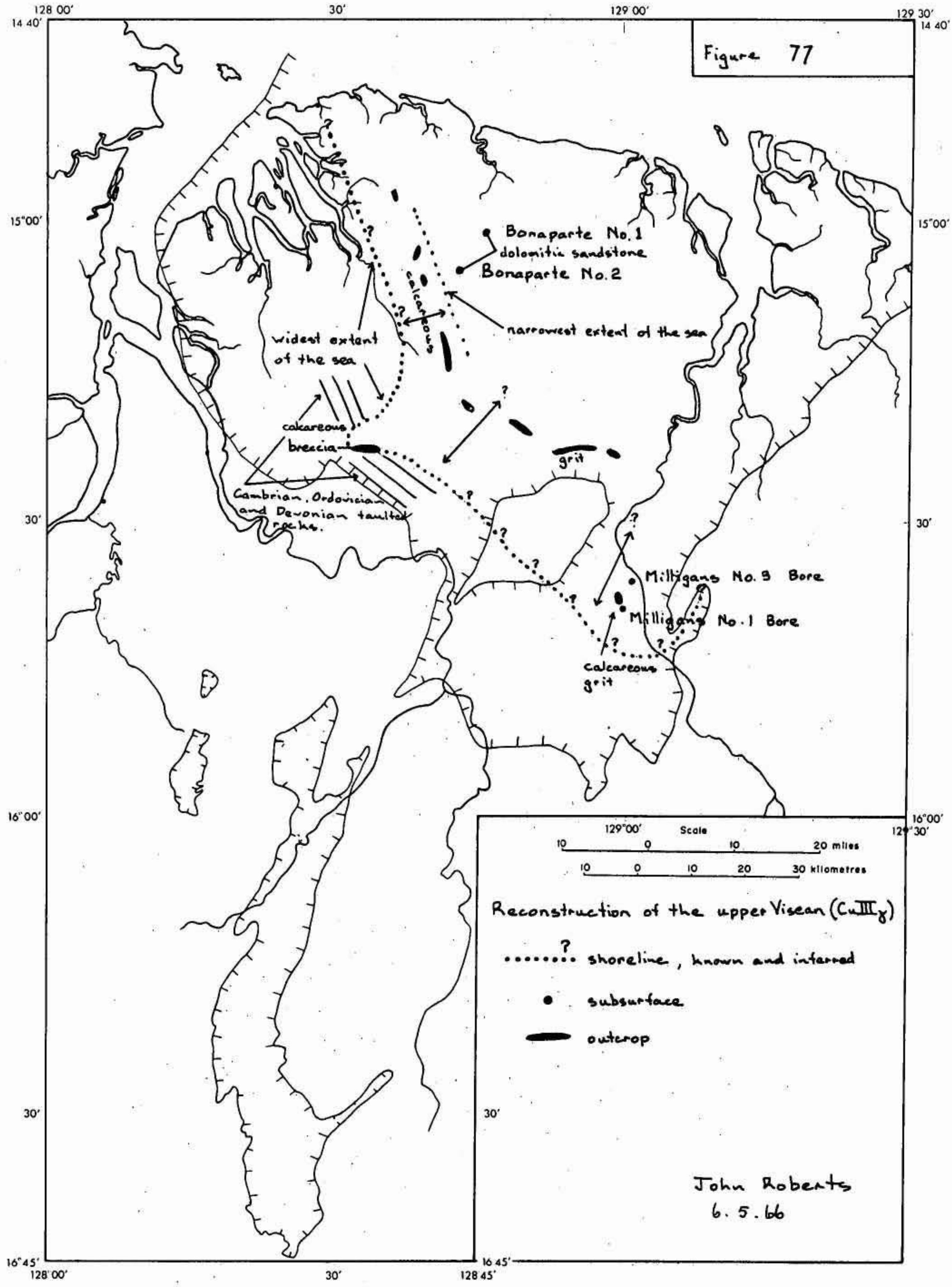


Figure 76
128°00'
30'
129°00'
129°30'
14°40'
15°00'
30'
16°00'
16°45'
128°45'
Bonaparte No.1
Bonaparte No. 2
Shot points 76, 77, 86 (BMR)
Shot points 303 - 307 (BMR)
Spirit Hill No.1 Well
Spirit Hill No. 1, 2, 3 Bores
Milligans Hills No. 1, 2, 3 Bores
?
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Reconstruction of the middle and upper Visean (CuIIIα – CuIIIβ)
shoreline, known and inferred
calcarenite outcrop
offshore shale, subsurface
nearshore shale, subsurface
nearshore shale, outcrop
present margin of basin
John Roberts
6.5.66



128 00'
30'
129 00'
129 30'
14 40'
15°00'
30'
16°00'
16°45'
Figure 77
Bonaparte No. 1
dolomitic sandstone
Bonaparte No. 2
calcareous
narrowest extent of the sea
widest extent of the sea
calcareous breccia
grit
Cambrian, Ordovician and Devonian faulted rocks.
Milligans No. 3 Bore
Milligans No. 1 Bore
calcareous grit
129°00'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Reconstruction of the upper Visean (CuIIIγ)
shoreline, known and inferred
subsurface
outcrop
John Roberts
6.5.66

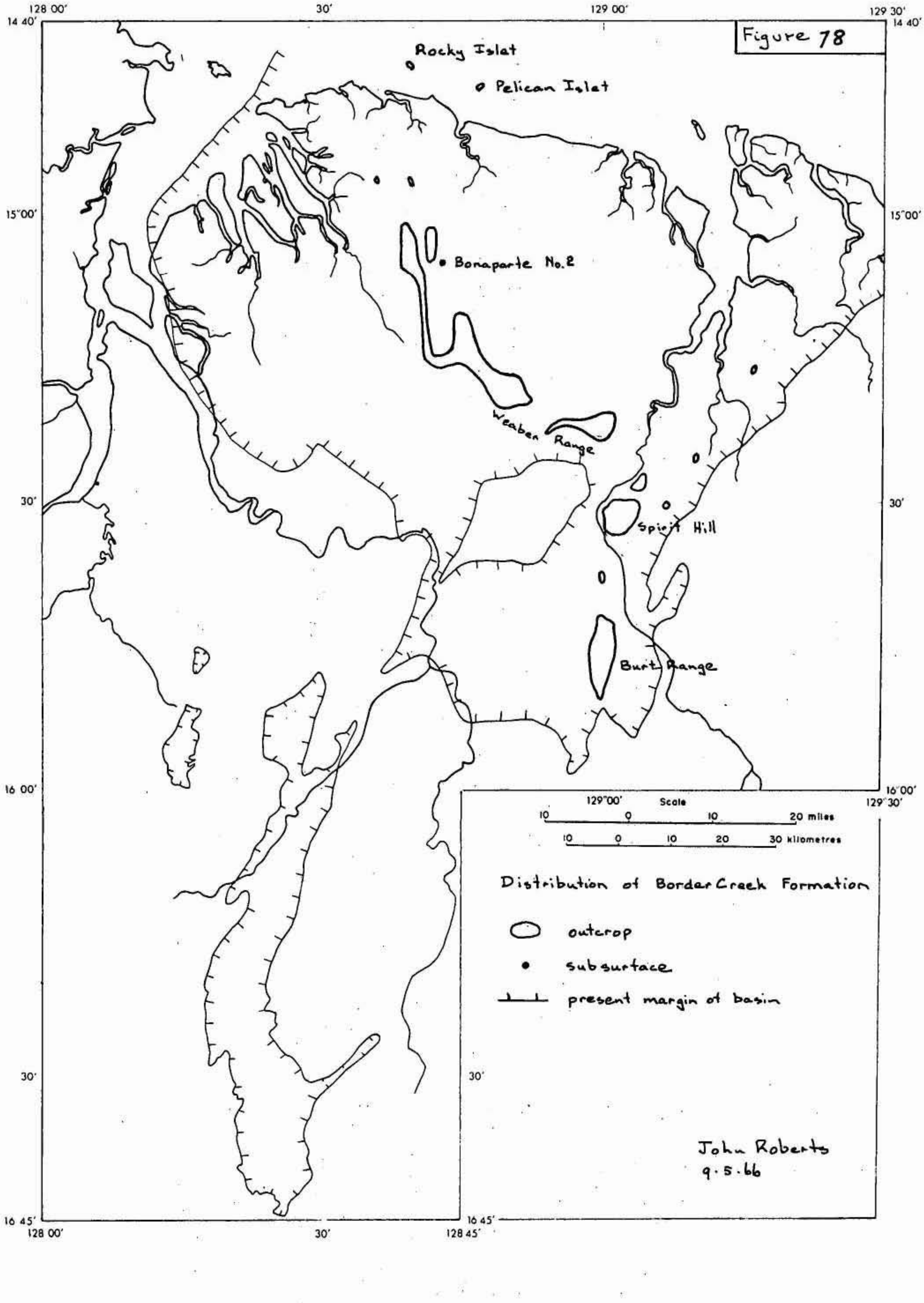


Figure 78
Rocky Islet
Pelican Islet
Bonaparte No. 2
Weaben Range
Spirit Hill
Burt Range
128 00'
30'
129 00'
129 30'
14 40'
15°00'
16 00'
16 45'
128 45'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Distribution of Border Creek Formation
outcrop
subsurface
present margin of basin
John Roberts
9.5.66

dark shale or siltstone in the Central area, which is analogous with the changes in the Upper Devonian formations. The Carboniferous formations, however, have a much narrower outcrop and are intrinsically more variable than the Upper Devonian formations or members. The variation within the formations follows Walther's Rule - that facies vary in analogous manner both horizontally and vertically.

During the Tournaisian, alternating limestones and sandstones were deposited in the Keep River area. The limestones became sandier and the sandstones coarser grained or conglomeratic towards the margin of the basin and hence the alternation between limestone and sandstone can be interpreted as a lateral shift of facies. The Burt Range Formation passes from a skeletal calcarenite to a calcareous sandstone, and finally (in part) to a pure quartz sandstone near the eastern margin of the basin. Boulders of Precambrian quartzite and coarse-grained sandstone are present in the easternmost outcrops of the Enga Sandstone, and the sandstone becomes finer grained away from the margin; carbonates in the base of the Enga Sandstone become shaley towards the central area. The Septimus Limestone parallels the Burt Range Formation and is sandier in the east.

Less is known of Tournaisian rocks in the Surprise Valley area. The oldest Carboniferous rocks are the lower to middle Tournaisian reef limestones at locality 7/1 near Ningbing which are indistinguishable from the surrounding Upper Devonian reef limestone and appear to be an integral part of the Ningbing Limestone. Reef growth may have continued from the Devonian into the Carboniferous, or there was a hiatus between the Devonian and Carboniferous and reef growth was re-established in the lower to middle Tournaisian (Fig.30).

In the middle Tournaisian, after the faulting, tilting and erosion of the Precambrian, Cambrian, Ordovician and Devonian rocks in the Pretlove, Hargreaves and Onslow Hills, the sea moved into the Waggon Creek Valley and deposited a dolomite breccia at locality 210/6 which is equivalent to the lower part of the Enga Sandstone.

In the Keep River area there was a break in sedimentation during the lower Visean, followed in the middle to upper Visean by the deposition of the Milligans Beds. The dark shale and siltstone of the Milligans Beds were deposited either as a result of an extensive marine transgression or were deposited in a restricted basin because the source areas had been deeply eroded and were not supplying coarse detritus. Support for the latter theory is provided by (a) the underlying fine to medium grained Zimmermann Sandstone which becomes silty towards the top, indicating a lowering of the source area; and (b) the high kaolinite and relatively low illite content in the Milligans Beds which Loughnan (Appendix 1) believes to indicate proximity to the margin of the basin.

In the upper Visean the Milligans Beds are succeeded by the Burvill Beds, a widespread gritty limestone which probably accumulated on a beach. Around Point Spring the Burvill Beds are carbonate rich, and they become increasingly rich in shale towards the Central area. The rising sea cut into cliffs of colomite and sandstone on the southern margin of Waggon Creek Valley and deposited a coarse, reworked basal sandstone and an extremely coarse dolomite breccia (Waggon Creek Breccia).

In the uppermost Visean or lower Namurian the Burvill Beds are succeeded by the Point Spring Sandstone. Both of these formations may be equivalent to the dolomitic Tanmurra Formation, in the subsurface of the Central area.

Following the deposition of the Point Spring Sandstone the greater part of the basin was uplifted and extensively eroded. In the Upper Carboniferous, further uplift of the source areas, presumably around the basin margins, resulted in the deposition of fluviatile conglomerates, sandstone and siltstone of the Border Creek Formation.

Geomorphology

by J. Hays

In a study of mature erosion surfaces in the northern part of the Northern Territory, Hays (in press) has idenfitied the Ashburton, Tennant Creek, Wave Hill, and Koolpinyah surfaces, each associated with major or minor periods of lateritization. The pre-Cretaceous Ashburton surface is absent from the Bonaparte Gulf Basin and there are only a few doubtful examples of the late-Cretaceous to mid-Tertiary Tennant Creek surface. The (?)mid-Tertiary to Recent Wave Hill surface and the (?)late-Tertiary to Recent Koolpinyah surface are both well developed in the Bonaparte Gulf Basin.

Koolpinyah Surface

The Bonaparte Gulf Basin may be divided into two similar geomorphological provinces separated by the joint estuary of the Victoria-Fitzmaurice Rivers.

The northern province consists of most of the Western Plains of the Katherine-Darwin area (Noakes, 1949) and is part of the type area of the Koolpinyah surface.

From Point Blaze south to the Port Keats area the surface is one of extremely low relief, broken by a few residuals of older surfaces. It is a complex multicyclic surface, consisting of remnants of Wave Hill surface, surfaces of sedimentation and young erosional surfaces which show local geological control. Extensive alluviation above present base level in drowned valleys points to a former rise in sea level, perhaps as a result of Pleistocene eustatism (Christian and Stewart, 1953). This was followed by a recent fall of about 20 feet as indicated by the depth of incision of some of the streams on the plains, stranded beach ridges (originally permanent berms), and emerged beaches and strandlines. However, the full history of the plains is not known and as a few of the smaller streams are lost in swamps before reaching the sea, it is probable that several changes of sea level, perhaps produced by local warping, are involved.

Deposits of detrital laterite are abundant at several levels in the area. Some of the deposits rest upon the pallid zone of a truncated lateritic profile to simulate a complete standard lateritic profile of ferruginous laterite, mottled zone, and pallid zone.

Over most of the area the Koolpinyah surface extends from the coast inland for about 40 miles, at heights ranging from sea level to about 100 feet above sea level and with gradients from nil to 2 or 3 feet per mile. It terminates against a scarp, between 200 to 500 feet high, which is, in some places, so extremely regular that it may be mistaken for a fault scarp, and in other places is discontinuous and irregular because of the extension of the surface up major valleys.

On a few coastal areas, cliffs have been formed on residuals of a shallowly dissected Wave Hill surface. These appear to be remnants of broad gently undulating irregular divides between the Finniss, Daly, Moyle, and Fitzmaurice Rivers. Most of the residuals are so low that they may be regarded as incorporated within the Koolpinyah surface but higher residuals occur in the north and south. The northern part of the Bonaparte Gulf Basin is almost completely separated from the Victoria-Fitzmaurice estuary by a large residual in the Port Keats-Pearce Point area. Coalescing panplains along tributaries of the Moyle and Fitzmaurice Rivers, east of the residual, form the main link between the northern and southern parts of the basin.

The southern part extends from the Victoria River to Cambridge Gulf and consists largely of alluvial plains and swamps, with subordinate young erosional surfaces, from which rise residuals of older surfaces. The general range of height of these residuals above the plains is from 500 to 1000 feet. The plains and swamps range in height from sea level to about 120 feet, 60 miles from the coast, and the mean gradient is less than 2 feet per mile.

The southern part differs from the northern in several respects although the general history appears to have been the same. The recent alluviation was much more extensive in the south so that the surface appears to be much less complex. Nevertheless, large irregular "islands" of detrital laterite stand two or three feet above the level of the alluvium, attesting the former existence of detrital laterite plains. Detrital laterite occurs beneath the alluvium in several areas.

Young erosional surfaces are represented by rock pavements at alluvium level and by benches formed local geological control on the sides of hills. A few flat topped hills in accordance with benches on adjacent hills are also attributed to local structural control and have no regional significance.

Wave Hill Surface

The Wave Hill surface has been traced without interruption from its type area on Wave Hill Station north to Legune Station and along the edge of the northern province of the Bonaparte Gulf Basin. It extends into the basin as scattered residuals with accordant summits, and dips generally to the east. Local variations have been produced by gentle northwest warping so that the Wave Hill surface merges into the Koolpinyah surface between the Daly River and Port Keats area and stands at least 100 feet above that surface farther north and south. Near Port Keats the Wave Hill surface is represented by a large partly dissected residual rising from about 200 feet above sea level near Port Keats to about 300 feet near the Fitzmaurice River, and having an area of about 300 square miles. The projection of this residual south across the Fitzmaurice and Victoria Rivers is in accordance with Wave Hill surface residuals near Legune Station at a height of between 500 and 600 feet above sea level. Deposits of detrital laterite are abundant on the surface in the northern province. In many places these deposits rest upon truncated lateritic profiles and simulate complete profiles.

In the southern part of the Bonaparte Gulf Basin all the highest hills observed, with the exception of House Roof Hill, appeared to be in accordance and to indicate the presence of an old mature land surface 1,000 feet above sea level in the south, tilted north or north-eastwards and so completely dissected that only scattered residuals, such as the Burt and Pincombe Ranges and Mt.Septimus, remain. Aerial observation indicated that this must be either the Wave Hill or Tennant Creek Surface. All the accordant summits except Mount Septimus were capped by ferruginous sandstone on which a standard lateritic profile would not necessarily be formed. Consequently the surface represented could not be identified although it appeared to be in accordance with the Wave Hill Surface identified on Legune Station.

Confirmation of this was obtained at Mount Septimus which, unlike the other hills examined, was capped by lateritized sediments and superficial deposits. A capping of a few feet of white to buff porcellanite (?), iron stained in parts, is overlain by detrital laterite which consists of fragments of ferruginous laterite and sparse sandstone pebbles cemented by iron oxides. The porcellanite is similar to that formed from Cretaceous shale in the pallid zone of lateritization in the Darwin area and represents a truncated standard lateritic profile. The cover of detrital laterite, which is leached in places near its base, combines with the truncated profile to simulate a complete standard lateritic profile. As the flat top of Mount Septimus is in accordance with the summits of the surrounding hills, these must represent a surface younger than the Tennant Creek surface, i.e. the Wave Hill Surface.

Tennant Creek Surface

The Bonaparte Gulf Basin appears to have been formed in an area from which most of the Tennant Creek surface has been removed by the encroaching Wave Hill surface and very few traces have been found. A few residuals stand about 300 feet or less above the Wave Hill surface in the northern province, particularly in the area south-east of Port Keats. Some of these are in accordance with remnants of the Tennant Creek surface east of the Basin; the rest have been eroded below this level.

House Roof Hill, 1265 feet above sea level, between Kununurra and Wyndham, standing 265 feet above sea level, is the only Tennant Creek surface residual identified in the southern province. Other residuals may be present but cannot be identified because of the lack of adequate topographic data and the absence of a standard lateritic profile.

ECONOMIC GEOLOGY

Petroleum Prospects

The only known occurrence of petroleum in the basin was found in AOD Bonaparte No.2 Well (Le Blanc, 1967b). From a drill-stem test of a sandstone bed in the Bonaparte Beds (interval 4,716 to 4,726 feet), gas flowed at a maximum rate of 1,540,000 cubic feet per day. The gas consisted mainly of methane, with 8 to 14 percent of higher hydrocarbons. Drill-stem tests of other parts of the well failed to yield hydrocarbons. The only indications of hydrocarbons in AOD Bonaparte No.1 Well were 'moderate "kicks" of gas with a high methane content which were recorded on the gas detector following each trip within the interval 5,000 feet to 10,283 feet' (Le Blanc, 1967a). These occurrences seem merely to show the low porosity and permeability of this part of the section, and so illustrate the chief problem of oil prospecting in the basin: finding high porosity and permeability. In this sequence, the dominant shale is considered an excellent source and also an excellent seal for the interbedded sandstones, which provide potential reservoirs. The juxtaposition of the shale and porous sandstone or limestone by facies changes or by faulting at the edge of the Moogarooga Depression makes this a favourable zone for the accumulation of petroleum. If a favourable structure could be found in the Tanmurra Fault Block (Fig.67), this would be an attractive place to drill. The area around Point Spring may also be prospective because of the possibility of sealed porous pinchouts against the Pincombe Inlier and reefs. Increased permeability would be expected in the area 5 miles south-east of Ningbing Homestead where we believe the main drainage in the Tournaisian flowed into the sea and dropped large volumes of porous sand. Finally, if the reefs of the Ningbing Limestone continue northward along the strike under a suitable cap or dip into the edge of the Moogarooga Depression, they would be potential reservoirs.

Lateral facies changes and fault structures are probably the chief means whereby petroleum has accumulated in the outcrop area; its preservation there probably depends on the presence of an effective seal, such as is provided by the Milligans Beds and perhaps also by parts of the carbonate units.

Limestone

Particular beds in the Ningbing Limestone are pure, and provide a large source of pure calcium carbonate.

Metals

Pyrite is a common constituent of much of the shale in Bonaparte Nos.1 and 2 Wells and the Spirit Hill No.1 Well; in the percussion holes near Milligans Lagoon, grains of framboidal pyrite or pyritomorphs have been found by P.J.Jones (pers.comm.). In the Burt Range Syncline, and in particular at Spirit Hill, the carbonates along many faults are mineralized. According to Allen (1956), a sample of limestone from Spirit Hill contains cerussite, psilomelane, and rhodochrosite.

Underground water

Probably because surface water is abundant in most parts of the area, few bores have been drilled for water, and the little information on this subject comes from seismic shot-holes and oil exploration wells. Spirit Hill No.1 Well was completed as an artesian well, with a flow of 100 gallons per hour of water with 332 parts per million of soluble salts from a depth of 850 feet (Hare et.al., 1961) at the unconformity between the Burt Range Formation and the overlying Milligans Beds. This is the only known record of pressure water in the basin.

Shallow ground water of unknown quality was found in some seismic shot-holes in the Moogarooga Depression, but most of them were dry. The only area that consistently yielded water in shallow shot holes (100 feet or shallower) was situated 4 miles north-east of Ningbing Homestead. No flows of water were recorded in Bonaparte Nos.1 and 2 Wells. The water supply for Bonaparte No.2 Well was obtained from a bore 2½ miles south-west of the well; the aquifer was at 80 feet, and water was pumped at a rate of 450 gallons per hour.

Ochre

Traves (1955, pp.105, 106) described the Ochre Mine, 8 miles west of Alligator Spring. No further information is available, except that we identify the host rock as the Ragged Range Member of the Upper Devonian Cockatoo Formation.

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APPENDIX 1

NOTES TO ACCOMPANY MINERALOGICAL ANALYSES OF CORE SAMPLES FROM THE BONAPARTE GULF BASIN

by F.C.Loughnan

School of Applied Geology, University of N.S.W.

Quantitative Determination of the Mineralogy

The procedure adopted has been outlined previously (Loughnan, 1963). X-ray analyses were carried out on all samples by the standard powder method using a Philips 1010 diffractometer. Oriented aggregates were prepared from the clay fraction ($< 2\mu$) and these were also subjected to X-ray examination without further treatment, with glycolation, and after preheating to 400°C and 600°C. From the results an estimate of the ratio of the individual clay minerals was made. The total clay content was then calculated from the thermogravimetric data after due allowance had been made for the presence of carbonates. Quartz was determined by difference.

This procedure has been found reliable, particularly when the relative amounts of the specific minerals are required. However, it assumes the proportion of each clay mineral in the clay fraction is identical with that in the whole sample and herein lies a possible source of error.

Montmorillonite was determined on the basis of the presence of a 17Å reflection after glycolation. Some highly degraded illites yield a similar reflection and no attempt has been made to differentiate between these two minerals. Moreover, probably some of the material listed as "mixed layers" is partly degraded illite.

The persistence of a 14-15Å reflection after heating to 400°C for half an hour was considered indicative of the presence of a chlorite mineral.

DISCUSSION

Examination of Tables 1 and 2 and Figures 1-4 shows several interesting features.

1. The mineralogy of the majority of samples from the Bonaparte No.1 Well is in accordance with a marine origin. However, it is possible the more kaolinitic sediments could be of brackish or freshwater origin.
2. In general, samples from the Spirit Hill No.1Well have a slightly higher ratio of kaolinite to other clay minerals than do those from the Bonaparte No.1 Well. This would suggest the Spirit Hill Well is located nearer the margin of the basin.

3. All samples below Core 26 in the Bonaparte No.1Well contain small but identifiable amounts of chlorite whereas chlorite was not detected above this level.
4. On the basis of the detrital mineralogy it is possible to subdivide the sediments in the Bonaparte No.1Well into three groups with distinct breaks occurring between Cores 5 and 6 and Cores 26 and 27.

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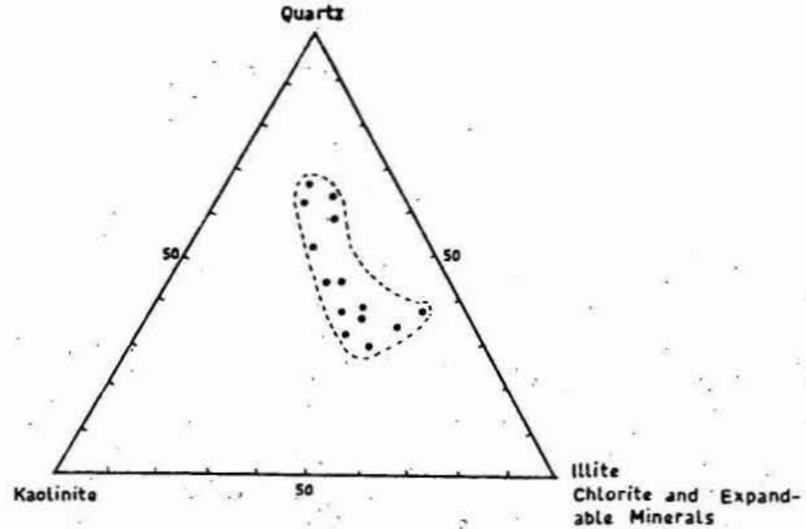


Fig 1. DETRITAL COMPOSITION OF MILLIGANS BEDS IN THE SPIRIT HILL No. 1. WELL.

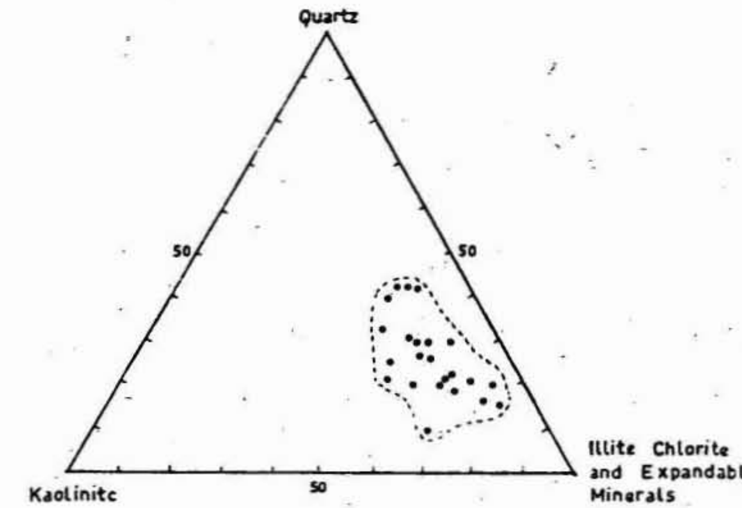


Fig. 3. DETRITAL COMPOSITION OF BONAPARTE BEDS IN THE BONAPARTE No. 1. WELL (1849'-7243')

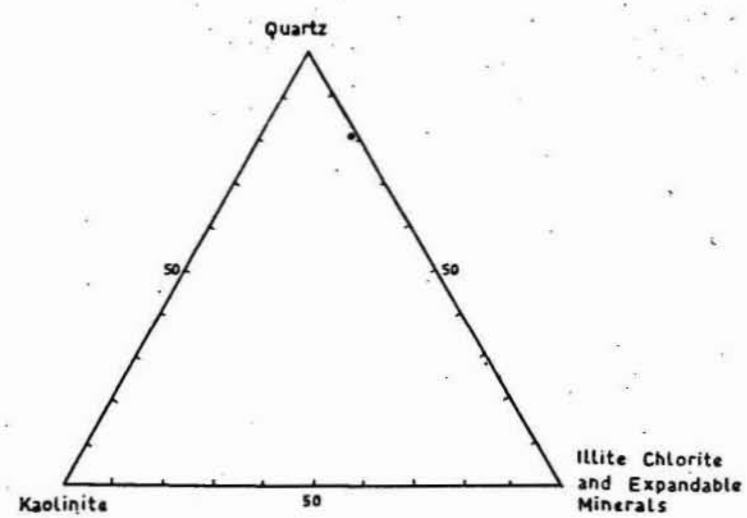


Fig. 2. DETRITAL COMPOSITION OF TANMURRA FORMATION SEDIMENTS IN THE BONAPARTE No. 1. WELL (965'-1564')

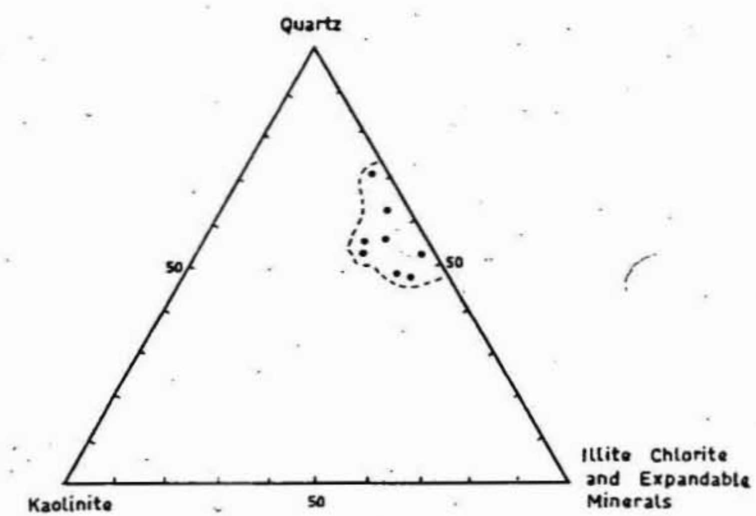


Fig. 4. DETRITAL COMPOSITION OF BONAPARTE BEDS IN THE BONAPARTE No. 1. WELL (7876'-9261')

TABLE 1 MILLIGANS BEDS IN SPIRIT HILL NO.1 WELL

Depth feet	Clay Minerals			Carbonate			Qtz
	K	I	ML	Calc	Dol	Sid	
100 - 150	15	7	40	7	-	5	30
150 - 200	20	10	15	-	10	2	40
200 - 250	20	8	10	-	20	1	40
250	15	10	15	1	25	1	35
250 - 300	20	10	30	-	15	1	25
350 - 400	20	15	20	3	4	10	30
400 - 450	15	5	10	-	5	7	55
450 - 500	15	5	10	-	-	4	60
500 - 550	15	5	15	-	-	7	60
600 - 650	15	15	20	-	15	8	30
700	15	9	20	-	-	-	55
700 - 750	15	15	20	2	10	10	30
800 - 850	20	9	25	3	8	10	25
826	5	15	20	-	40	-	20

K = Kaolinite Calc = Calcite
I = Illite Dol = Dolomite
ML = Mixed Layers Sid = Siderite

Qtz = Quartz

TABLE 2

BONAPARTE NO.1 WELL

Core	Depth feet	Clay Minerals					Carbonates			Qtz	Remarks
		K	I	ML	M	Chl	Calc	Dol	Sid		
3	965	1	4	10	2	-	5	5	-	70	Tanmurra Fm.
5	1,564	15	5	20	-	-	1	-	-	60	
6	1,849	10	6	30	7	-	9	-	-	40	
7	2,164	20	3	-	35	-	3	-	-	40	
8	2,405	20	5	40	-	-	-	-	5	30	
9	2,549	10	2	50	6	-	-	-	2	30	
10	2,858	15	3	50	2	-	-	-	-	30	
11	3,154	15	2	60	2	-	2	-	-	20	
12	3,493	25	10	40	6	-	-	-	-	20	
13	3,825	15	8	45	-	-	-	-	1	30	
14	4,349	20	9	45	-	-	-	-	-	25	
15	4,803	10	8	60	-	-	-	-	-	20	
16	4,814	15	10	45	-	-	1	-	1	30	
17	5,222	25	9	40	-	-	-	-	1	25	
18	5,227	15	6	35	-	-	1	-	1	40	
19	5,522	10	6	40	-	-	2	-	-	40	Bonaparte
19	5,529	15	8	50	-	-	-	-	3	25	
20	5,827	15	8	60	-	-	-	-	-	20	Beds
21	5,835	15	10	55	-	-	-	-	-	20	
22	6,265	20	10	50	-	-	-	-	-	20	
24	6,606	6	10	65	-	-	-	-	-	20	
24	6,614	6	10	70	-	-	-	-	-	15	
24	6.619	10	15	60	-	-	-	-	-	15	
25	6,981	20	25	45	-	-	-	-	-	10	
26	7,243	15	10	45	-	-	5	-	-	25	
27	7,876	2	8	30	-	Tr	12	2	-	45	
28	8,311	10	8	20	-	2	15	2	-	45	
28	8,312	7	10	30	-	2	10	-	-	40	
28	8,313	7	10	30	-	2	3	-	-	45	
28	8,322	2	6	15	-	1	15	3	-	60	
29	8,857	7	10	25	-	2	1	-	-	55	
29	8,866	10	15	25	-	2	-	-	-	50	
30	9,261	3	9	20	-	1	4	4	-	60	

K = Kaolinite M = Montmorillonite Dol = Dolomite

I = Illite Chl = Chlorite Sid = Siderite

ML = Mixed Layers Calc = Calcite Qtz = Quartz

APPENDIX 2

PLANT FOSSILS FROM THE BONAPARTE BULF BASIN

by Mary E.White, 34 Beatty Street,
Balgowlah, N.S.W.

Contents:

<u>Figure 1</u> - <u>Leptophloeum australe</u> (M'Coy)

Natural size, Specimen F22736A

Surface view of Mature Stem

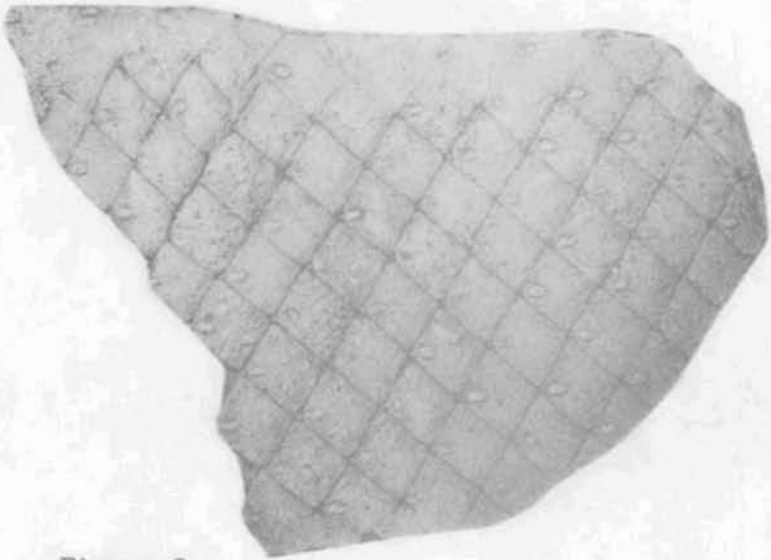


Figure 2 -

Natural size, Specimen F22736B

Surface view mature stem.

AGE: Upper Devonian.

4. <u>Locality 406/1</u>: Kununurra

Specimens F22737 - Decorticated Lycopod stems, some with leaf traces as small round depressions, as occurs in <u>Leptophloeum australe</u>. Genus indeterminate at this decortication level.

AGE: Indet. (Upper Devonian or Lower Carboniferous)

5. <u>Locality AAP 9</u>: Mt.Cecil

Specimens F22745 - Surface impressions of <u>Leptophloeum australe</u>

AGE: Upper Devonian

6. <u>Locality AAP 10</u>: Mt.Cecil

Specimens F22746 - <u>Leptophloeum australe</u> surface impressions

AGE: Upper Devonian

7. Locality AAP 11: Mt.Cecil

Specimens F22747 - A decorticated stem, on parts of which the rhombic leaf pattern of Leptophloeum australe is visible, is associated with numerous pelecypods.

AGE: Upper Devonian

8. Locality AAP 25: Eastern Pretlove Hills

Specimens F22749 - a clear surface impression of a mature stem of Leptophloeum australe is present

AGE: Upper Devonian

9. Locality AAP 49: Cockatoo Spring area

Specimens F22750 - Fragment of ribbed Equisetalean stem.

AGE: Indeterminate

AGE OF COCKATOO FORMATION: UPPER DEVONIAN

III. BUTTONS BEDS

1. Locality 100/1: Eight-mile Creek area

Specimens F22726 - An impression of a deeply decorticated Lycopod stem has leaf traces as oval protruberances in the striated tissue of a deep cortical layer. No generic determination is possible.

AGE: Indeterminate (Upper Devonian or Carboniferous)

2. Locality 100/3: Eight-mile Creek area

Specimens F22727 - Surface impressions of Leptophloeum australe (M'Coy)

AGE: Upper Devonian

3. Locality 105/125: near Buttons Crossing, Ord River

Specimens F22729 - Indeterminate

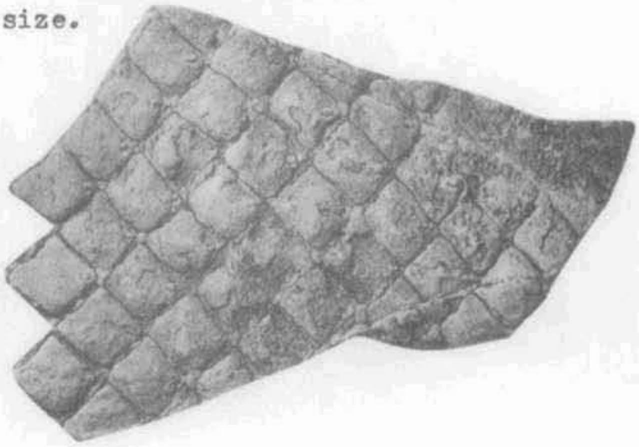
AGE: Indeterminate

4. Locality 105/1075: near Buttons Crossing, Ord River

Specimens F22730 - Illustrated specimen in Figure 3 shows the characteristic surface impression of a mature stem of Leptophloeum australe.

Figure 3 - Leptophloeum australe

Natural size.



AGE: Upper Devonian.

AGE OF BUTTONS BEDS : UPPER DEVONIAN

IV. POINT SPRING SANDSTONE

1. Locality 25/0: Weaber Range

    Specimens F22723 - Indeterminate stem casts.

    AGE: Indeterminate

2. Locality 441: Basal talus, Weaber range

    Specimens F22740 - Indeterminate stems.

    AGE: Indeterminate

3. Locality 441/1: Weaber Range

    Specimens F22741 - Decorticated Lycopod stems, genus indeterminate.

    AGE: Indeterminate (Upper Devonian or Lower Carboniferous)

4. Locality 441/2: Weaber Range

    Specimens F22742 - Figure 4 illustrates this specimen. Part of a stem of Lepidodendron Sp. with ascending spiral of pear-shaped depressions. Preservation is poor and no specific identification is possible. It is of the L.veltheimianum general type.

    AGE: Lower Carboniferous

Figure 4 - Lepidodendron sp.

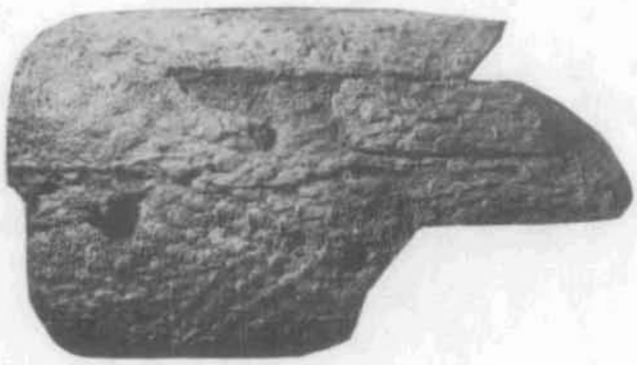
5. Locality 441/2A: Weaber Range

    Specimens F22743 - Two casts of decorticated Lycopod stems are present. One is deep level, an inside cast of a piece of bark. The other is a large stem in "Knorria" condition with the leaf traces projecting from the surface. This specimen is illustrated in Figure 5. It is a typical Lepidodendron decortication form, but no generic determination can be made in the absence of surface or near-surface impressions.

Figure 5 -

Half Natural Size

"Knorria" decortication form



Age: Probably Lower Carboniferous

6. Locality 465/2: Tanmurra Creek area
   Specimens F22744 - Indeterminate stem casts.
   AGE: Indeterminate

AGE OF POINT SPRING SANDSTONE: LOWER CARBONIFEROUS

V. ENGA SANDSTONE

1. Locality 78/3: Policeman Waterhole, Keep River
   Specimens F22725 - Indeterminate stem impressions and one decorticated Lepidodendroid stem which cannot be referred to a genus.
   AGE: Indeterminate (Upper Devonian or Carboniferous).

2. Locality 109/125: Enga Ridge
   Specimens F22731 - Decorticated Lycopod stem impressions. Genus indeterminate.
   AGE: Indeterminate (Upper Devonian or Lower Carboniferous).

AGE OF ENGA SANDSTONE on plant evidence Indeterminate (Upper Devonian or Lower Carboniferous).

VI. BURT RANGE FORMATION

1. Locality 103/6: Enga Ridge
   Specimens F22728 - Decorticated Lycopod stems with oval leaf traces.
   AGE: Indeterminate (Upper Devonian or Lower Carboniferous)

2. Locality 117/1: Spirit Hill
   Specimens F22732 - Decorticated Lycopod stems, genus indeterminate,
   AGE: Indeterminate (Upper Devonian or Lower Carboniferous)

AGE OF BURT RANGE FORMATION: on plant evidence Indeterminate, (Upper Devonian or Lower Carboniferous)

VII. MILLIGANS BEDS

1. Locality 118/3: Spirit Hill
   Specimens F22733 - Indeterminate stem impressions
   AGE: Indeterminate

2. Locality 118/7: Spirit Hill
   Specimens F22734 - An impression of a young stem of *Lepidodendron* cf. *Lepidodendron veltheimianum* Stbg. indicates a Lower Carboniferous age.
   Figure 6 illustrates this specimen.
   AGE: Lower Carboniferous

Figure 6 - *Lepidodendron sp.*
Natural size.

AGE OF MILLIGANS BEDS: LOWER CARBONIFEROUS

VIII. BORDER CREEK FORMATION

1. Locality 436C: Weaber Range
   Specimens F22739 - Indeterminate stem impressions
   AGE: Indeterminate

APPENDIX 3

NEW GEOGRAPHICAL NAMES IN THE BONAPARTE GULF BASIN

by J.J.Veevers & J.Roberts

Name	Derivation of Name	Feature	Geographical co-ords.
ABNEY HILL	From 'Abney Level', the instrument used in geologically surveying this feature	Scarp, 200 ft. high in red sandstone	$15^{\circ}44'$S $128^{\circ}44'$E
ALPHA HILL	From the registration letters of the helicopter (VH-AHH) which conveyed the authors to this hill	Highest point in a sandstone ridge	$15^{\circ}26'$S $129^{\circ}10'$E
BURVILL POINT	After Mr.G.H.Burvill, Dept.Agriculture,Perth	Top of sandstone hill, 1 mile E.S.E. of Ningbing Hs.	$15^{\circ}16'$S $128^{\circ}40'$E
HARGREAVES HILLS	After Mr.F.Hargreaves, Manager of Carlton Hill Station	Group of sandstone ridges	$15^{\circ}20'$S $128^{\circ}33'$E
JEREMIAH HILLS	After one of the children of the Durack family	Group of limestone hills	$15^{\circ}26'$S $128^{\circ}43'$E
LANGFIELD POINT	After Mr.E.C.B.Langfield, the first officer-in-charge K.R.S.	South-west tip of Burt Range	$15^{\circ}48'$S $128^{\circ}58'$E
MATHESON RIDGE	After Mr.R.S.Matheson, who, as geologist of the W.A. Geol.Survey, jointly wrote the first scientific report of the Devonian and Carboniferous rocks of the area	[illegible] Ridge of sandstone and basalt	From $15^{\circ}48'$S $128^{\circ}58'$E to $15^{\circ}53'$S $128^{\circ}55'$E
MOUNT ZIMMERMANN	After Dr.Zimmermann, who in 1963 was leader of Aust. Aquitaine Petroleum party that worked in this area	Conspicuous peak of sandstone and conglomerate in western part of Burt Range	$15^{\circ}46'$S $128^{\circ}57'$E
NINGBING RANGE	After Ningbing Homestead	Dissected range of limestone	From $15^{\circ}20'$S $128^{\circ}36'$E to $14^{\circ}57'$S $128^{\circ}35'$E
ÖPIK HILL	After Dr.A.A.Öpik, who in 1949 made several geological discoveries in the area	Sandstone peak in the head-waters of Tanmurra Creek	$15^{\circ}03'$S $128^{\circ}36'$E
SIGGINS SPRING	After Mr.A.Siggins, surveyor, P.W.D., Kununurra	Fresh-water spring in limestone, at head of Mistake Creek	$15^{\circ}17'$S $128^{\circ}36'$E
SORBY HILLS	After H.C.Sorby, an eminent carbonate petrologist	Group of limestone hills at N.E.tip of Pincombe Range	$15^{\circ}28'$S $128^{\circ}43'$E
UTTING GAP	After Mr.E.P.Utting, who geologically pioneered the Ningbing Range and the area	Gap between Ningbing Range and sandstone	$14^{\circ}58'$S $128^{\circ}36'$E

AIR-PHOTO CO-ORDINATES

Feature	(b)	Run	(c) No.	(e) quadrant	X	Y (inches)	Diagonal
ABNEY HILL	CG	12	5047	C	3.50	0.20	3.60
ALPHA HILL	AU	7	5076	B	1.75	0.70	1.90
BURVILL POINT	CG	4	5165	B	1.90	0.80	2.10
HARGREAVES HILL*	CG	5	5181	A	2.50	2.40	3.50
" "	"	"	"	C	3.20	3.00	4.35
LANGFIELD POINT	CG	12	5053	D	2.75	3.80	4.70
MATHESON RIDGE*	CG	14	5139	C	2.75	4.30	5.10
" "	"	"	"	D	1.10	1.45	1.80
MOUNT ZIMMERMANN	CG	12	5053	D	1.55	4.20	4.45
NINGBING RANGE*	CG	5	5179	A	1.90	1.50	2.45
	MB	14	5080	D	1.90	2.10	2.80
ÖPIK HILL	CG	2	5077	A	1.80	0.25	1.85
SIGGINS SPRING	CG	5	5179	B	0.10	1.35	1.35
SORBY HILLS*	CG	8	5109	D	1.50	1.65	2.20
" "	"	"	"	C	1.00	1.40	1.75
JEREMIAH HILLS*	CG	7	5027	C	0.70	0.65	0.95
" "	"	"	"	C	4.00	0.10	4.00
UTTING GAP	MB	15	5010	C	3.80	1.25	4.00

NOTE: CG - Cambridge Gulf 1:250,000 Sheet area
MB - Medusa Banks " "
AU - Auvergne " "

* Co-ordinates of extremities of feature.

APPENDIX 4

Geometry of air-photograph linears in sandstones of the Bonaparte Gulf Basin

J.J.Veevers

The air photographs of many areas of outcropping Upper Devonian and Carboniferous sandstones in the Bonaparte Gulf Basin contain abundant linear features. Most if not all of these are furrows or ravines cut along outcropping joints. The deep etching of the complementary sets of joints leads to the isolation of blocks of sandstone in characteristic shapes likened to bee-hives, castles, or ruins. Outcrops of this kind are common in parts of the Ragged Range Conglomerate Member, Kellys Knob Sandstone Member, and Cecil Sandstone Member of the Cockatoo Formation, the Point Spring Sandstone, and the Border Creek Formation. From scattered field observations, most of the joints are known to have a steep or vertical dip, so that their outcrop trace is not seriously affected by the low dips, commonly 5 degrees or less, only exceptionally steeper, in the areas studied. The areas shown in Figure 1 were studied because they contain fairly large continuous outcrops of jointed quartz sandstone.

Methods

Linears were traced from the air photographs on to translucent overlays which were then compiled over a controlled base. Air photographs at a scale of 1:16,000 were available for the Weaber Range and Spirit Hill, and at a scale of 1:50,000 for the other areas. Each area was subdivided into squares along a rectangular grid: the Weaber Range and Spirit Hill into squares with side ½-mile long, and the other areas into squares with side 1-mile long. Parallel and continuous linears were grouped into sets, and the length and azimuth of individual linears were listed according to set and square. Resultant azimuths of each set within each square were computed using Curray's (1956) method. The computations were carried out on the CSIRO CDC 3600 computer with a program written by T.Quinlan. The program provided for each square and set resultant azimuths, the vector magnitude or degree of preferred orientation, the probability that the resultant azimuth is due to chance, the standard deviation about the resultant azimuth, and the total length of the set. A probability value of 5% ($p < 0.05$) was taken as significant. The azimuths of all but a few sets were significant; for most sets, the probability of the resultant is less than 10^{-4}. The resultant azimuths were plotted proportional to their length on the maps, and generalized trends of linears were interpolated on the maps of the Weaber Range, Spirit Hill, and Nigli Gap area, in all of which the linears are visibly continuous.

Weaber Range (Fig.2)

The main outcropping rocks of the Weaber Range are the Point Spring Sandstone and the overlying Border Creek Formation, which are separated by a disconformity. Both formations contain numerous thick bodies of coarse-grained jointed quartz sandstone. Despite the disconformity, both formations have the same pattern of linears.

Four sets were recognised:

Set 1, with east-north-east trend, complemented by

Set 2, with north-north-west trend.

Set 3, with north-west trend, complemented by Set 4, with north-east trend

All these sets are expressed by the same kind of linear, which is individually narrow and short, except in the central part of the area, which contains widely-spaced linears up to a mile long. The long linears lie parallel to the sets of short linears.

Set 1 linears are found in the entire mapped area. Near Point Spring Set 1 parallels the strike but elsewhere is independent of the strike. North and west of Point Spring, all but a few of the linears belong to Set 1.

Set 2 is found only in the area 4 miles north-east of Point Spring, where it parallels faults of short throw, and in the eastern part of the Weaber Range.

Sets 3 and 4 also have a limited distribution. Set 4 is best expressed north-north-east of Point Spring, where it parallels a system of faults.

Spirit Hill (Fig.3)

The Border Creek Formation crops out in the western part of Spirit Hill, and consists of jointed conglomeratic quartz sandstone. Like its namesake in the Weaber Range, Set 1 trends east-north-east, and it is the dominant set. It is complemented by Set 2. The other sets are minor: Set 3 is known only in the northern part of Spirit Hill, and Set 4 in the southern part.

Nigli Gap (Fig.4)

The jointed sandstone in this area belongs to the Kellys Knob Sandstone Member of the Cockatoo Formation. Two curved systems of complementary sets were found. Set 1 changes trend from north to north-north-east, and this change is followed by the complementary Set 2. Likewise, Set 3 changes trend from north to north-north-west, and this change too is followed by the complementary Set 4.

Martin Bluff (Fig.5)

Martin Bluff is a cuesta capped with jointed sandstone of the Kellys Knob Sandstone Member of the Cockatoo Formation; the cuesta is cut by faults into two compartments. In the western compartment, the linears fall into two complementary sets, which are parallel and normal to a fault. A similar pattern is found in the other compartment.

Ragged Range (Fig.6)

Two areas of the Ragged Range Conglomerate Member and probable Cecil Sandstone Member of the Cockatoo Formation in the Ragged Range contain abundant linears. In both areas, the north- to north-north-east - trending set follows the curve of the Ivanhoe Fault system. A complementary set is minor. In the northern part of the Ragged Range, major sets with east-north-east to north-west trends are distributed symmetrically about the north-north-east - trending set.

Geometrical conclusions

Except in the Ragged Range, the linears are distributed in one or two systems of complementary sets. The sets of linears in the Weaber Range and at Spirit Hill are roughly parallel. In the other areas, the sets are geometrically unrelated. The only obvious geometrical relationships between structure and the sets of linears are (a) a major linear set in the Ragged Range parallels the curve of the Ivanhoe Fault system; and (b) in the Martin Bluff area, sets of linears lie parallel and normal to faults. Less markedly, some sets in the Weaber Range parallel faults.

Geological conclusions

Without much more information on the geological structure and structural history, little of geological value can be concluded from the geometry of the linears. The Weaber Range and Spirit Hill are the only areas with a roughly parallel pattern. Perhaps this is the regional pattern of the Carboniferous or later, whereas the dissimilar patterns in the Cockatoo Formation are merely local.

REFERENCE :

CURRAY, J.R., 1956 - The analysis of two-dimensional orientation data. J.Geol., 64(2), 117-131

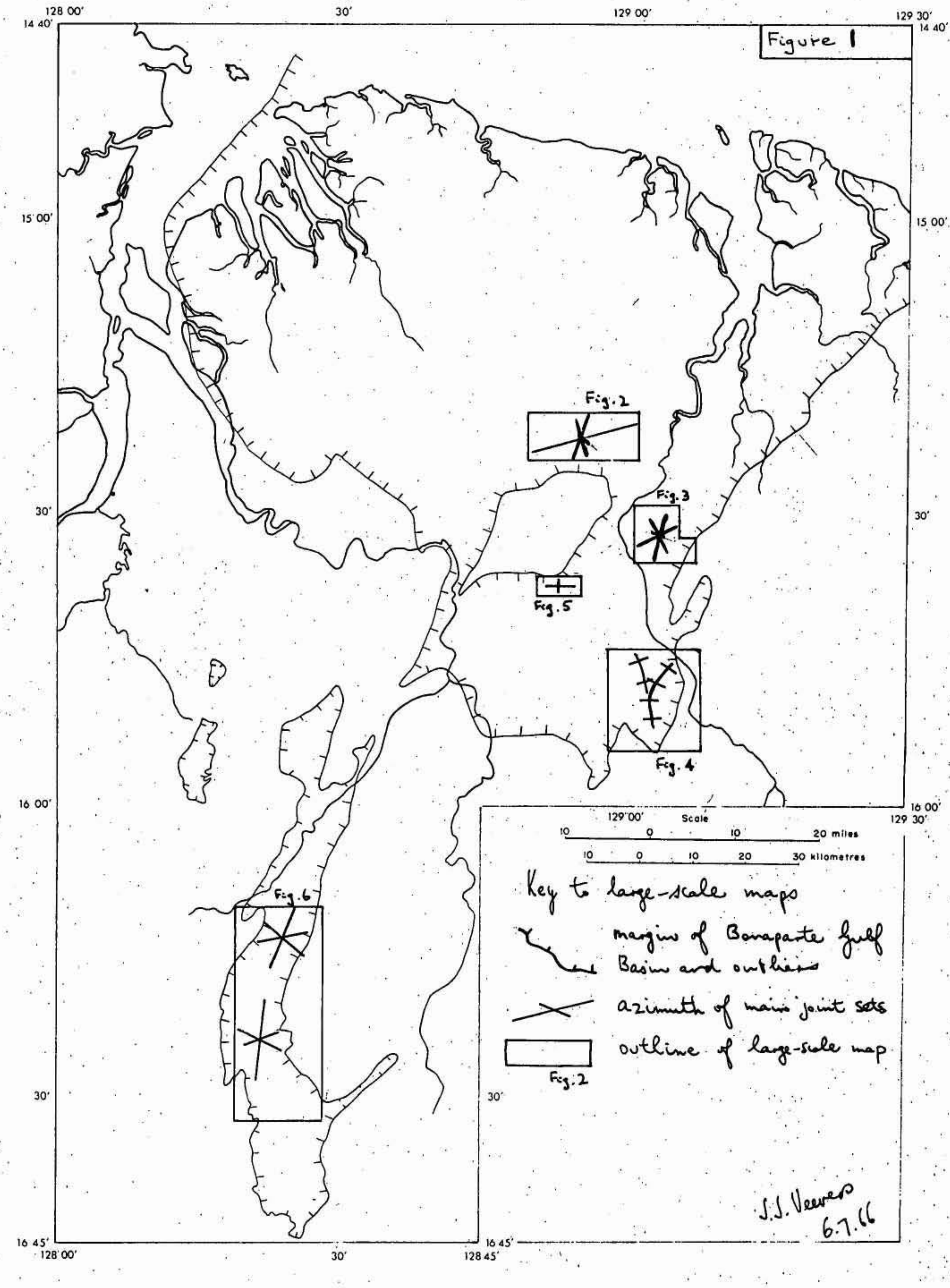


Figure 1
128 00'
30'
129 00'
129 30'
14 40'
15 00'
30'
16 00'
16 45'
128 00'
128 45'
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
129°00'
Scale
10 0 10 20 miles
10 0 10 20 30 kilometres
Key to large-scale maps
margin of Bonaparte Gulf Basin and outliers
azimuth of main joint sets
outline of large-scale map
Fig. 2
J.J. Veevers
6.7.66

Figure 2

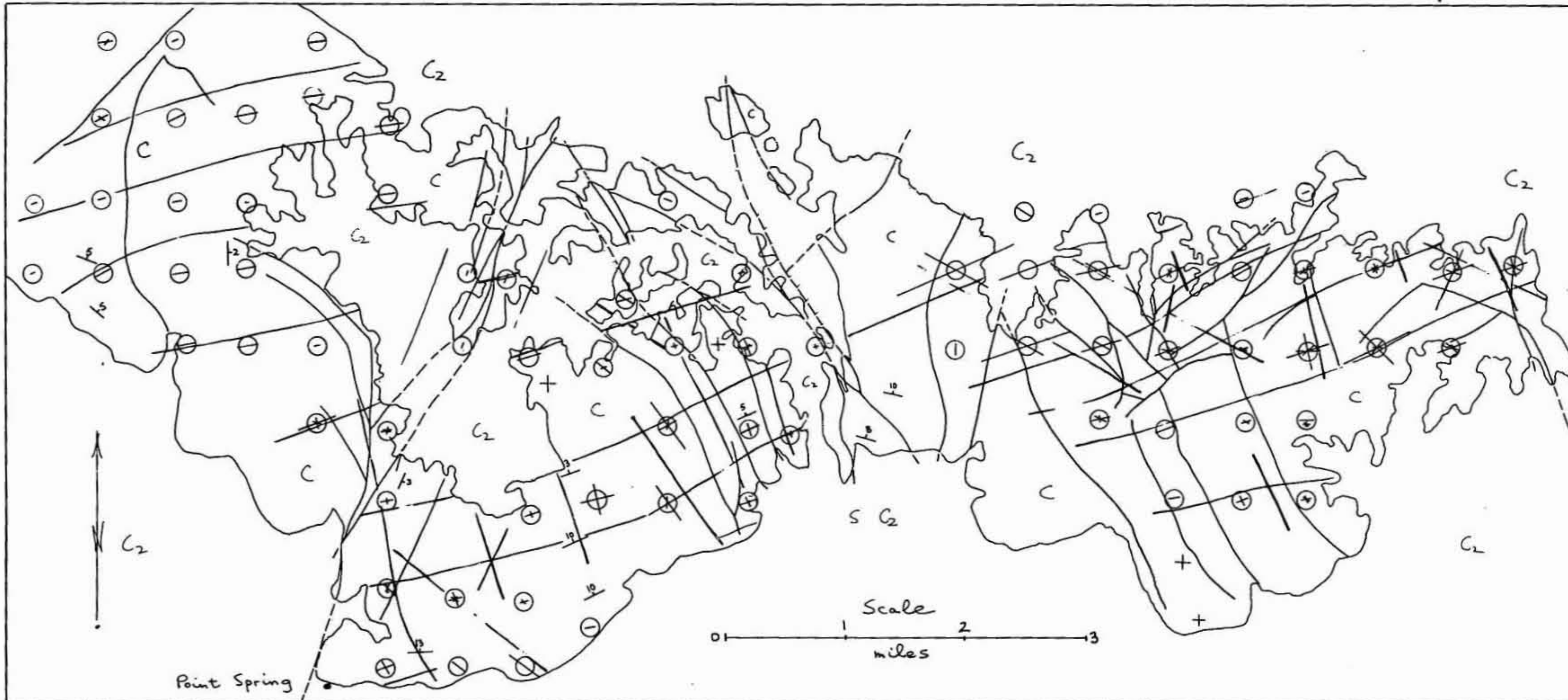


Figure 2 — Joint distribution in the eastern part of the Weaber Range

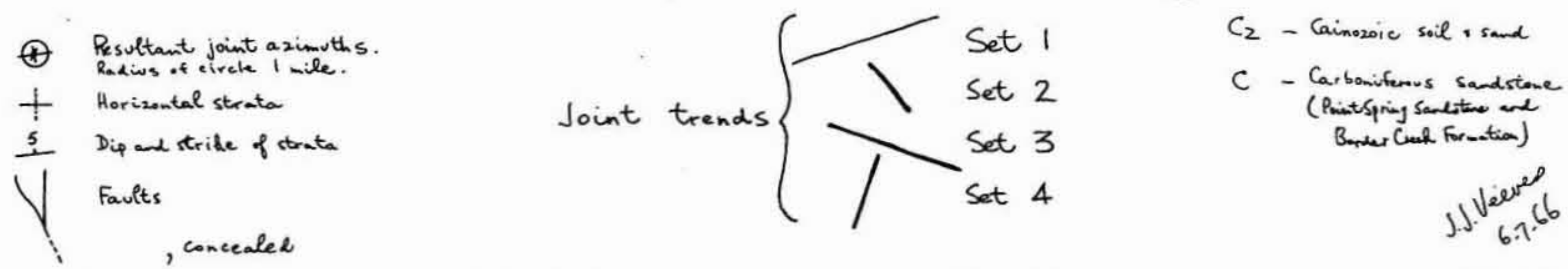
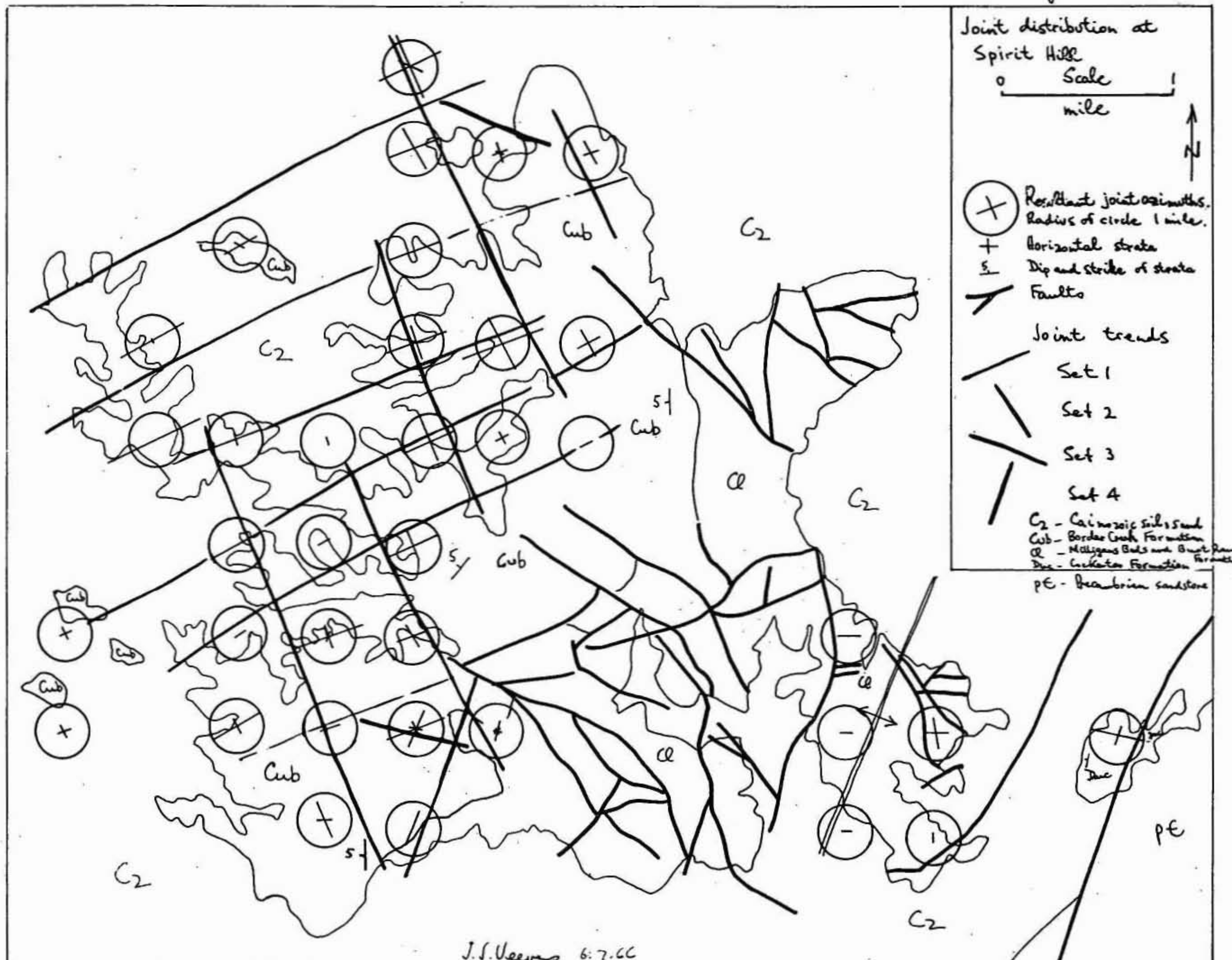
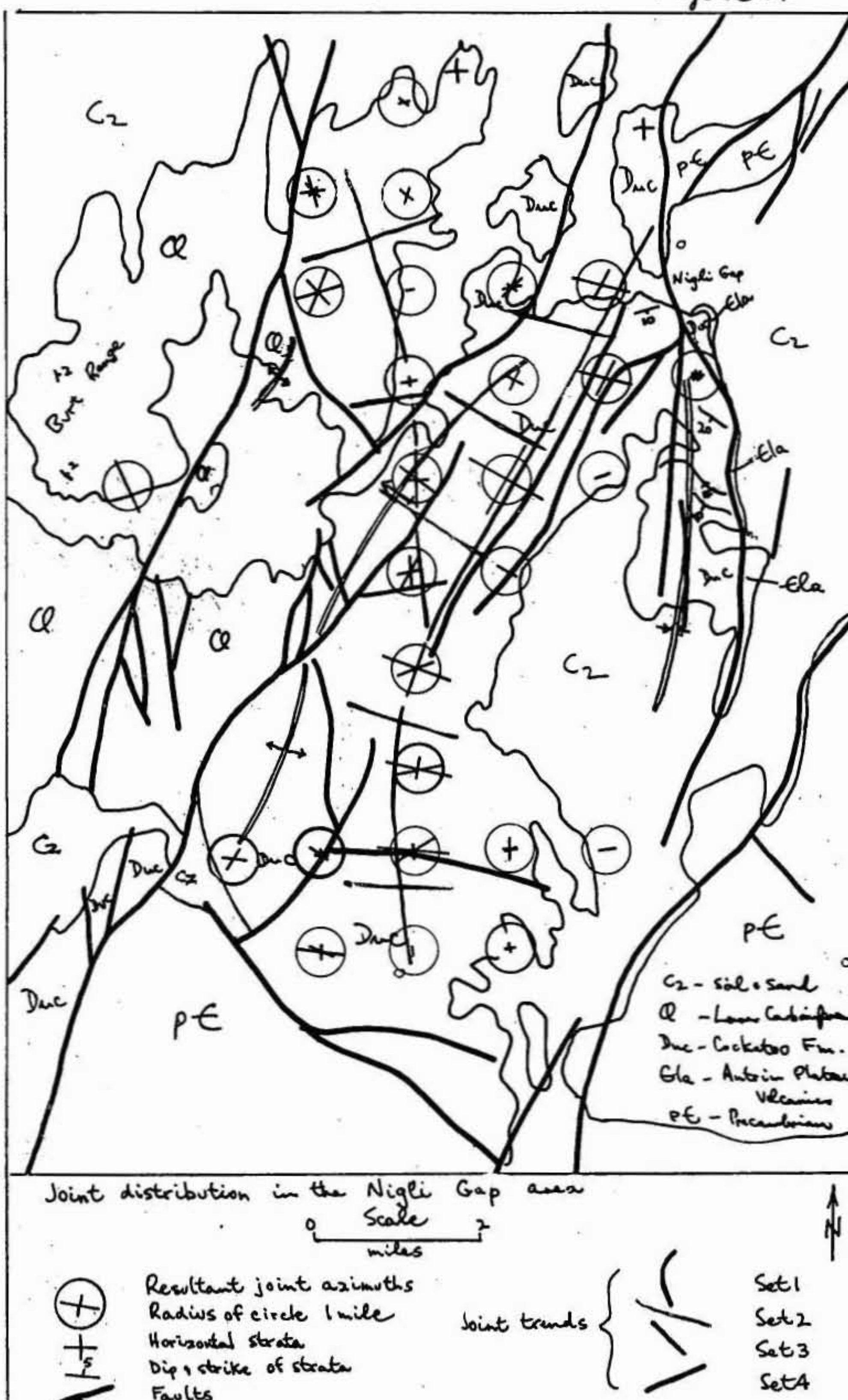


Figure 3



Joint distribution at Spirit Hill
Scale
0
1
mile
N
Resultant joint azimuths. Radius of circle 1 mile.
Horizontal strata
Dip and strike of strata
Faults
Joint trends
Set 1
Set 2
Set 3
Set 4
C2 - Cainozoic soil & sand
Cub - Border Creek Formation
Cl - Milligans Beds and Burt Range Formation
Dcc - Cockatoo Formation
pЄ - Precambrian sandstone
C2
Cub
Cl
pЄ
J.S. Veevers 6:7.66

Figure 4



Joint distribution in the Nigli Gap area

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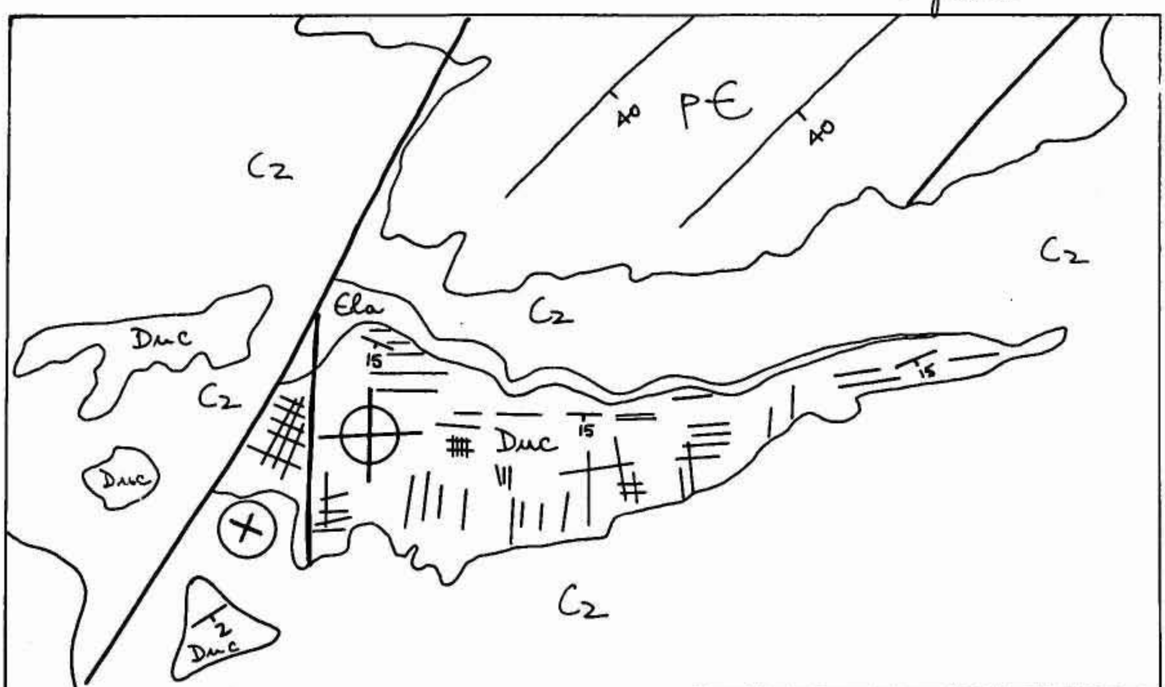
Figure 5



Joint distribution in the Martin Bluff area

Scale

0 — 1 — 2
miles

N

⊕	Resultant joint azimuths. Radius of circle 1 mile.	Cz	Cainozoic soil and sand
		Duc	Cockatoo Sandstone
⟋2	Dip and strike of strata	Ela	Antrim Plateau Volcanics
/	Faults	pЄ	Precambrian sedimentary and metamorphic rocks

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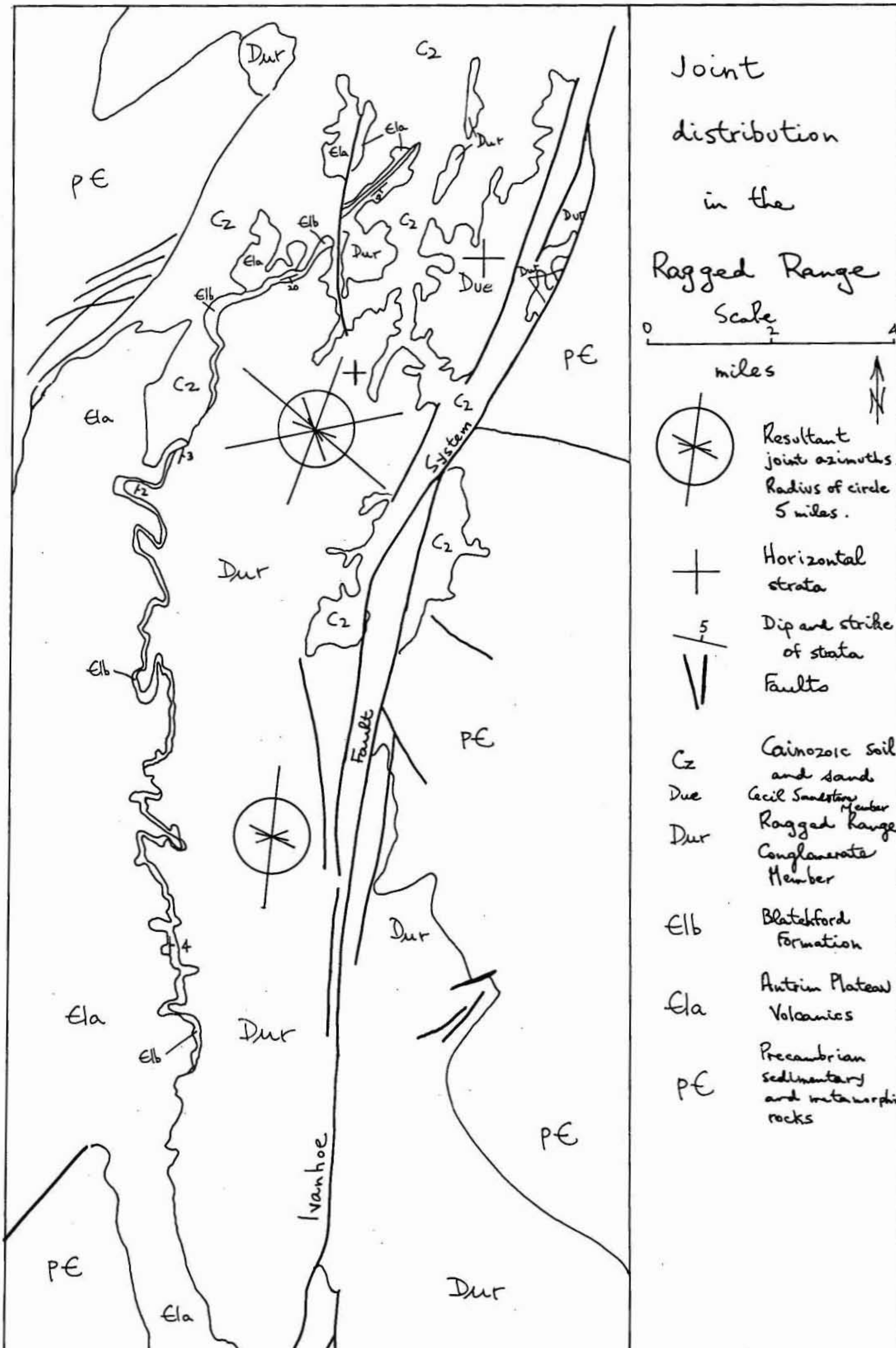
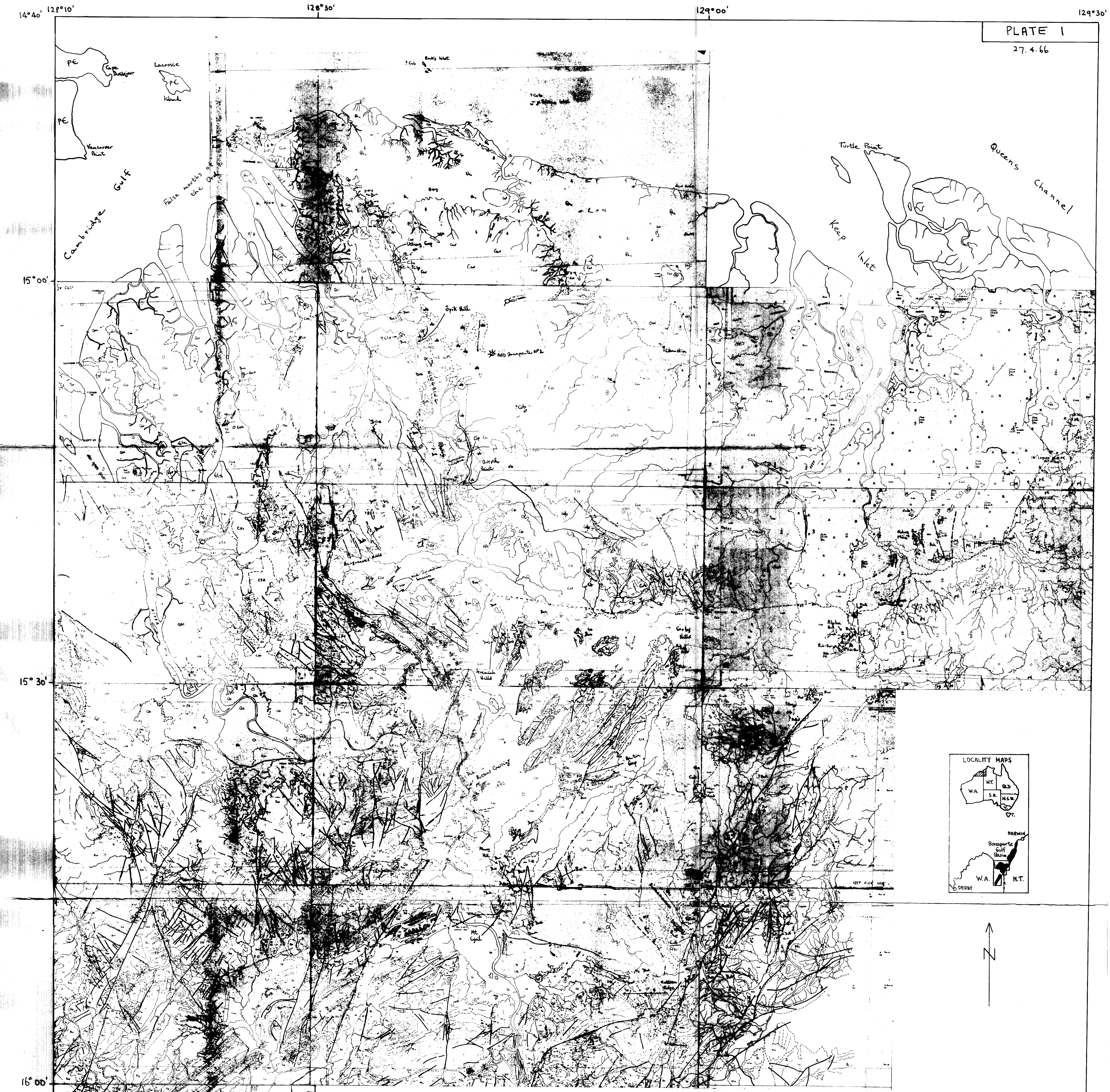
7.7.66

Figure 6



Joint distribution in the Ragged Range
Scale
0 2 4
miles
Resultant joint azimuths. Radius of circle 5 miles.
Horizontal strata
Dip and strike of strata
Faults
Cz Cainozoic soil and sand
Due Cecil Sandstone Member
Dur Ragged Range Conglomerate Member
Єlb Blatchford Formation
Єla Antrim Plateau Volcanics
pЄ Precambrian sedimentary and metamorphic rocks
Ivanhoe Fault System
Dur
Cz
Єla
Єlb
Due
pЄ



Geological map of the southern part of the

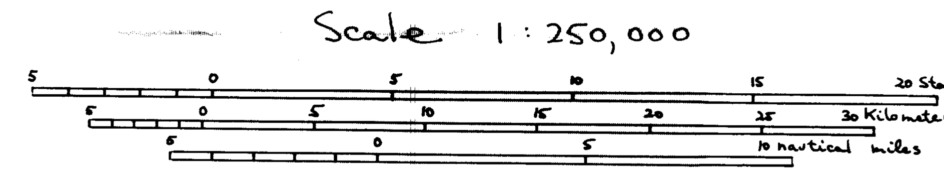
Bonaparte Gulf Basin

W.A. and N.T.

Geology and compilation by J. J. Veevers and J. Roberts

May 1966

Scale 1:250,000



Reference

Cainozoic		coastal alluvium	Qac
		alluvium	Qa
		sand	Czs
		black soil	Czb
Palaeozoic	Permian	Keep Inlet Beds	Pk
	Upper Carboniferous	Border Creek Formation	Cub
	Lower Carboniferous	Point Spring Sandstone	Clp
		Burvill Beds	Clr
		Utting Calcarenite	Clu
		Waggon Creek Breccia	Clw
		Milligans Beds	Clm
		Zimmermann Sandstone	Clz
		Septimus Limestone	Cls
		Enga Sandstone	Cle
		Burt Range Formation	Clb
	Upper Devonian	Buttons Beds	Dub
		Ningbing Limestone	Dun
	Upper Devonian	Cockatoo Formation	Duc
		Jeremiah Member	Duj
		Cecil Sandstone Member	Due
		Abney Sandstone Member	Dua
		Kununurra Member	Duu
		Kellys Knob Sandstone Member	Duk
		Westwood Member	Duw
		Hargreaves Member	Duh
		Ragged Range Conglomerate Member	Dur
	Lower Ordovician	Pander Greensand	Olp
	Upper Cambrian	Clark Sandstone	€uc
		Pretlove Sandstone	€up
	Middle Cambrian	Skewthorpe Formation	€ms
		Hart Spring Sandstone	€mh
		Tarrara Formation	€mt
	Lower Cambrian	Blatchford Formation	€lb
		Antrim Plateau Volcanics	€la
	Cambrian	Undifferentiated	€
PRECAMBRIAN		Undifferentiated	P€